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Processing Control Procedures for Ansco Color Film*

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Summary—**Reproducible processing of Ansco color film requires continuous control of the solution compositions. Early experience showed that frequent change of processing solutions was necessary to maintain consistency. New replenisher formulas are described which together with sensitometric controls and occasional chemical analysis have proved successful for maintaining the processing solutions in a satisfactory condition indefinitely. Color-balance differences resulting from varied types of agitation, depending on the processing equipment, may be adjusted by changing the chemical constitution of the first developer.**

The continuous processing of Ansco color film requires control of speed, gradation, fog, D-max., and other variables common to the processing of black-and-white films, but with the complicating factor that these variables must be kept constant in each of three superimposed emulsion layers.

When this color film was first introduced, frequent changes of processing solutions were advised to prevent the deteriorating effects of aging and exhaustion. With experience, methods of processing control gradually have evolved using continuous replenishing procedures controlled by sensitometric and analytical tests. This paper presents an outline of the essential control steps necessary at each operating stage of a processing laboratory. Through the use of these practices an experienced control man can maintain a set of processing solutions indefinitely. Tests are outlined not only for actual machine operations but also to check raw chemicals and individual mixes of solutions. Although essentially designed for motion picture laboratories, the basic methods are also applicable to roll- and sheet-film processing units, and with different developer replenishers, to the processing of Printon.

I. Basic Control Methods

Three general control methods, photographic, analytical and *p*H, are recommended for the various testing operations. The necessary

* Presented May 18, 1948, at the SMPE Convention in Santa Monica.

tests are outlined briefly in Fig. 1. For simple solutions such as short stop and hardener, simple *p*H tests suffice. For developer solutions and actual machine controls, both photographic and analytical tests are necessary. A chemical standard is used as the basis for all tests. A supply of high-purity chemicals should be maintained as the processing standards and type solutions should be prepared from these chemicals with accurate mixing.

A. *p*H Tests

*p*H is controlled with Coleman or Beckman Laboratory Model *p*H instruments using glass-calomel electrode systems. Other instruments of equal sensitivity would suffice. All *p*H readings including those of developers given in the paper are based on the use of a normal glass electrode. It is recognized that the use of an electrode introduces sodium ion errors due to the high salt concentration of the solution, but in practice, since the salt concentration remains constant, consistent and useful readings are obtained and no attempt is made to correct the data. If a special electrode designed for high salt concentrations at a high *p*H (10 to 11) is used, the developer *p*H readings will range about 0.10 higher than indicated in this paper. It is to be emphasized that except for short stop and hardener solutions which are fully controlled by *p*H, the *p*H values are used merely as a guide.

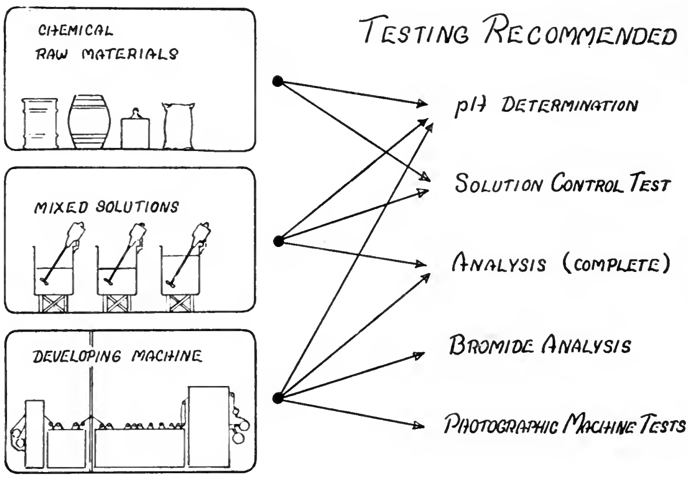

Fig. 1

Solutions can be rejected and trouble located if pH measurements fall outside normal limits, but proper pH does not insure satisfactory performance.

B. Photographic Tests.

These can be divided into two parts: (1) photographic solution control tests, and (2) photographic tests made on the machine during operation.

1. Photographic Solution Control Tests

Tests so termed are used for testing raw materials, solution mixes, and in locating possible sources of trouble with machine solutions. The photographic test consists simply in processing duplicate sensitometric strips of color film through the standard cycle of color-film processing except that the strips are separated at the solution to be tested and one strip run through the sample solution and one through the type solution. These sensitometric strips should be exposed on the same type of color emulsion the machine will process. A supply of film of a single emulsion number sufficient for several months' control operation should be set aside to avoid too frequent typing in of emulsions. Either time or intensity-scale sensitometry may be used, although intensity-scale instruments are recommended because they give a more accurate indication of a film's practical performance. The instrument, however, must be capable of highly reproducible results and should be adjusted to produce a color balance close to neutral. Both visual and densitometer measurements are more accurate when made with neutrally exposed film. Latent-image changes in exposed strips are normally of small magnitude. However, it is recommended for optimum consistency that no exposures more than two months old be used for control work.

It is essential that solution testing be done under carefully controlled conditions of agitation, time, and temperature so that the system itself has reproducibility greater than the solution tolerance to be tested. In practice it is possible to construct apparatus that will give results deviating by not more than $^1/_8$ stop speed or $^1/_{16}$ stop color balance when identical solutions are used for type and sample. This degree of reproducibility requires mechanical agitation, water baths for solution temperature control, and methods of quickly changing film from solution to solution. In the Ansco laboratory, an apparatus has been constructed employing a series of stainless-steel tubes each holding $1^1/_2$ liters of solution (Figs. 2 and 3). Special racks each holding two 35-mm strips in a film slide-type holder fit into the tubes. A rubber-edged vane, with a vertical movement operated by a series of pulleys over the tubes, is built into each rack. The whole unit is set into a water bath with temperature control. It is not necessary to employ exactly this design of apparatus, but mechanical agitation is strongly recommended.

Photographic solution control tests are interpreted by reading the color densities of the type and sample sensitometric strips on an

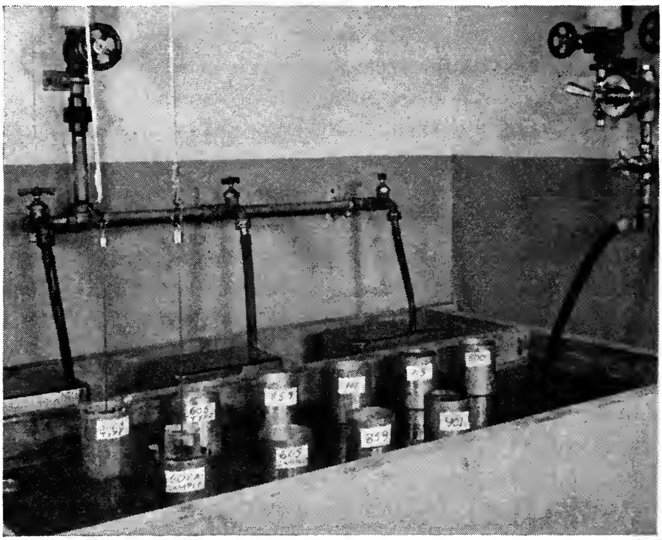

Fig. 2

Ansco color densitometer[1] and comparing the plotted results for speed, density, and color-balance differences. Acceptable tolerances in processing solutions necessarily are high but specific acceptable limits must depend somewhat on circumstances. In general, solutions can be accepted that do not give speed differences greater than $^1/_4$ stop or color-balance differences greater than $^1/_8$ stop from type. Should an occasion arise where both the first developer and color developer or their respective replenishers show $^1/_8$ stop color-balance difference, both in the same direction, the combination obviously would produce an intolerable result on the machine.

Normal machine-processing times are recommended for the solution control test machine except replenisher solutions are tested with two thirds the developing time of their basic solutions. It is desirable, although not absolutely necessary, that the solution control test machine and the processing machine turn out closely matched results. Often differences in agitation will make this difficult. The procedure for chemically adjusting color balance described in the section on machine adjustments would not be applicable in this case because it is necessary that the solution control machine operate to test the exact machine formulas.

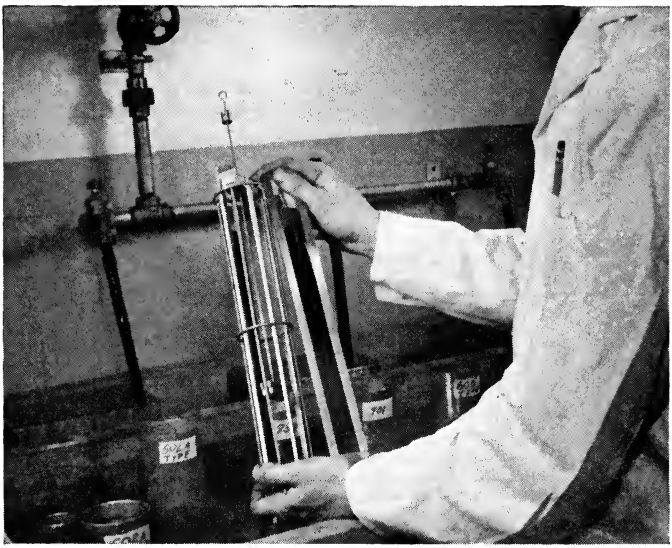

Fig. 3

2. Photographic Tests of Machine Operation

The basic purpose behind all preliminary testing is, of course, to control the actual developing machine. To this end the greatest reliance is placed on photographic controls because these indicate directly the results the machine is producing. Test strips are run through at 15- to 30-minute intervals. As the strips come off the machine, they are quickly compared visually with the preceding strips and the color densities of three representative toe, middletone, and shoulder steps read and plotted as shown in Fig. 4. The control chart that gradually accumulates as a result of plotting these continuous strips is of great value in controlling the machine. By connecting the points as the graph is constructed, a running record is obtained of the speed and color-balance fluctuations. Speed increases in reversible film are denoted by a drop in all layer densities, a speed decrease by a rise in all densities, while color-balance shifts are denoted by unequal changes in the various layer densities.

As can be seen from Fig. 4, minor fluctuations in over-all speed and

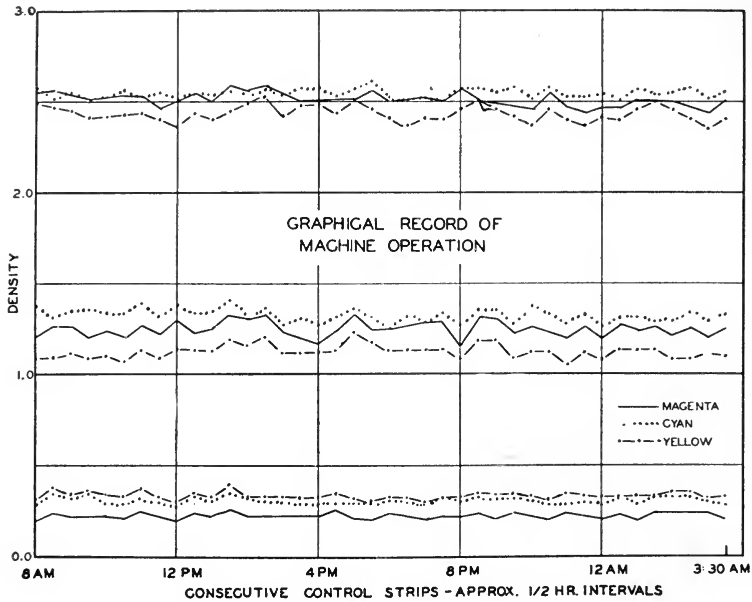

Fig. 4

very slight deviations in color balance occur between successive developments. These fluctuations are normal in the best regulated machines made to date and are caused by a variety of effects all minor in character but which add up to measurable differences.

The variables which cannot be absolutely controlled include slight differences in film emulsions, film exposures, chemicals, solution mixes, developing times and temperatures, circulation rates, drying conditions, and even final densitometry. These additive deviations may amount to as much as plus or minus $^1/_4$ stop speed variation as well as color-balance shifts of plus or minus $^1/_8$ stop. It is the controlman's responsibility to distinguish between a fluctuation that is within the optimum operating capability of his apparatus and a deviation that represents improper control. For this reason, graphical methods are employed. By following such a graph, it is possible to control the machine output within narrow limits. Fig. 5 illustrates another series of developments; it can be seen that for developments *A* through *B* fluctuations ranged upward and downward in a fairly regular pattern. This was normal machine operation. Beginning with *B*, although the fluctuations were still up and down, the majority was running higher

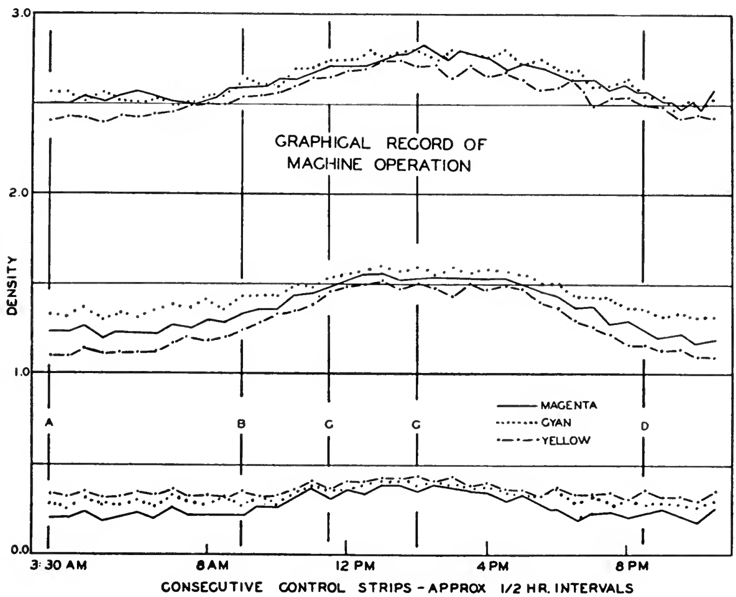

Fig. 5

than normal in density. This to the controlman indicated a definite trend toward lower speed that would require corrective measures. Since this rise was accompanied by a slight gain in the magenta and yellow density over the cyan layer in the middletone region (density 1.2) and also in the shoulder densities, he increased the replenishment rate of the first developer by 10 per cent. As can be seen by *C′* to *D* (film *C* to *C′* had passed through the first developer before the correction could be applied), this change of replenishment rate achieved the desired result as the speed increased and the color balance became more neutral.

In case of questionable deviations in the graph, complete sensitometric curves should be plotted for the strips involved. For general purposes, the three-step plot will suffice.

Many machine operators will prefer to run a pictorial type in addition to the sensitometric type since this gives them a clearer picture of the actual effect of machine differences on picture quality. The interpretation of pictorial strips should, of course, be given secondary emphasis as compared to the more accurate, numerical interpretation of the sensitometric control strips.

When deviations occur in the machine photographic tests, it is advisable to run a chemical analysis immediately to fix the cause of the deviation. Photographic side tests also may be made by using the solution control machine to compare a solution withdrawn from a machine tank with a type solution. Provided proper prechecking of solutions is made at the time of mixing, no serious deviations ever should occur. Such differences as do occur will normally arise from an excessive amount of high or low key film exposures, or from excessive aeration of solution due to leaky circulation pumps or from the aging of unused solutions.

C. Analytical Controls

The analysis procedure for the developer and bleach solutions are outlined in the paper by Brunner, Means, and Zappert.[2] For routine machine operation, complete developer analysis should be run approximately every 48 hours. Bromide analysis of developers should be run every 4 to 8 hours as changes in bromide concentration are an accurate indication of improper replenishment rate. Bleach titrations should be run at 8-hour intervals. The condition of the bleach can be judged roughly by visually noting the time required for the bleach to etch out the silver antihalo layer. Bleach performance is generally satisfactory if this takes place in $^1/_3$ the total bleaching time. It should never exceed $^1/_2$ the total bleaching time.

The fixer tank should be analyzed for silver content at intervals of 8 hours of machine operation. Fixer performance is satisfactory if time of clearing does not exceed $^1/_2$ total time of fixing.

II. MACHINE CONTROL AND REPLENISHMENT DATA

Successful replenishment can be carried out on any type of equipment having fully controlled and reproducible temperature and agitation conditions. Within the Ansco plant, the system has been adopted to machines used for 16-mm film processing as described by Forrest,[3] for 35-mm film processing as described by Harsh and Schadlich,[4] and for rack-type sheet-film processing machines varying from a large Pako machine to small vane-agitated $3^1/_2$-gallon tanks. The value of replenishment is questionable for hand-agitation systems. The greatest control normally is obtained with the larger size machines that are in constant rather than intermittent use. It is desirable to maintain continuous filtration systems in both color and first-developer tanks as the build-up of gelatin particles, specks of oxidized developer, and other foreign material hasten the chemical breakdown of solutions. Proper filtration will keep both first developer and color developer clear and light in color after months of operation.

A. Modification of Processing Solutions to Change Color Balance

The widely varying agitation conditions existing in the different types of processing equipment introduce a complicating factor because variations in agitation can produce different color balances. Partial compensation for these balance differences can be obtained by increasing or decreasing developing times. However, in order to achieve the closest possible matches in speed, gradation, and color balance, it is sometimes necessary to make slight chemical changes in the processing solutions themselves.

The most convenient tools for modifying color-balance differences resulting from different agitation conditions are variations of the thiocyanate and iodide concentrations in the first developer solution. Chemical analysis of No. 502 first developer has shown that iodide accumulates during film development, and, depending somewhat on the type of film processed, exposure level and volume of replenisher added, normally reaches an equilibrium of from 3 to 6 milligrams per liter of developer. Iodide-analysis methods and a discussion of iodide equilibrium for black-and-white film developers were given by Evans, Hanson, and Glasoe.[5, 6]

Practical tests with color film show that even a small concentration of iodide exerts an appreciable restraining effect on the yellow and magenta layers giving an effective speed loss in these layers and a shift in the over-all color balance toward the brown. It can be shown that accumulation of iodide is responsible for a large part of the color-balance shifts that occur when a first developer is used. If small amounts of potassium iodide are added initially to the fresh developer, the color-balance changes are reduced. We have adopted the practice of adding small quantities of potassium iodide to fresh No. 502 first developer. No iodide is added to the replenisher solution.

Under processing conditions where only moderate agitation is encountered (as in Pako processing) bluish-cyan color balances are often encountered because the first developer is most active on the top layers of the film and does not easily penetrate to the bottom layer. Increased first development times under such conditions do not change the relative rates of development in the layers. However, the maintenance of a higher than normal iodide concentration will restrain first development in the top layers more than in the cyan layer and by use of slightly longer than normal developing times, a normal color balance can be achieved. In this case, it is necessary to maintain this high iodide concentration by adding a small amount to the replenisher solution.

The above color-balance shifts are essential for the processing of Types 234, 634, 235, and 635 sheet, roll, and 35-mm cartridge films since these materials must be balanced so they can be processed successfully both by amateurs with hand-processing outfits and by factory finishing. Obviously it is not necessary to achieve a so-called normal balance for a machine used to process a printing-type film whose balance is normally modified by printing filters, but it is of course essential that whatever balance is obtained be maintained consistently.

B. Replenishment Procedure

1. General

The following developer replenishers were worked out using the solution analysis technique described by Brunner, Means, and Zappert.[2] Although the exact replenishment rates may require adjustment from time to time, use of the replenishers will maintain the solution ingredients very close to their initial concentrations.

Greater than 10 per cent variation in replenishment rates rarely are necessary. Trends that are not corrected by such changes eventually are traced to a mechanical or physical fault. Such difficulties should be solved by chemical analysis of the solutions in doubt. Through the knowledge of the film response to different chemical variations, skilled controlmen have maintained consistent color balances and speed over months of operation. The exact effects produced by photographic variations differ somewhat among different emulsions depending on the exact color balance of the emulsion. In general, variations of color developer affect the heavier densities to a greater degree than the lower densities whereas variations in first developer cause deviations in the over-all speed and balance of the film.

Relatively large quantities of replenishers are utilized in most cases. In the first developer, the rate is high to avoid build-up of bromide in the developer. In the color developer, replenishment rate is high because the replenisher solution is nearly as concentrated as possible. Bromide accumulates so slowly in the color developer it is necessary to add it in the replenisher solution to maintain the original amount. The short stop and hardener solutions are replenished at these high rates to prevent excessive accumulation of contaminants. No continuous replenishment is used with the bleach and fixing baths. The bleach is shifted to a separate tank, rejuvenated with bromine and after adding additional salts to make up for those lost by dilution, is returned to the machine tank. The fixer is used to exhaustion, then dumped into a large crock for sulfide recovery of silver.

2. Detailed Replenishment Procedure

The replenishment rates given in this paper are based on the rates used for the Ansco 16-mm and 35-mm developing machines. Other machines may perform best with slightly modified conditions or formulas. In fact, replenishment rates normally vary slightly during routine operation of any single machine. However, the formulas and rates of replenishment listed provide a close approximation of the requirements of any machine and are to be recommended as a starting point.

The developer replenishers were formulated using solution-analysis techniques and when used in combination with photographic and analysis tests have maintained developers over periods of months in the Ansco laboratories.

It is recommended that 3.5 to 5.0 milligrams per liter of potassium iodide be added to fresh tanks of No. 502 first developer. Analysis data indicate that the normal iodide-equilibrium ranges around these figures, subject somewhat to the exposure level of the film processed.

Changes in first developer activity are evidenced by over-all speed changes of the complete film. The exact color-balance differences

TABLE I

FIRST DEVELOPER REPLENISHMENT

	No. 502 First Developer	No. 502 *R*-3 First Developer Replenisher
Calgon	1 gram	1.0 gram
Metol	3	3.2
Sodium Sulfite	50	50.0
Hydroquinone	6	7.5
Sodium Carbonate	40	40.0
Potassium Bromide	2	..
Sodium Thiocyanate	2	2.4
Sodium Hydroxide	..	1.1
Water to make	1 liter	1.0 liter
Basic replenishment rate—23 cc./ft. 35-mm film		

obtained by increased or decreased amounts of first development vary slightly from film to film but generally increases of first development show up as reduced magenta density in the balance.

TABLE II

SHORT STOP REPLENISHMENT

	No. 859 Short Stop	No. 858 Short Stop (Replenisher for No. 859)
Glacial Acetic Acid	5 cc.	10 cc.
Sodium Acetate	30 grams	20 grams
Water to make	1 liter	1 liter
	*p*H fresh 5.20–5.30	*p*H fresh 4.70–4.80
Basic replenishment rate—24 cc./ft. 35-mm film		

This solution is replenished at a rate necessary to maintain a *p*H of 5.0 to 5.5. The volume of replenisher is great enough to provide sufficient solution change to prevent accumulation of excessive developer solution. If the short stop *p*H is maintained at a higher *p*H than 5.5, increased hardening will result from the No. 901 hardener, but reduced short stopping action and scumming will be obtained. A *p*H lower than 5.0 produces less hardening by the No. 901 hardener and a *p*H lower than 4.5 may give difficulty with film blistering.

TABLE III

HARDENER REPLENISHMENT

(These statements apply to the solution used after either first or color developer)

	No. 901 Hardener	No. 901 Replenisher
Potassium Chrome Alum	30 grams	30 grams
Water to make	1 liter	1 liter
Basic replenishment rate—30 cc./ft. 35-mm film		

This solution is replenished with the same solution as the original at a rate necessary to keep the tank *p*H approximately 3.5 to 4.0. If the *p*H rises above 4.5 (although the hardening effect will increase up to a *p*H of about 5.0) chrome alum sludge and scum may also result. If the *p*H falls below 3.5, reduced hardening is obtained. Since a solution of chrome alum will hydrolyze on standing, the subsequent release of acid causes a natural drop of *p*H. The carry-over of a small quantity of alkali is not undesirable because it aids in maintaining the optimum *p*H.

TABLE IV

COLOR DEVELOPER REPLENISHMENT

	A-605 Color Developer	A-605 *R*-2 Color Developer Replenisher
Calgon	1.0 gram	1.0 gram
Sodium Bisulfite	2.0	2.3
S-3	4.0	5.6
Sodium Carbonate	67.5	80.0
Potassium Bromide	1.0	0.6
Water to make	1 liter	1 liter
Basic replenishment rate—23 cc./ft. 35-mm film		

Use of this replenisher, like the first developer replenisher, is designed to maintain the original concentration of developer ingredients. Regular bromide analysis will assist in maintaining the proper replenishment rate. No iodide is added to this bath. Analysis indicates some iodide is accumulated during use but the formula is relatively insensitive to this restrainer in the quantities involved.

TABLE V

BLEACH REPLENISHMENT

No. 713 Bleach	
Mono Sodium Dibasic Potassium Ferricyanide	100 grams
Potassium Bromide	15
Dibasic Sodium Phosphate	40
Sodium Bisulfate	25
Water to make	1 liter

It is recommended that No. 713 bleach be rejuvenated intermittently with bromine additions.

During normal bleaching operations, the bleach exhausts caused by depletion of ferricyanide and bromide ions as well as from dilution of the bleach solution by water carried into the tank by the wet film. The accumulation of ferrocyanide ions slows the rate of bleaching to a much greater extent than would be predicted from the depletion of ferricyanide. In practice, a concentration of potassium ferrocyanide greater than 5 grams per liter should be avoided. These concentrations can be detected using either the potentiometer method described by Brunner, Means, and Zappert[2] or, if desired, the colorimetric method described by Varden and Seary.[7]

The ferrocyanide can then be reoxidized to ferricyanide by the direct addition of liquid bromine to the solution. This reaction produces bromide ions equivalent to the number of reoxidized ferricyanide ions and thus effectively regenerates the bleach bath. The chemical reactions of bleach exhaustion and rejuvenation are shown in Table VI.

TABLE VI

BLEACH EXHAUSTION

I $4Ag + 4K_3Fe(CN)_6 \longrightarrow Ag_4Fe(CN)_6 + 3K_4Fe(CN)_6$

II $Ag_4Fe(CN)_6 + 4KBr \longrightarrow K_4Fe(CN)_6 + 4AgBr$

BLEACH REJUVENATION

$$4K_4Fe(CN)_6 + 4Br^\circ \longrightarrow 4K_3Fe(CN)_6 + 4KBr$$

It is recommended that a bleach bath be rejuvenated at intervals corresponding to 25 feet of 35 millimeters per liter of tank solution.

This is conveniently done by providing two hard-rubber or ceramic mixing tanks for the bleach with pumps so that the solution may be pumped from the machine tank to either mixing tank for the rejuvenation treatment while machine operation is continued using the other tank of bleach solution.

A bleach exhaustion of 25 feet per liter normally corresponds to a potassium-ferrocyanide concentration of 4.5 to 5.0 grams per liter. With most technical grades of bromine, roughly 1.05 grams or 0.33 cubic centimeter per liter would be required to rejuvenate the bleach completely. In practice, however, in order to avoid the danger of adding an excess of bromine which would give excessive fuming and would be dangerously active both on the color film and on the tanks, spool banks, and so forth, it is desirable to retain a small amount of ferrocyanide in the bleach, normally 1.0 gram per liter or equivalent to the exhaustion produced by 5 feet of film per liter.

The addition of bromine should be made in a well-ventilated room or with a hood over the tank. Protective clothing and goggles should be worn as contact with the bromine will cause bad burns. The addition should be made slowly with vigorous stirring continued for a minimum of 30 minutes after the bromine addition is complete. The bromine will be assimilated more rapidly and with less fuming if it is first dissolved in 5 to 10 times its own volume of cold methanol and the mixture then added to the bleach mixing tank.

A second potentiometer titration should be made after the bromine addition to check the accuracy of the replenishment.

3. Replenishment of Diluted Bleach

The dilution of the bleach by the wet film can be corrected by making additions of the original chemicals in the same proportion as they were originally compounded. The degree of dilution can be detected by specific-gravity measurements using a hydrometer. No chemical additions are necessary unless the dilution exceeds 10 per cent. The specific gravity of fresh bleach No. 713 is approximately 1.110 at 20 degrees centigrade. Upon dilution, the specific gravity is reduced. An estimate of the degree can be made from the following calculation:

$$\frac{\text{Specific Gravity of Fresh Bleach Minus Specific Gravity of Diluted Bleach} \times 100}{\text{Specific Gravity of Fresh Bleach Minus 1.000 (Specific Gravity of Water)}} = \text{Per Cent Loss of Dry Salts of Original Bleach.}$$

Table VII may be used as a guide for determining the required amounts of solid chemicals.

TABLE VII

Bleach, Specific Gravity	Film Bleach No. 713
Original Specific Gravity	1.110
At 5 Per cent Dilution	1.104
At 10 Per cent Dilution	1.098
At 15 Per cent Dilution	1.093
At 20 Per cent Dilution	1.087
At 25 Per cent Dilution	1.081
At 30 Per cent Dilution	1.076

4. Fixing-Bath Control

No replenishment or rejuvenation is recommended for the No. 800 fixer. Electrolytic methods of silver recovery are difficult to apply to neutral or alkaline fixing baths. It is recommended that the No. 800 fixer be used until a silver concentration of about 2.5 grams per liter is reached or the time of clearing exceeds $^1/_2$ the total available fixing time. When this point is reached, the fixer solution should be replaced by a fresh bath. The used solution may be treated with sulfides to recover the silver.

III. SUMMARY OF TESTING OPERATIONS RECOMMENDED FOR CONTROL OF COLOR-PROCESSING LABORATORY

A. Testing of Raw Materials

The recommended raw material tests are tabulated in Table VIII. The frequency of tests will, of course, depend principally on the supply situation, size of shipments received, and number of manufacturer's lot numbers involved. Emphasis should be placed on pretesting all lots of developing agents, sodium disulfite, and thiocyanate since variations in these chemicals are most likely to affect results. Less attention is required with the other chemicals once the consistency of a new source of supply has been ascertained. It is advisable to keep careful records of stock, date each chemical received, and date of its use for ready reference in tracking down variations in a solution mix.

A thorough pretesting policy will often prevent bad solution mixes and reduce the possibility of machine slowdown because of solution supply.

TABLE VIII—TESTING OF CHEMICAL RAW MATERIALS

All new chemicals to be compared with types of known purity

Chemical	Testing Recommended	Suggested Tolerance	Recommended Action to Correct Deviation
Metol Hydroquinone Sodium Thiocyanate	Photographic test in No. 502 developer	$\pm 1/8$ stop speed $\pm 1/16$ stop color balance	If deviation can be corrected by small change in concentration, chemical can be used. Otherwise, return to manufacturer.
Color Developing Agent Sodium Bisulfite	Photographic test in No. 605 developer	$\pm 1/8$ stop speed $\pm 1/16$ stop color balance	If deviation can be corrected by small change in concentration, chemical can be used. Otherwise, return to manufacturer.
Sodium Sulfite Sodium Carbonate Potassium Bromide Potassium Iodide	When obtained from new supplier make photographic test in No. 502 developer	$\pm 1/8$ stop speed $\pm 1/16$ stop color balance	If deviation can be corrected by small change in concentration, chemical can be used. Otherwise, return to manufacturer.
Dipotassium Mono Sodium Ferricyanide *or* Potassium Ferricyanide	Potentiometric titration	Contains maximum of 1% Potassium Ferrocyanide	Oxidize with bromine or return to manufacturer.
Dibasic Sodium Phosphate Sodium Bisulfate	Titrate Dibasic Sodium Phosphate with type Bisulfate and vice versa	$\pm 10\%$ concentration	Adjust relative quantities to obtain bleach *p*H of 5.7–6.0, maintaining a minimum phosphate concentration of 35 grams per/liter.
Acetic Acid Sodium Acetate	Titrate Acetic Acid with Sodium Acetate and vice versa	$\pm 10\%$ concentration	Adjust relative quantities to obtain short stops of proper *p*H.
Potassium Chrome Alum	*p*H	*p*H of 3% solution 3.0 to 4.0	If *p*H deviation small, adjust with sodium hydroxide or sulfuric acid. If large, return to manufacturer.
Sodium Thiosulfate	When obtained from new supplier make photographic tests in No. 800 fixer	$\pm 1/8$ stop speed $\pm 1/16$ stop color balance	Return to manufacturer.

TABLE IX

TESTING OF PROCESSING SOLUTION MIXES

Chemical	Testing Recommended	Suggested Tolerance	Recommended Action to Correct Deviation
No. 502 First	1. *p*H 2. Photographic Test 3. Analysis (if indicated by Photo Test)	1. 10.00–10.05 2. ±1/4 stop speed ± 1/8 stop color balance 3. Correct chemical concentration until photographic test is satisfactory. Generally ±5% chemical concentration can be tolerated	Analyze for suspected ingredients, adjust concentration and make new photo test. Discard if error cannot be corrected.
No. 502 *R*-3 First Developer Replenisher	1. *p*H 2. Photographic Test 3. Analysis (if indicated by Photo Test)	1. 10.00–10.10 2. Same as for First Developer 3. Same as for First Developer	Analyze for suspected ingredients, adjust concentration and make new photo test. Discard if error cannot be corrected.
No. 605 Color Developer	1. *p*H 2. Photographic Test 3. Analysis (if indicated by Photo Test)	1. 10.30–10.40 2. Same as for First Developer 3. Same as for First Developer	Analyze for suspected ingredients, adjust concentration and make new photo test. Discard if error cannot be corrected.
No. 605 *R*-2 Color Developer Replenisher	1. *p*H 2. Photographic Test 3. Analysis (if indicated by Photo Test)	1. 10.35–10.45 2. Same as for First Developer 3. Same as for Color Developer	Analyze for suspected ingredients, adjust concentration and make new photo test. Discard if error cannot be corrected.

TABLE IX (*continued*)

Chemical	Testing Recommended	Suggested Tolerance	Recommended Action to Correct Deviation
No. 859 Short Stop	1. *p*H	1. 5.2–5.3	Titrate with NaOH to determine total acidity and adjust concentration of acetic acid and sodium acetate on that basis.
No. 858 Short Stop (Replenisher for No. 859)	1. *p*H	1. 4.7–4.8	Titrate with NaOH to determine total acidity and adjust concentration of acetic acid and sodium acetate on that basis.
No. 901 Hardener	1. *p*H	1. 3.0–4.0	Discard if *p*H is below 2.5. Otherwise, adjust *p*H with sodium hydroxide or sulfuric acid if necessary to bring *p*H to between 3.0 and 4.0.
No. 713 Bleach	1. *p*H 2. Potentiometric titration	1. 5.7–6.0 2. Less than 1.0 gram per liter potassium ferrocyanide	Correct *p*H by adjusting dibasic sodium phosphate or sodium bisulfate concentration. If ferrocyanide present, oxidize with bromine.
No. 800 Fixer	1. *p*H	1. 7.0–8.5	If *p*H is low, adjust with borax. If high, discard.

TABLE X

TESTING REQUIRED DURING MACHINE OPERATION

Tank Solution	Testing Recommended	Interval to Be Regularly Tested	Suggested Tolerances	Recommended Action to Correct Deviation
No. 502 First Developer	1. Temperature	1. 1 hr.	1. $\pm 1/2°$ F.	1. —
	2. pH	2. 1 hr.	2. 10.0–10.1	2. Make immediate bromide analysis.
	3. Bromide Analysis	3. 4 hrs.	3. 2.0 ± 0.1 g.	3. Make immediate complete analysis. Adjust replenishment rate.
	4. Complete Analysis	4. 48 hrs. (or more often if difficulty is encountered)	4. $\pm 5\%$ variation in chemicals	4. Make photographic side test of tank solution. Adjust replenishment rate. Make additions of individual chemicals.
No. 859 Short Stop (after First and Color Developer)	1. Temperature	1. 1 hr.	1. $\pm 3°$ F.	Adjust replenishment rate
	2. pH	2. 1 hr.	2. 5.0–5.5	
No. 901 Hardener (after First and Color Developer)	1. Temperature	1. 1 hr.	1. $\pm 3°$ F.	Adjust replenishment rate
	2. pH	2. 1 hr.	2. 3.5–4.5	
No. 605 Color Developer	1. Temperature	1. 1 hr.	1. $\pm 1/2°$ F.	1. —
	2. pH	2. 1 hr.	2. 10.30–10.45	2. Make immediate bromide analysis.
	3. Bromide Analysis	3. 4 hrs.	3. 1.0 ± 0.05 g.	3. Make immediate complete analysis. Adjust replenishment rate.
	4. Complete	4. 48 hrs.	4. $\pm 5\%$ variation in chemicals	4. Make photographic side tests of tank solution, adjust replenishment rates. Make additions of individual chemicals

TABLE X (*continued*)

Tank Solution	Testing Recommended	Interval to Be Regularly Tested	Suggested Tolerances	Recommended Action to Correct Deviation
No. 713 Bleach	1. Temperature	1. 1 hr.	1. ±3° F.	
	2. pH	2. 1 hr.	2. 5.7–6.0 (does not usually change)	
	3. Observe rate of Bleaching	3. 1 hr.	3. Bleaching of anti-halo silver should not require more than $^1/_2$ of total bleach times	Change bleach solution. Pump machine solution to mixing tank where it can be rejuvenated with bromine and adjusted for salt concentration.
	4. Specific Gravity	4. 8 hrs.	4. 1.000–1.120	
	5. Potentiometer Analysis	5. 8 hrs.	5. Less than 5 g. per liter of potassium ferrocyanide	
No. 800 Fixer	1. Temperature	1. 1 hr.	1. ±3° F.	
	2. pH	2. 1 hr.	2. 7.0– 8.5 (does not usually change)	
	3. Observe rate of Fixing	3. 1 hr.	3. Clearing should not require more than $^1/_2$ of total fixing time	Change fixer tank. Recover silver by sulfide method.
	4. Silver Analysis	4. 8 hrs.	4. Less than 3 g./liter silver	
Complete Machine Process	Sensitometric Control	15 min.	$\pm^1/_4$ stop speed–$\pm^1/_8$ stop color balance	Correlate with bromide analysis, pH, and temperature differences and adjust replenishment rates as necessary. In severe cases make direct chemical additions based on chemical analysis.

B. Testing of Solution Mixes

The recommended tests for solution mixes are shown in Table IX. Considerable attention should be paid to pretesting solution mixes before they are placed on the machine. Unless errors of solution mixing or of previously unobserved chemical differences are detected at this point, quality of machine output will suffer.

C. Testing During Machine Operation

The tests indicated in Table X should be made at consistent intervals to provide a constant flow of information to the machine control chemist.

In order to make correct decisions when photographic tests indicate trends away from normal, the control chemist should have at hand complete records of temperature and *p*H variations of all solutions as well as analysis of developers.

ACKNOWLEDGMENTS

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Analysis of Developers and Bleach for Ansco Color Film*

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Summary—**Published procedures for black-and-white developer analysis are reviewed. New analytical methods are described or old ones modified to achieve the accuracy required for the complete control of all constituents of the developers used for Ansco color film. To evaluate the bleach solution prior to regeneration, a procedure is presented for the determination of ferrocyanide ion in this solution.**

Introduction

It has been recognized for some time that the accurate analysis of black-and-white developing solutions is especially important in the control of continuously replenished developers. As shown by Bates and Runyan,[1] it is of even greater importance in color-processing developers because proper color balance must be maintained among three different emulsions. In the past few years, several articles have appeared in the technical literature concerning the analysis of black-and-white photographic developers, but nothing has been published on the analysis of developers used for processing color film because, until recently, color film was processed only by the manufacturer.

Little has appeared in the literature concerning the control of photographic bleach solutions but when this solution is to be regenerated, as described by Bates and Runyan,[1] a method for its analysis is necessary.

The procedures here described are, for the most part, adaptations of methods previously reported for use with the usual black-and-white developers. They have been selected for their brevity, simplicity, and accuracy and have been used for the control of continuously replenished solutions for some time by unskilled technicians and require no special equipment other than a potentiometer.

Discussion

The procedures discussed here have been adapted especially for use with the Ansco developers listed in Table I but may be used for other developers with some modification.

* Presented May 18, 1948, at the SMPE Convention in Santa Monica.

TABLE I

First Developer—A-502	
Water, 65 to 90 degrees Fahrenheit	750 milliliters
Metol	3 grams
Sodium Sulfite	50 grams
Hydroquinone	6 grams
Sodium Carbonate Monohydrate	40 grams
Sodium Thiocyanate	2 grams
Potassium Bromide	2 grams
Water to make	1 liter
Color Developer—A-605	
Water, 65 to 70 degrees Fahrenheit	750 milliliters
Calgon	1 gram
Sodium Bisulfite	2 grams
Diethyl-*p*-Phenylenediamine Hydrochloride	4 grams
Sodium Carbonate Monohydrate	67.5 grams
Potassium Bromide	1 gram
Water to make	1 liter

Determination of Metol and Hydroquinone

The first developer used in the Ansco color process is similar to the usual reversal first developer containing sodium thiocyanate.

All the earlier methods for the determination of metol and hydroquinone were based on two separate extractions of the developing agents and possessed several disadvantages, one of which was the determination of metol by difference. Baumbach[2] made a definite advance in 1946 by describing a single methyl acetate extraction method involving a potentiometric acid titration of metol followed by oxidation of both metol and hydroquinone with iodine. Shaner and Sparks[3] modified this by using a U-tube extractor and methyl ethyl ketone as solvent. The difficulty in determining the end point in the iodine titration is a disadvantage common to both methods. When the *p*H is maintained at 6.5 to 7.0, the solution is so highly colored by oxidation products that it is extremely difficult to see the blue starch-iodine end-point. Oxidation at low *p*H values results in a nearly colorless solution, but the iodine oxidation is not quantitative.

Because of the small sample used in the Shaner and Sparks procedure, the volume of acid needed to titrate the metol is very small. Four developers, cited by these authors, containing 2.0, 3.0, 0.22, and 0.31 grams of metol per liter, require only 1.16, 1.74, 0.13, and 0.18 milliliters of 0.1 normal acid when determined in accordance with their procedure. Even if the procedure is changed and 0.05 normal acid is used, the volumes needed are still too small for reasonable accuracy with ordinary equipment. Moreover, with a sample of this size, the amount of metol present is too little to give a usable inflection in the titration curve.

The disadvantage of the iodine titration may be avoided by oxidizing the developers with ceric sulfate. Since this oxidation is performed in a strongly acid solution, highly colored oxidation products are not formed, and the end-point is easily observed. Stott[4] described a ceric sulfate titration to determine developing agents, but he determined the end-point potentiometrically. Use of the ortho-phenanthroline ferrous complex (ferroin) as indicator makes the titration simpler and faster since the color change is easily discernible.

Equally satisfactory results have been obtained with methyl acetate, ethyl acetate, or isopropyl acetate as extracting solvent. With the methyl acetate used, a slight dark color appeared during the ceric sulfate titration which may be objectionable, but no such darkening occurred with the other two acetates. Methyl ethyl ketone, the solvent used by Shaner and Sparks, is itself oxidized by ceric sulfate, and therefore cannot be used.

This modified Baumbach procedure involving the acid titration of metol and ceric sulfate oxidation of both metol and hydroquinone has been tested on developer A-502 with variation in the concentration of the developing agents from 50 per cent less to 20 per cent more than normal. Within this range, the metol determination was found to be accurate to 100.7 ± 2.4 per cent and the hydroquinone to 99.5 ± 1.5 per cent. Occasional values above 100 per cent are probably due to mechanical carry-over of traces of developing solution with the solvent.

Determination of Diethyl-p-phenylenediamine Hydrochloride

Diethyl-*p*-phenylenediamine hydrochloride or its derivatives may be extracted in exactly the same manner as metol and hydroquinone. It may be titrated with acid the same as metol but since it is more basic and no hydroquinone is present, a better inflection point is obtained in the titration curve. It may also be oxidized with ceric sulfate, and this oxidation using ferroin indicator is preferred to the potentiometric acid titration because it is faster and simpler. Immediately on addition of the ceric sulfate, a bright cherry red color is produced which is an intermediate oxidation product. The intensity of this color soon reaches a maximum, and then begins to fade until just before the end-point it disappears and is replaced by the same orange-pink indicator color observed in the metol-hydroquinone titration. Another few drops of reagent produce the usual indicator color change.

Determination of Sodium Sulfite and Bisulfite

The bisulfite used in developer A-605 is converted to sulfite by the sodium carbonate. The same analytical procedure for the sulfite ion is, therefore, applicable to both developers. Atkinson and Shaner[5] and Stott[4] have described a procedure in which an acidified standard iodine solution is titrated with the developer. This method may be used for these developers except that a weaker iodine solution should be used for developer A-605 since it contains a very small amount of sulfite ions. The only precaution required is that sufficient acid be present to keep the solution below pH 4 during the entire titration and thus prevent oxidation of the developing agents.

This method was found to be accurate to 100.4 $\pm$ 2.0 per cent for concentrations ranging from 50 per cent less to 25 per cent more than the concentrations normally used.

Determination of Sodium Carbonate

Evans and Hanson[6] described a procedure in which carbon dioxide and sulfur dioxide are liberated by acidification of the developer, the sulfur dioxide is then oxidized to sulfate and the remaining carbon dioxide is measured volumetrically. Atkinson and Shaner[5] determined carbon dioxide by absorption in soda lime or Ascarite. A simpler method described by Stott[4] involved the potentiometric titration of the developer with standard acid using glass or platinum and calomel electrodes. In this titration, the first inflection point in the titration curve corresponds to the change of carbonate to bicarbonate, but because of the buffering action of the sulfite present, this inflection is not at all sharp.

We have found it easier and faster to titrate the developer directly with standard acid to about pH 4 (gray color of methyl orange-indigo carmine) at which point the carbonate has been completely neutralized and the sulfite has been converted to bisulfite. By deducting the volume of acid required for the sulfite present, the carbonate content may be calculated. Since developer A-605 has no alkalinity due to sulfite, no deduction is required. This method of determining carbonate was found to be accurate to 99 $\pm$ 1 per cent.

Determination of Potassium Bromide

Since developer A-502 contains thiocyanate which behaves very similarly to bromide, a separation of the two must be effected. To determine bromide in the presence of chloride or thiocyanate, Atkinson and Shaner[5] recommended a rather lengthy iodometric procedure. To determine bromide in the presence of chloride, Stott[4] used the method of Evans, Hanson, and Glasoe[7] in which the developer was boiled, acidified, and boiled again, cooled, and titrated potentiometrically with silver nitrate using silver and calomel electrodes. This method cannot be used in the presence of thiocyanate because the boiling removes some but not all of the thiocyanate.

Potassium bromide may be determined in developer A-502 in the range 1.0 to 3.5 grams per liter with an accuracy of 100.0 ± 0.2 per cent by oxidation with 30 per cent hydrogen peroxide followed by the standard Volhard bromide procedure.

Developer A-605 does not contain thiocyanate but does contain chloride ions from the color-developing agent which is added in the form of its hydrochloride. The method of Evans, Hanson, and Glasoe[7] cited above gives satisfactory results, but it has been found that boiling, either before or after acidification, is unnecessary. After acidification, the bromide may be determined by potentiometric titration with silver nitrate. Experience has shown that no advantage is gained by the addition of barium nitrate, sodium acetate, or aluminum sulfate, as is sometimes recommended. The above procedure gave an accuracy of 100.0 ± 0.5 per cent for concentrations of 1.0 to 3.5 grams of potassium bromide per liter.

Determination of Sodium Thiocyanate

No method has been reported for the determination of thiocyanate in developers. Separation of thiocyanate from bromide is a lengthy procedure. Since the solubilities of silver thiocyanate and bromide are about the same, they are precipitated together and cannot be differentiated by the usual potentiometric titration. However, the sum of bromide and thiocyanate may be determined and, by deduction of the titer caused by the bromide, the thiocyanate concentration calculated. The Volhard method cannot be used because the developing agents present reduce the ferric ion added as indicator.

The sum of bromide and thiocyanate may be conveniently determined by acidification of the developer and direct potentiometric titration with standard silver nitrate to the inflection point using silver wire and calomel electrodes (Fig. 1). With this procedure the thiocyanate was determined with an accuracy of 100 ± 1 per cent.

Determination of Ferrocyanide in Bleach

Ansco color bleach A-713 has the following composition:

Dipotassium Mono Sodium Ferricyanide or Potassium Ferricyanide	100 Grams
Potassium Bromide	15 Grams
Dibasic Sodium Phosphate	40 Grams
Sodium Bisulfate	25 Grams
Water to make	1 Liter

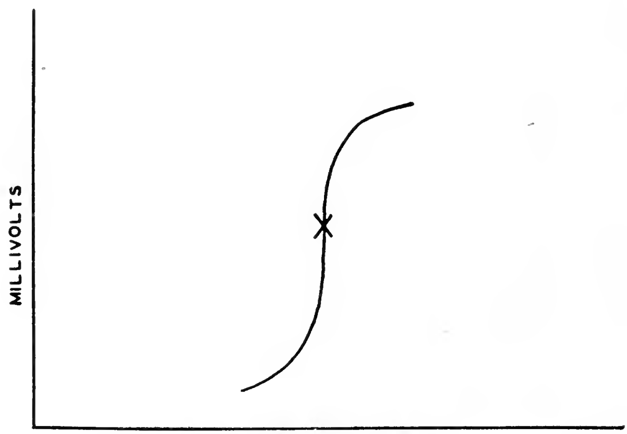

Fig. 1—Titration curve for bromide plus thiocyanate.

During use some of the ferricyanide is reduced to ferrocyanide. Varden and Seary[8] described a colorimetric procedure for the rapid determination of color bleach exhaustion. When the bleach solution is to be regenerated with bromine as described by Bates and Runyan,[1] the concentration of ferrocyanide must be determined more accurately than is possible with the colorimetric method. Standard textbooks on chemical analysis describe the determination of ferrocyanide in acid solution by titration with potassium permanganate or ceric sulfate. Either of these oxidants may be used with bleach A-713, but because of the deep color of the solution, the titration must be followed potentiometrically. In the permanganate titration, considerable time is required for the potential to reach equilibrium as the end-point is approached. With ceric sulfate equilibrium is reached more rapidly and the length of time required for the titration is thus shortened. It is necessary that the sample be diluted as described since the position and magnitude of the inflection is influenced by the salt content of the solution (Fig. 2). The ceric sulfate method gave an accuracy of 99.5 ±0.5 per cent in the range of 2.5 to 10.0 grams of ferrocyanide ion per liter.

PROCEDURES

Determination of Metol and Hydroquinone

A. Metol—Pipet a 25.0-milliliter sample of developer into a 125-milliliter separatory funnel. Add 2 drops of thymol blue indicator

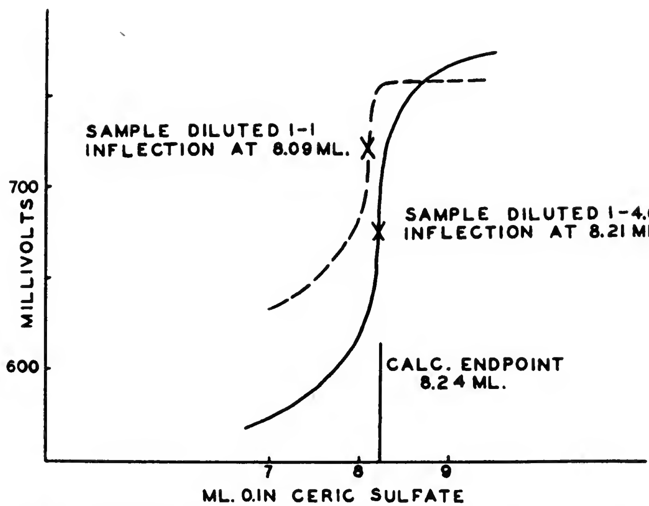

Fig. 2—Effect of dilution on titration of ferrocyanide in bleach.

and one-to-one sulfuric acid until the color of the solution just turns yellow (*p*H 8 to 8.5). Add 12 grams potassium bromide, 25 milliliters of iso-propyl acetate, shake for 3 minutes and then allow the layers to separate completely. Drain the aqueous layer into a 50-milliliter beaker, allowing a small amount of solvent to enter the stopcock bore. Pour the solvent into a small dry beaker. Return the aqueous portion to the funnel, rinse the beaker with an additional 25 milliliters of solvent and add this to the funnel. Repeat the shaking and separation.

Pour the first solvent extract, containing most of the extracted developing agents, from the first to a second and to a third small dry beaker, and finally to a 400-milliliter beaker. After draining off the aqueous layer, pass the second portion of solvent through the same three small beakers to the 400-milliliter beaker.

Add 100 milliliters of distilled water and 50 milliliters of methanol to the combined solvent layers and titrate potentiometrically with approximately 0.05 normal hydrochloric acid, using glass and calomel electrodes and mechanical stirring. Plot the titration curve of *p*H versus milliliters of acid and determine the inflection point.

Grams of metol per liter =

6.88 × milliliters of hydrochloric acid × normality of hydrochloric acid.

B. Hydroquinone—After the acid titration add 5 milliliters of one-to-one sulfuric acid and 2 drops of 0.025 molar ferroin indicator (*o*-phenanthroline ferrous complex). Titrate with approximately 0.1 normal ceric sulfate solution, using mechanical stirring, until the pink-orange color changes to greenish yellow and remains changed for 30 seconds.

Grams of hydroquinone per liter =

$$2.20\left[\text{milliliters } Ce(SO_4)_2 \times \text{normality } Ce(SO_4)_2 - \frac{\text{grams metol per liter}}{3.44}\right].$$

Determination of Diethyl-p-phenylenediamine Chloride

A 25.0-milliliter sample of developer is extracted exactly as described in the procedure for metol. After the addition of 100 milliliters of distilled water, 50 milliliters of methanol, 5 milliliters of one-to-one sulfuric acid, and 2 drops of 0.025 molar ferroin indicator to the combined solvent layers, the solution is titrated with approximately 0.1 normal ceric sulfate solution as described above.

Grams of diethyl-*p*-phenylenediamine hydrochloride =

$$4.01 \times \text{milliliters } Ce(SO_4)_2 \times \text{normality } Ce(SO_4)_2.$$

Determination of Sodium Sulfite in Developer A-502

Place a portion of the developer in a 25-milliliter buret. Pipet 20.0 milliliters of approximately 0.5 normal iodine solution into a 250-

milliliter Erlenmeyer flask containing 100 milliliters of distilled water and 5 milliliters of concentrated hydrochloric acid. Titrate the iodine solution with the developer until the iodine color is nearly discharged. Add 3 milliliters of starch solution and continue the titration until the solution becomes colorless.

Grams of sodium sulfite per liter =

$$\frac{\text{milliliters of iodine} \times \text{normality of iodine} \times 63}{\text{milliliters developer required}}.$$

Determination of Sodium Bisulfite in Developer A-605

Place a portion of the developer in a 25-milliliter buret. Pipet 5.0 milliliters of approximately 0.1 normal iodine solution into a 250-milliliter Erlenmeyer flask containing 100 milliliters of distilled water and 5 milliliters of concentrated hydrochloric acid. Titrate the iodine solution with the developer until the iodine color is nearly discharged. Add 3 milliliters of starch solution and continue the titration until the solution becomes colorless.

Grams of sodium bisulfite per liter =

$$\frac{\text{milliliters of iodine} \times \text{normality of iodine} \times 52}{\text{milliliters developer required}}.$$

Determination of Sodium Carbonate

Pipet a 20.0-milliliter sample of developer into a 250-milliliter Erlenmeyer flask containing 100 milliliters of distilled water and 4 drops of methyl orange-indigo carmine indicator.* Titrate with approximately 1 normal hydrochloric acid to the gray end-point.

Grams of sodium carbonate monohydrate per liter A-502 =

$$\frac{\text{milliliters HCl} \times \text{normality HCl} - (0.159 \times \text{grams } Na_2SO_3 \text{ per liter})}{0.323}$$

Grams of sodium carbonate monohydrate per liter A-605 =

$$\frac{\text{milliliters HCl} \times \text{normality HCl}}{0.323}.$$

* The mixed indicator is prepared by dissolving 0.1 gram methyl orange and 0.25 gram indigo carmine in 100 milliliters of water. The end point is taken as the neutral gray color which occurs between the alkaline green and the acid violet shades. Bromphenol blue may be used in place of the mixed indicator, but the dichroic red-yellow end point is more difficult to see.

Determination of Potassium Bromide in Developer A-502

Pipet a 25.0-milliliter sample of developer into a 500 milliliter Erlenmeyer flask. Add 10 milliliters of 30 per cent hydrogen peroxide and warm gently until a vigorous reaction begins and then remove the source of heat. When the reaction has subsided, heat to boiling and boil for 3 minutes. Cool, add 100 milliliters of distilled water, and neutralize to alkacid paper by dropwise addition of one-to-one nitric acid and then add 5 milliliters in excess.

Add 10.0 milliliters of approximately 0.1 normal silver nitrate from a pipet followed by 3 milliliters of saturated ferric ammonium sulfate solution which has been slightly acidified with nitric acid. (If desired 10 milliliters of chloroform may be added and the solution well shaken to coagulate the precipitate.) Titrate with approximately 0.05 normal ammonium thiocyanate to the appearance of a dirty pink color which persists for 30 seconds.

Grams of potassium bromide per liter =

$$4.76\ [(10 \times \text{normality } AgNO_3) - (\text{milliliters } NH_4SCN \times \text{normality } NH_4SCN)].$$

Determination of Potassium Bromide in Developer A-605

Pipet a 50.0-milliliter sample of developer into a 400-milliliter beaker and neutralize to alkacid paper by the careful addition of one-to-one nitric acid, and then add about 5 milliliters in excess. Titrate potentiometrically with approximately 0.1 normal silver nitrate using silver and calomel electrodes. The end-point is the inflection in the curve of millivolts versus milliliters.

Grams of potassium bromide per liter =

$$2.38 \times \text{milliliters } AgNO_3 \times \text{normality } AgNO_3.$$

Determination of Sodium Thiocyanate in Developer A-502

Pipet a 25.0-milliliter sample of developer into a 400-milliliter beaker containing 100 milliliters of distilled water. Add one-to-one sulfuric acid until the solution has a pH of about 2 and titrate potentiometrically with approximately 0.1 normal silver nitrate using silver and calomel electrodes. The end-point is the inflection in the curve of millivolts versus milliliters.

Grams of sodium thiocyanate per liter =

$$3.24\left[\text{milliliters } AgNO_3 \times \text{normality } AgNO_3 - \frac{\text{grams KBr per liter}}{4.76}\right].$$

Determination of Ferrocyanide in Bleach A-713

Pipet 50.0 milliliters of bleach solution into a 400-milliliter beaker, add 20 milliliters of concentrated hydrochloric acid and dilute to about 300 milliliters with distilled water. Titrate potentiometrically with approximately 0.1 normal ceric sulfate using platinum and calomel electrodes. Take the end-point as the inflection in the curve of millivolts versus milliliters or, in routine determinations, titrate to that millivolt reading which corresponds to the inflection point.

Grams of ferrocyanide ion per liter =

$$4.24 \times \text{milliliters } Ce(SO_4)_2 \times \text{normality } Ce(SO_4)_2.$$

ACKNOWLEDGMENT

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Note on an Improved Filter Holder for Color Printing*

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Summary—**The modification of the printer head of a Bell and Howell Model J printer to accept filters for color printing is described. The novel location of the filters has the advantages of easy accessibility for quick interchanging of filters, ability to use smaller size filters, and greatly increased filter life.**

Introduction

With the increasing use of 16-mm color motion pictures by the United States Navy, it became necessary to find a better means of inserting optical filters in the light system of the Model J, 16-mm Bell and Howell printer. Previously, gelatin color-correction filters had been inserted in various positions in the lamphouse assembly. In these locations the filters soon buckled and faded, after short periods of operation. Various means of cooling the filters by increasing air circulation, by blowing compressed air, or by installation of fans have been attempted. However, in all such installations attempted, an inadequate filter life was obtained.

The printer head was next considered as a possible location for the filters. (See Fig. 1.) The problem of placing the filters in the printer head consisted in making the filter holder lighttight, in order to stop all light rays except those which pass through the filter aperture, and yet not interfere with the mechanical operation of the printer.

The problem of making the filter holder lighttight around its edges was accomplished by placing the filter-holder slide in contact with the inner surface of the printer-head housing and just clearing the aperture mechanism. The filter holder is made to just clear the main drive sprocket hub, and yet not allow extraneous light to pass around the end of the filter.

A spring clip is provided to lock the filter holder in its proper position. (See Fig. 2.) The filter holder is constructed to allow different

* Presented October 28, 1948, at the SMPE Convention in Washington.

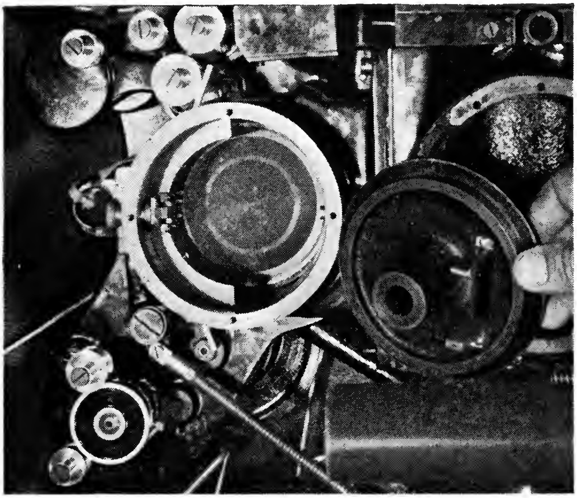

Fig 1—Printer head with face plate removed.

filter-pack combinations to be inserted quickly and easily. (ee Fig. 3.) Additional holders may be provided to allow easy changes when emulsions requiring different filter balances are printed.

Fig. 4 shows the filter holder being inserted into the printer-head

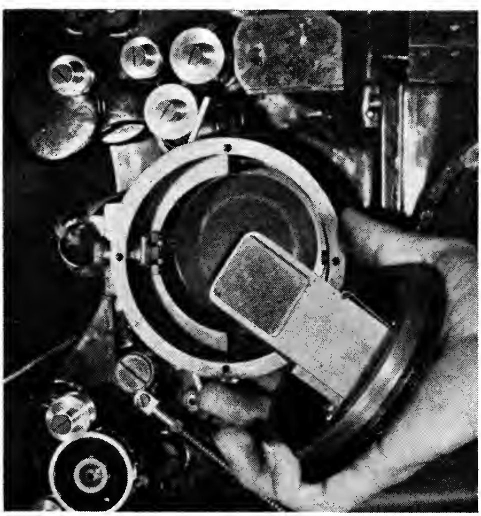

Fig. 2—Filter inserted in face plate.

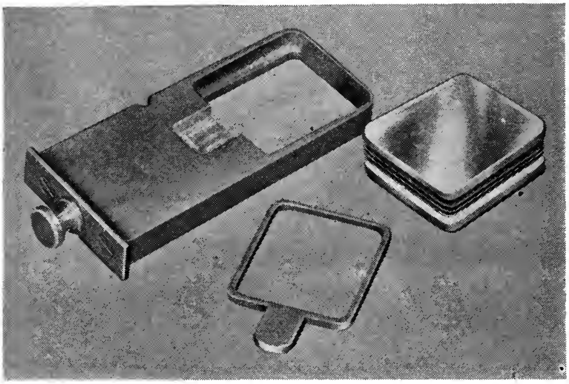

Fig. 3—Components of filter holder.

slot. The filter holder is equipped with a flange which is recessed into the printer-head face plate and is flush with the surface. This flange acts as a light trap over the slot and also determines the limit of travel of the filter holder into the printer head.

Fig. 5 shows the filter holder in position for operation. In this position it does not interfere with the operation of the diaphragm light-changing mechanism.

FILTER LIFE

Location of the filters in the printer head, utilizes the present air-circulation system of the Bell and Howell printer to cool the filters.

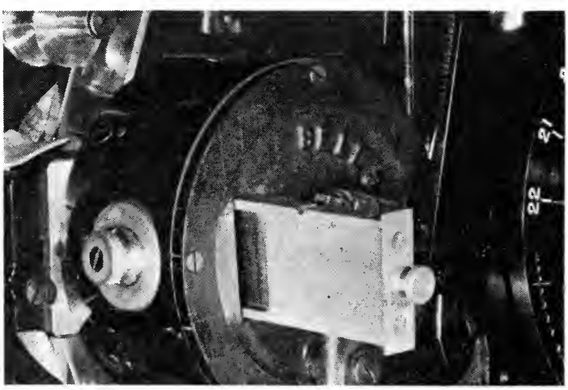

Fig. 4—Filter holder being inserted into printer head.

Production runs with this filter device have been made over a period of days with little or no loss of color balance due to filter deterioration.

Assuming a lamphouse filter arrangement, in which the filters are located 1.5 inches from the lamp as compared with 8 inches from the lamp in the present printer-head location of the filter, the intensity of illumination reaching the printer-head filter pack is approximately $^1/_{28}$ the intensity reaching a lamphouse filter pack.

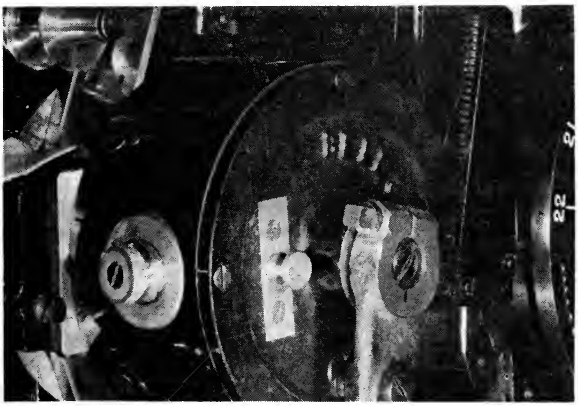

Fig. 5—Filter holder in operating position in printer head.

ADVANTAGES

1. In this location the filters are removed as far as possible from the light and heat of the light housing and from the heat of the standard heat-absorbing glass which is located in the lamphouse.
2. Ability to change filter packs in a darkroom while the operator is in a sitting position without use of tools or without disassembly of the lamphousing.
3. Freedom from distracting sounds of extra blower systems.
4. Ability to insert an ultraviolet filter in the printing head for sound-track printing.
5. Ability to print long-production runs without rapid filter deterioration and consequent change of color balance.
6. Ability to convert the Bell and Howell Model J printer to color printing at very low cost.

Metallic-Salt Track on Ansco 16-Mm Color Film*

By J. L. FORREST

Ansco, Binghamton, New York

Summary—**In 16-mm Ansco color motion picture film the silver is removed from the image, leaving dye in the three layers. The combination (maximum density) of the subtractive colors has a visual density of about 3, which is sufficient to produce good screen contrast. The maximum density, while being visually opaque, has a transmission band in the near infrared in the region of 8000 angstrom units, which is the most sensitive region of the cesium-type phototube. While for many purposes this may not be objectionable, it can be overcome by differentially processing the film so that the sound-track modulations are opaque to red light without affecting the dye picture area. This paper describes a method by which differential treatment of the sound track area can be accomplished.**

The method of processing Ansco color film has been presented in numerous publications and the procedure for machine processing of 16-mm Ansco color film has been presented.[1] In this process, the silver is removed from the image area, leaving dye in the three layers. The combination (maximum density) of the subtractive colors—cyan, magenta, and yellow—has a visual density of from 2.8 to 3, which is sufficient to produce good screen contrast. The maximum density, while being visually opaque, transmits the far-red and near-infrared radiation.

A sound track on Ansco color film, processed in the usual way, is a dye track, the density of which is made up of the cyan, magenta, and yellow from the three layers. These dyes (Fig. 1) have good absorption in the visible region of the spectrum, but transmit the far-red and infrared. If a track of this kind is played on sound-reproducing equipment utilizing a blue-sensitive phototube such as that described by Glover and Moore[2] (Fig. 2), the resulting volume will compare favorably with a silver track played on conventional equipment (Fig. 3).

Most sound-projection equipment, however, uses a cesium-type phototube (Fig. 4). This applies particularly to 16-mm projectors.

* Presented October 28, 1948, at the SMPE Convention in Washington.

This tube has most of its sensitivity in the near infrared region of the spectrum. The dye track, therefore, is not so efficient as a metallic type of track for modulating a light beam from an incandescent source when read by a cesium-type phototube.

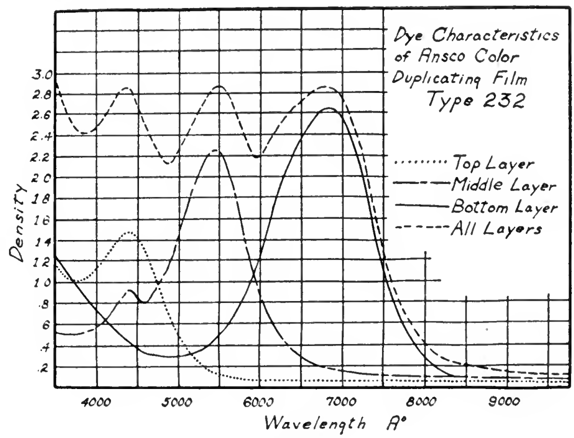

Fig. 1

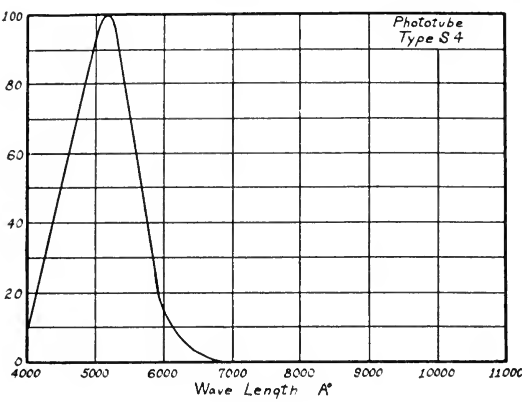

Fig. 2

The easiest and most direct approach to the solution of this problem is to suggest the use of a blue-sensitive phototube.[3–6] Since it seems unlikely that a change-over to blue-sensitive phototubes will be made for some time, differential processing of the picture and sound track is necessary to make the sound-track modulations opaque to infrared light. Differential treatment of the sound-track area of motion picture film is not new to the motion picture industry. The patent literature[7] describes many procedures and methods for such treatments, each one more or less special and adapted to the process

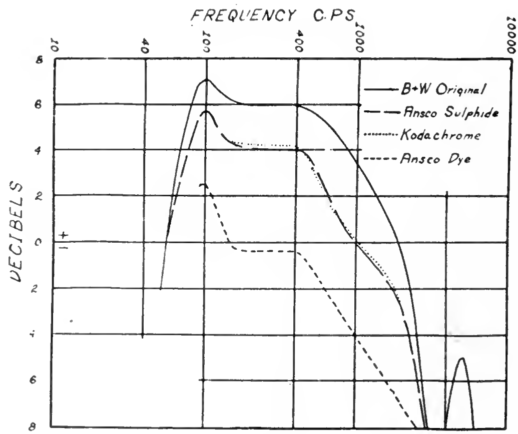

Fig. 3

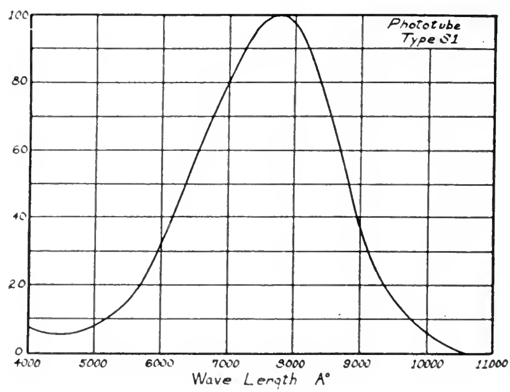

Fig. 4

being used. All such processes involve special equipment and techniques which add extra steps to the processing procedure. Furthermore, because the sound track must be confined to a definite area of the film specifically defined by established standards,[8] precision application equipment is required and skilled technicians must be available to operate it.

Patent literature[9] teaches that, in the case of Kodachrome, the sound-track area may be treated with a solution of a sulfide plus an iodide in order to retain the metallic salts in the sound-track area and thus increase its opacity to infrared light.

A procedure for increasing the opacity of 16-mm Ansco color duplicating film to infrared light has been worked out in which the silver halides forming the modulations are converted to silver sulfide.

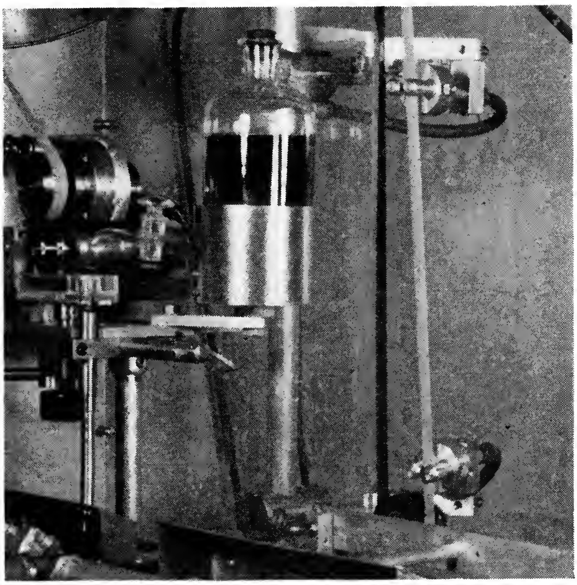

Fig. 5

This treatment produces a sound track on Ansco color film which compares favorably in volume with a silver track when reproduced on the conventional red-sensitive phototube (Fig. 3). Careful measurements have not shown any serious distortions introduced in the track by this treatment. Listening-test comparisions between a treated track and a silver track on a large number of samples indicated that there is a slight increase in noise level over the silver track, but in no case was this found sufficient to be judged objectionable.

Unfortunately, the filter layer used in Ansco color film was found to contribute a slight stain to the clear area. The maximum absorption band of this stain, however, does not correspond to the peak of sensitivity of the cesium photo surface; therefore, it is not so objectionable as a visual inspection of the track might indicate.

For reversible-type 16-mm film, the variable-area sound track is preferable and with a track treatment of this kind on reversible color film, the characteristics of the treated track lend it best to the variable-area method.

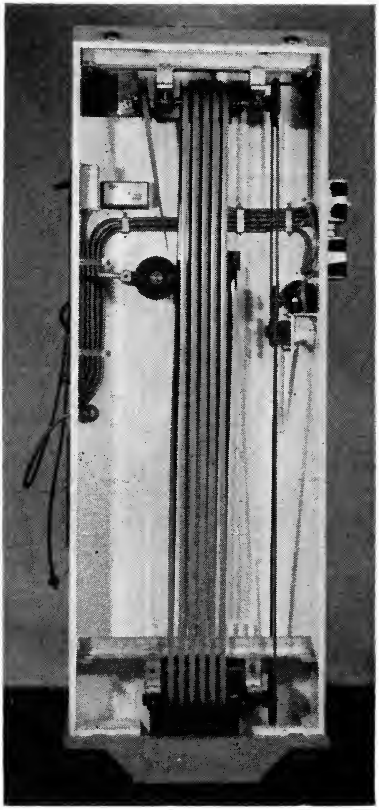

Fig. 6

For economical reasons, the procedure and equipment used for treating the film have been worked out to operate in connection with the Ansco color-film processing machines operating at the normal processing speed. The equipment can be used with any type of developing machine providing a uniform steady film flow. A uniform flow of film through the equipment is absolutely essential for satisfactory results.

In practice, since it is a reversal process, the sound track on Ansco color duplicating film is exposed from a positive-type track. A recorded track having characteristics favorable for printing on black-and-white reversible duplicating stock will be suitable for printing on Ansco color duplicating film. After printing, the color film is processed in the usual way up to the wash before the color developer. In the middle of this wash, the film is lead out of the wash into the sound-track treating equipment (Table I). In the sound-track-treating equipment, the film is first surface-dried to prevent creeping of the treating solution beyond the area allocated for the sound track. This drying is accomplished by passing the film through air squeegees (Fig. 5) and then into a small drying cabinet (Fig. 6). This drying

TABLE I

ANSCO COLOR REVERSIBLE 16-MM SOUND-FILM PROCESS

Dark	1.	First Develop	8–14 Minutes
	2.	Rinse	5–10 Seconds
	3.	Stop	3 Minutes
	4.	Hardener	3 Minutes
	5.	Wash and Second Expose	Approximately 2 Minutes
		Sound-Track Treatment →	A. Feed to Edge-Treating Device
			B. Air Squeegee and Surface Dry—45–55 Seconds
			C. Edge-Treating Solution Application
			D. Reaction Time—15 Seconds
			E. Jet Wash (Track Downward) —5 Seconds
		←	F. Return to Color Processing Machine
White Light	6.	Finish Wash	Approximately 1 Minute
	7.	Color Develop	10–15 Minutes
	8.	Rinse	5–10 Seconds
	9.	Stop	3 Minutes
	10.	Hardener	3 Minutes
	11.	Wash	3 Minutes
	12.	Bleach	6 Minutes
	13.	Wash	3 Minutes
	14.	Fix	6 Minutes
	15.	Wash	9 Minutes
	16.	Dry	

requires about 50 seconds. From the drying chamber, the film is lead over the applicator roller and here the edge-treating solution is applied to the track area (Fig. 7). The reaction of the solution is very rapid; only about 15 seconds are required to convert the silver halides in the track to silver sulfide. The treating solution is essentially an aqueous solution of sodium sulfide with Cellosize WS-100 (hydroxyethyl cellulose) added to increase the viscosity (Table II). After this

TABLE II

EDGE-TREATMENT SOLUTION FORMULA

Cellosize WS-100	100 Cubic Centimeters
Sodium Sulfide (Anhydrous)	20 Grams
Water to make	1 Liter

reaction, the excess solution is washed off the track area and the film is returned to the wash tank from which it was taken. This entire treatment requires about 75 seconds. After its return to the wash tank, the film continues on through the rest of the process in the usual way.

Although this process of treating the track requires care, it is a straightforward procedure and is not untidy or odorous. The solution contains sodium sulfide; however, the amount of solution required is small, only about 10 cubic centimeters or $^1/_3$ ounce is required for 100 feet of film. Therefore, the handling of the solution

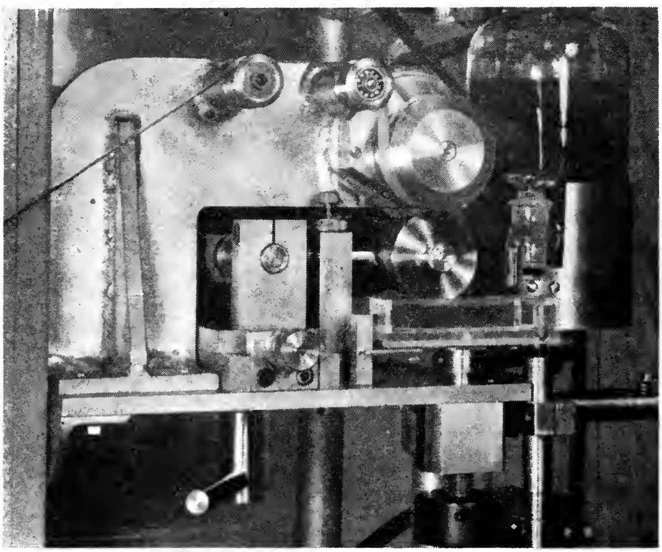

Fig. 7

presents no problem or hazards in the processing laboratory if ordinary precautions are taken.

The unit is compact and portable on casters (Fig. 8) and when used, it is moved alongside the developing machine and remains there through the run. Even for developing machines continuously processing sound film, the portable construction is desirable. This type of construction makes it possible to move the unit out of the way to give free access to the processing machine for maintenance and cleaning.

The unit itself does not propel the film. This is accomplished entirely by the processing machine. Actually, the processing machine pulls the film through the sound-track-treating unit. In order that no undue strain be placed on the film, the sound-track-treating unit is tendency-driven, that is, the shafts in the rollers of the drying cabinet are turning in loose rollers. After leaving the drying cabinet, the film is fed over a roller cluster to guide it accurately over the edge-treating roller (Fig. 7). Here, the sound-track area comes in con-

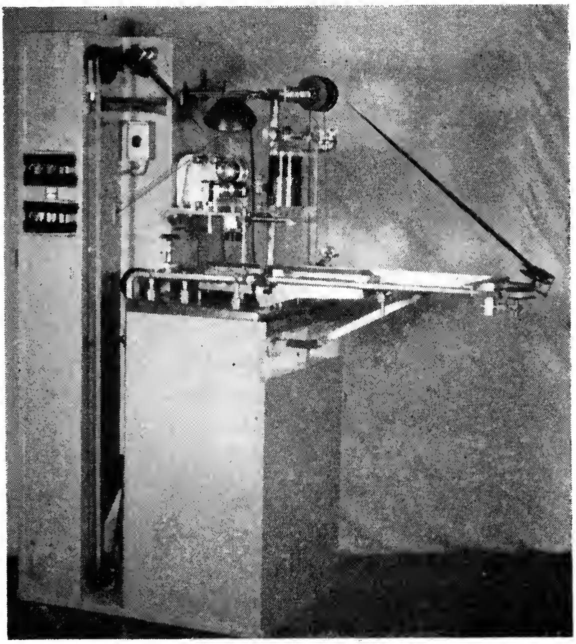

Fig. 8

tact with a bead of the edge-treating solution carried on the slightly concave periphery of the applicator wheel. The bead wheel travels at a slightly faster rate of speed than the film and in the same directions as the film. This maintains a uniform bead in contact with the track area.

The amount of solution applied is controlled by the depth of dip of the applicator wheel in the solution, and lateral movement of the wheel is controlled by two micrometer adjustments on the applicator assembly. With these adjustments, no difficulty has been experienced in confining the track area within the established standard.

After edge-treating, the solution is allowed to react for 15 seconds and is then removed by a special spray washing the excess solution off the track area (Fig. 9). From this point, the film is returned to the processing machine and continues on through the rest of the process in the usual way.

Sound tracks processed in this way are permanent and are no more subject to scratches and abrasions than normal silver sound tracks made on black-and-white film. Any subsequent treatment, such as lacquering or waxing, which can be applied safely to the color film, will not harm the treated sound track.

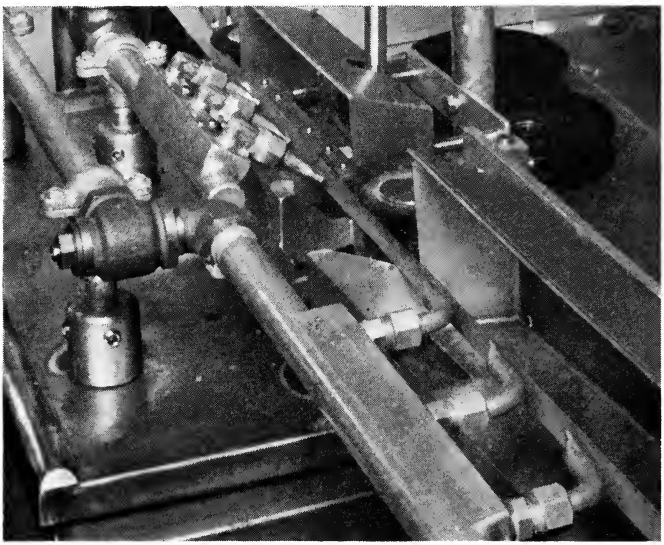

Fig. 9

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(2) A. M. Glover and A. R. Moore, "A phototube for dye image sound track," *J. Soc. Mot. Pict. Eng.*, vol. 46, pp. 379–387; May, 1946.

(3) Glover and Jones, "A new high sensitive photo-surface," *Electronics*, August, 1940.

(4) R. O. Drew and S. W. Johnson, "Preliminary sound track tests with variable-area dye tracks," *J. Soc. Mot. Pict. Eng.*, vol. 46, pp. 387–405; May, 1946.

(5) R. Görisch and P. Görlich, "Reproduction of color film sound records," *J. Soc. Mot. Pict. Eng.*, vol. 43, pp. 206–214; September, 1944.

(6) Schinzell, Kinotechnik, p. 464, 1929.
(7) U. S. Patents 2,143,787; 1,973,463; and 2,330,796.
(8) ASA Standard Z52.16-1944 or succeeding Standard.
(9) U. S. Patent 2,258,976.

Discussion

MR. EARL I. SPONABLE: What material do you use for making the applicator disk?

MR. J. L. FORREST: Stainless steel.

MR. R. T. VAN NIMAN: Has this process been worked out for application to 35-mm film yet?

MR. FORREST: I have not used it with 35-mm although there is no reason why it could not be used.

MR. C. R. KEITH: Do you have any figures of the over-all gamma of the sulfide track in terms of the light used in reproducing it?

MR. FORREST: The data are being collected now but are not ready at this time.

FORTY-ONE YEARS AGO

Open-Air Theater in Jacksonville, Fla.

The opening of the Summer season at Dixieland Park proved a remarkable success. In the afternoon fully 1500 people visited the park and enjoyed the concert, but it was in the evening that the big crowd turned out to see the open-air moving pictures.

At least 2500 people were on the grounds before eight o'clock, and the seating capacity, which had been arranged for 2000, proved entirely inadequate. Manager Da Costa and several of the directors were present, and it was at once decided to arrange seats for at least 1000 more people.

The pictures started promptly at 7:30, and were very good. They could be seen nicely at a distance of 1000 feet from the elevated canvas, and were thoroughly enjoyed by the immense audience. The full 3000 feet of films were run and the entertainment lasted a little over an hour.

—*The Moving Picture World, May 16, 1908*

Laboratory for Development Work on Color Motion Pictures

By H. C. HARSH and K. SCHADLICH

Ansco, Binghamton, New York

Summary—**Precise control of all of the laboratory operations in producing color motion pictures is essential to obtain release prints of high quality. A description is given of a new building and equipment especially designed to carry on development work on all the laboratory phases of producing motion pictures in Ansco color.**

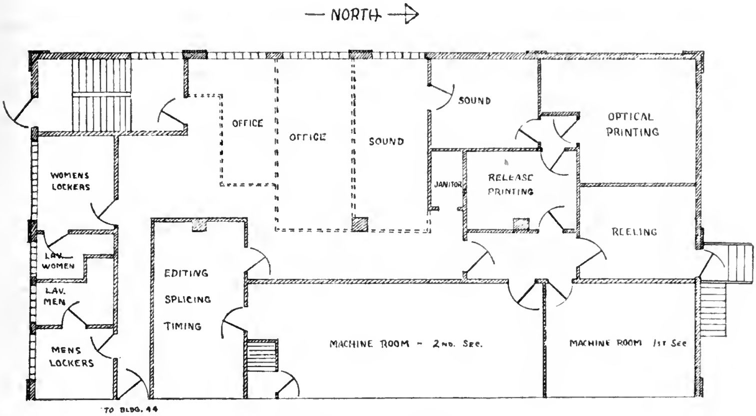
Color-film materials for the professional motion picture industry have to meet a number of exacting requirements. In the case of multilayer color materials many of these properties have to be already incorporated in the film. However, of equal importance is the proper processing of these materials and the requirements which are of particular importance can be summarized as follows:

1. Steadiness of the color image, free from processing fluctuations, streaks, and processing shimmer.
2. Methods for the preparation of dupes for optical effects, process photography, and protection masters.
3. Good sound reproduction.

In order to solve these well-recognized problems, a new laboratory was completed during 1948 which will be described briefly in this paper. Its facilities are used primarily to carry out development work on new and improved 35-mm color films and all aspects connected with the processing and use of these materials. The laboratory will provide technical assistance and data to commercial laboratories which are now processing and printing Ansco color films and serve as a source of information for those who are planning to set up a laboratory for this purpose.

The building, which is constructed of reinforced concrete and brick is 40 by 80 feet and is attached to a larger building which is now used as a finished goods warehouse but which is being converted entirely for research and development purposes.

* Presented May 18, 1948, at the SMPE Convention in Santa Monica.



FIRST FLOOR PLAN

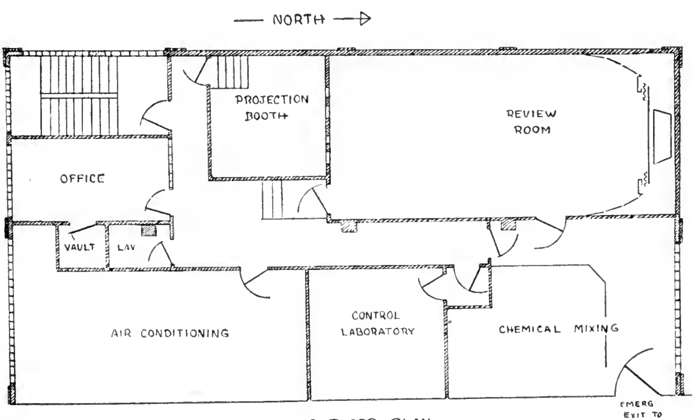
Fig. 1

Fig. 1 shows the plan of the first floor which includes two rooms for the processing machine, rooms for reeling, optical printing, release printing, sound testing, and editing as well as office space.

Fig. 2 shows the plan of the second floor which includes the solution-mixing room, control laboratory, air conditioning, office space, film vault, projection booth, and review room.

PROCESSING MACHINE

It was realized that the success of this pilot installation would be



SECOND FLOOR PLAN

Fig. 2

dependent to a great extent on the quality of processing which could be realized and the flexibility of the machine for experimental changes. In order to obtain a smooth screen quality every attempt has been made to provide the optimum developer turbulence conditions based on the available experience from the industry and consistent with other requirements.

The basic design is the same as the Ansco 4C 16-mm color machine described by Forrest.[1] Substitution of 35-mm spools results in a

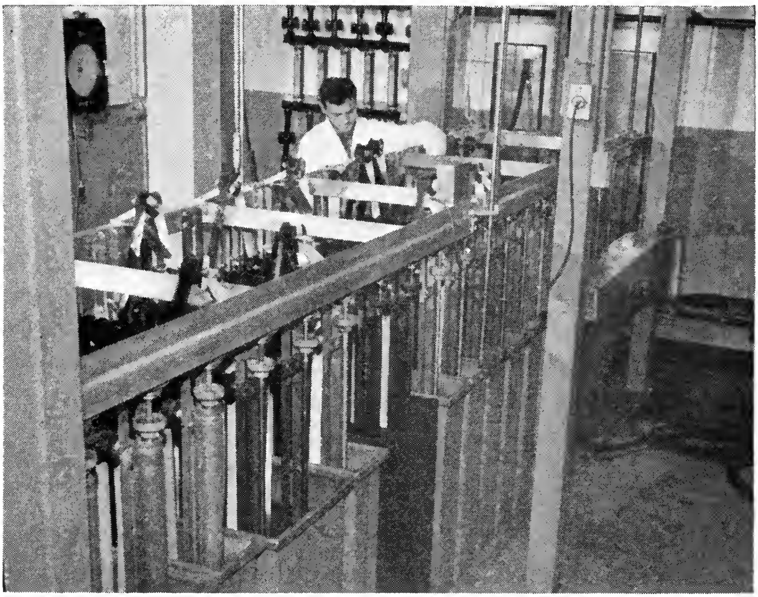


Fig. 3—White-light section of processing machine.

lower machine speed of 30 feet per minute which for experimental purposes is quite adequate. The bottom-friction-drive principle, combined with an underdriving take-up spool, provides a smooth motion of the film through the machine which is very important for effective use of the high-pressure jet agitation system which will be described below.

The first section of the machine consists of the elevator and seven spool banks in four tanks. This section accommodates the first development, short stop, and hardening steps of reversal processing and when in operation is in no light. A lighttight pass box is provided between this room and the next which comprises the white-light section. In this section there are nineteen spool banks in twelve tanks which comprise the color development, short stop, hardening bleach, fixing and the several washing steps, followed by the drying cabinet.

Fig. 3 shows a side view of the white-light section of the machine with the spool banks partially raised. The wall on the west or operat-

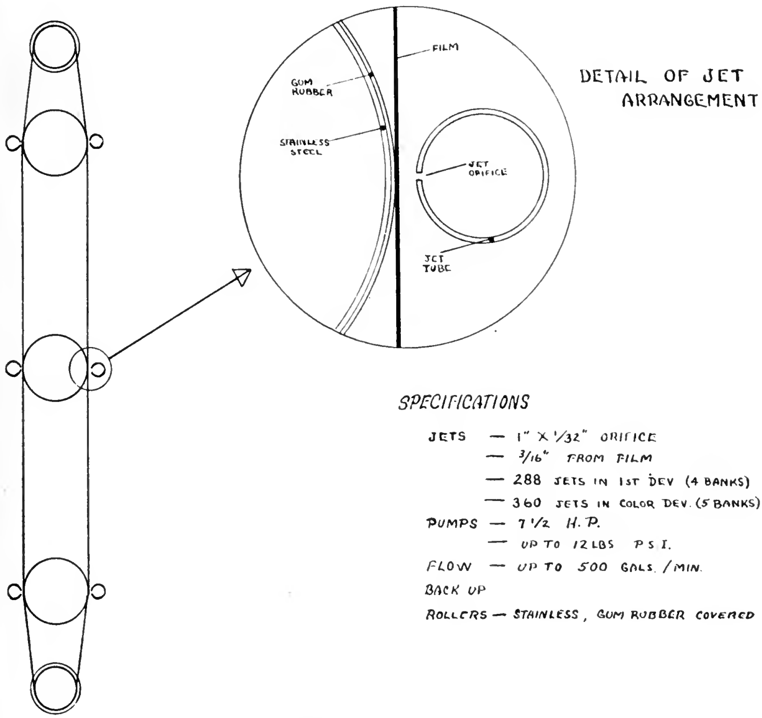


Fig. 4—Schematic of jet arrangement.

ing side of the machine carries the control switches and recording instruments. The adjacent wall, near the pass box, partially visible in Fig. 3, supports the valves and flow meters which control the continuous replenishment of the developers, short stops, and hardeners.

An important new feature of this machine is the high-pressure jet turbulation which has been provided in both developers. A manifold coming into the top side of the tank supplies six jet tubes per spool bank. A cross-section schematic diagram of the jet arrangement on each bank is shown in Fig. 4. The jets are $^3/_{16}$ inch from the film surface and opposite each jet tube are cloth-covered back-up rollers to support the film. It is important that the jets are regularly spaced and in this case the film passes a jet every $2^1/_2$ seconds. The jet orifice is $1 \times {}^1/_{32}$ inch. The two pumps have $7^1/_2$-horsepower motors which supply up to 12 pounds pressure at the jet and circulate the solution at the rate of 500 gallons per minute.

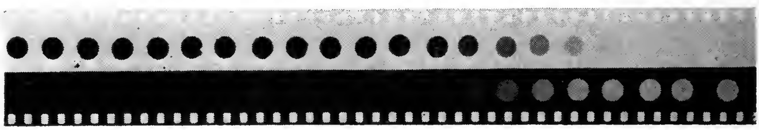


Fig. 5—Sensitometric strip to measure bromide drag.

To the best of our knowledge, this is the first time that high-pressure jet turbulation has been used effectively on a bottom-friction-drive machine. As mentioned earlier, it is possible because of the uniform motion of the film.

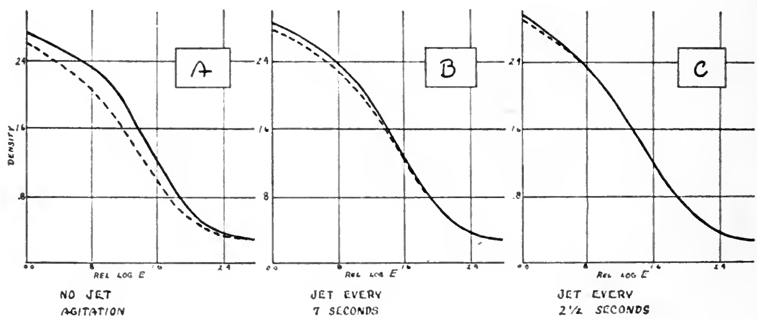


Fig. 6—Graphs showing effect of jet agitation.

The importance of adequate turbulence in processing color film can be demonstrated easily. For example, let us consider its effect in eliminating bromide drag. In Fig. 5 a type of sensitometric strip is shown which is designed to measure this effect quantitatively. The opposite circular areas receive equal exposures but in one case the immediate surrounding area receives maximum exposure and in the other the immediate surrounding area receives no exposure. The difference in the measured densities of the circular areas after processing gives a good quantitative evaluation of the efficiency of the processing in eliminating bromide drag. Fig. 6 shows sensitometric curves for the cyan layer of Ansco Color Type 735. The set of curves marked *A* were those obtained without using the jets and the dotted curve represents the exposures having the dark surrounding area. The second set of curves marked *B* shows the improvement obtained when only two jet tubes per spool bank at 10 pounds pressure are used. Finally, the set of curves marked *C*, with all the jets in use at 4 pounds pressure, are nearly coincident at all densities, which is the desired result for good screen quality. The effect in the magenta and yellow layers is similar although with inadequate agitation the difference is not so great as with the cyan layer. This result would be expected since the latter is at the bottom of the monopack.

Agitation is also used in the bleach, short stops, and fixer although the high pressure and frequency of jets as described for the developers is not necessary in these cases. Agitation of the short stops is very important for eliminating processing streaks and shimmer and in this installation the short stops are agitated by bubbling air through the tanks. For the bleach and fixer, single low-pressure jets without back-up rollers are located in the center of the tanks. For washing, nozzle sprays are used and have been found more efficient than full tanks.

The filters, jet and circulation pumps, air compressor, filter for the wash water, and other units are located in the basement under the machine.

The solution mixing room is located on the second floor directly above the front end of the machine. Seven stainless-steel mixing tanks, two small stoneware tanks, and a sink are located over this area with an operating platform in the center. The plumbing from these tanks to the machine is through black Seran pipe.

Six of the stainless-steel mixing tanks are used to supply the first developer, short stop, hardener, color developer, bleach, and fixer. The seventh tank is a spare connected to the color developer system. The two stoneware tanks are arranged so that they can supply solution to any machine tank through a utility line with flexible couplings.

By closing two valves the circulating pumps can be used to return the first developer, color developer, and bleach from the machine to their mixing tanks. This feature has proved expedient in experimental work and is convenient for maintenance and cleanup. In the case of the bleach, it is the most desirable procedure for carrying out the replenishment.

An exhaust system removes fumes from the color developer and bleach-mixing tanks.

CONTROL LABORATORY

The control laboratory, which is located next to the mixing room, is equipped to carry out the control procedures and chemical analyses described in the papers by Bates and Runyan[2] and Brunner, Means, and Zappert.[3]

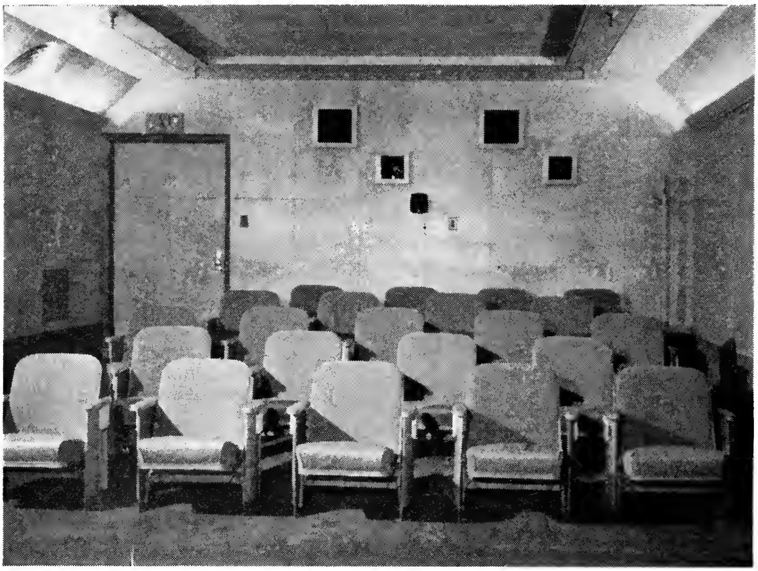


Fig. 7—Photograph from front of review room.

PRINTING

Standard equipment with slight modification is used for optical and release printing. An Acme optical printer is used for printing masked duplicates and special effects. The basic features of this printer have been described by Dunn.[4] A Bell and Howell Model D, modified with an optical system for increased illumination and with a filter-change devise for scene-to-scene correction, is used for printing.

SOUND TESTING

The equipment for sound testing, which has not yet been installed, will include complete channels for recording and re-recording variable-area and variable-density tracks and the necessary accessory instruments for measurements.

PROJECTION ROOM

The projector is a standard Super-Simplex E7. Because of the relatively short throw, wire screens are used in the light beam to reduce the screen brightness to $10^1/_2$ foot-lamberts.

A photograph taken from the front of the review room is shown in Fig. 7. For the acoustical treatment of the walls and ceiling, perforated panels of Johns-Manville gray Transite backed up with rock wool are arranged appropriately with unperforated panels of the same material. The floor is carpeted to within 11 feet of the screen. Live sections in the front of the room are provided in order to give the optimum results at the rear three rows of seats. Measurement of the reverberation time as a check on the efficiency of the design gave results very close to the desired theoretical values.

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(2) J. E. Bates and I. V. Runyan, "Processing control procedures for Ansco color film," *J. Soc. Mot. Pict. Eng.*, this issue, pp. 3–25.

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(4) L. S. Dunn, "The new Acme-Dunn optical printer," *J. Soc. Mot. Pict. Eng.*, vol. 42, pp. 204–211; April, 1944.

1000-Foot Bipack Magazine and Adapter*

By WILTON R. HOLM and JAMES W. KAYLOR
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Summary—**Users of 35-mm bipack film have been restricted to the use of 400-foot rolls of negative stock. This is because present standard photographic equipment will not handle 1000-foot rolls in the conventional-type bipack magazine. Loss of production time and excessive negative wastage, as well as severe photographic limitations, are the result.**

An adapter has been developed at Cinecolor Corporation which permits the use of 1000-foot rolls of negative film in side-by-side position, rather than one over the other. This arrangement gives an attractive and convenient operating assembly, which keeps the center of gravity low. It eliminates the need for unwieldy and top-heavy blimps. The adapter causes the films to be changed from a side-by-side to the superimposed emulsion-to-emulsion relationship required in bipack photography. In the Cinecolor arrangement, the 1000-foot rolls are fed from a single 70-mm magazine into the adapter. Two individual 1000-foot magazines can be used equally well.

PRODUCERS OF FEATURE PHOTOPLAYS in a two-color process, using 35-mm bipack as a photographing medium, are restricted to 400-foot lengths of picture negative film. Many disadvantages, both artistic and economic, are attendant upon this limitation. It is impossible to photograph a scene longer than 400 feet, and directors often want longer master scenes. Likewise, it is impossible to retake a scene longer than 200 feet without pausing to reload the camera. Often it becomes extremely difficult to obtain the desired dramatic interpretation of a scene when it is necessary to stop and reload after every take. From an economic point of view, this excessive reloading time represents a loss of valuable production time. An additional economic factor is one of excessive picture negative wastage, because of the number of rather long "short ends" which accumulate.[1]

Bipack picture negative film is manufactured in 400-foot, rather than the customary 1000-foot lengths, only because all commercially available bipack magazines for production-type cameras have a capacity of 400 feet. This is perhaps because bipack photography has developed around the use of existing black-and-white equipment.

* Presented May 18, 1948, at the SMPE Convention in Santa Monica.

Since the demand was not great, the bipack magazine evolved with a minimum of modification and design expense, resulting in the over-and-under type of magazine, which has persisted to the present time.

In effect, the over-and-under-type bipack magazine is a unit made up of two conventional magazines, one mounted on top of the other. Such a magazine is shown in Fig. 1. The upper section contains the panchromatic film; the front spool is the supply spool, and the rear spool the take-up spool. The lower section contains the orthochromatic film, and, as in the case of the "pan" section, the front spool is the supply spool and the rear spool the take-up spool.

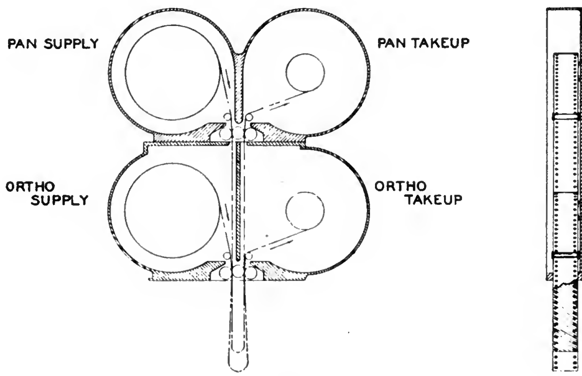

Fig. 1

As is well known to users of bipack film, a bipack is composed of two separate strips of film. One, the orthochromatic, records the blue and part of the green components of the scene to be photographed; the other, the panchromatic, records the red and the remaining green components. In bipack photography, the exposure is made with the two films in emulsion-to-emulsion superimposed relationship, with the orthochromatic emulsion nearest the lens. Thus the exposure is made through the base of the orthochromatic film. When using the over-and-under type magazine, the panchromatic film travels from the forward, or supply spool of the upper section, down into the lower section. The panchromatic film is wound "emulsion in" on the supply spool and travels down into the lower section with the emulsion side facing the lens. Here it is joined by the orthochromatic film, which is wound "emulsion out" on the supply spool.

As the orthochromatic film unwinds, it thus moves into the required emulsion-to-emulsion superimposed relationship with the panchromatic film, with the orthochromatic film nearest the lens (Fig. 1). The films now travel together down into the camera. After exposure the films travel up out of the camera into the lower section of the magazine. Here the orthochromatic film is rewound onto the "ortho" take-up spool, while the panchromatic film continues up into the upper section of the magazine where it, in turn, is rewound onto the "pan" take-up spool.

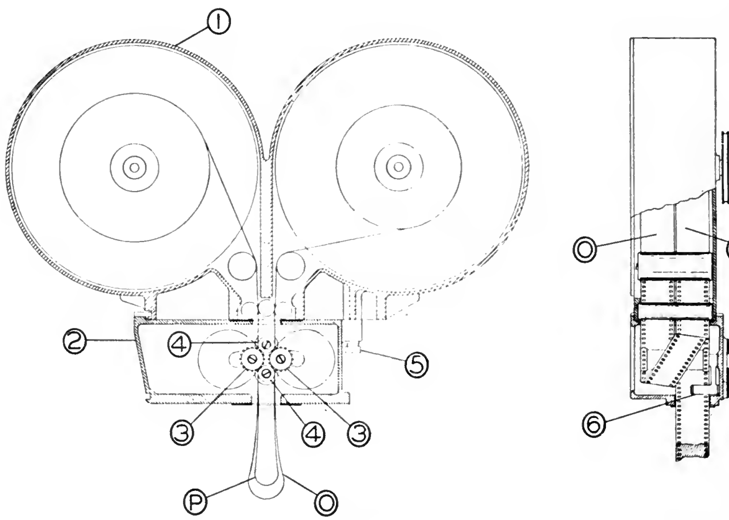

Fig. 2

It can easily be visualized that such an over-and-under magazine of 1000-foot capacity would be an extremely ungainly and inconvenient camera assembly, having a high center of gravity. This, in turn, necessitates the use of cumbersome, top-heavy blimps.

An adapter has been developed which permits the use of 1000-foot rolls of negative picture film in a side-by-side, rather than an over-and-under position. Two standard 1000-foot capacity, 35-mm magazines, or one double width (70-mm) magazine of 1000-foot capacity, can be mounted on top of the adapter to hold two 1000-foot rolls of film. The 70-mm magazine is used here in describing the operation of the adapter.

The orthochromatic film (*O*) and the panchromatic film (*P*) emerge from the magazine (*1*) and enter the adapter (*2*) in a coplanar, side-by-side relationship, as shown in Fig. 2. The orthochromatic film is wound emulsion side out, and the panchromatic film emulsion side in, on the supply spools. In the adapter the films are superimposed to bring them into emulsion-to-emulsion relationship, with the orthochromatic film nearest the lens. This superimposition is accomplished by looping and laterally displacing the orthochromatic film as shown

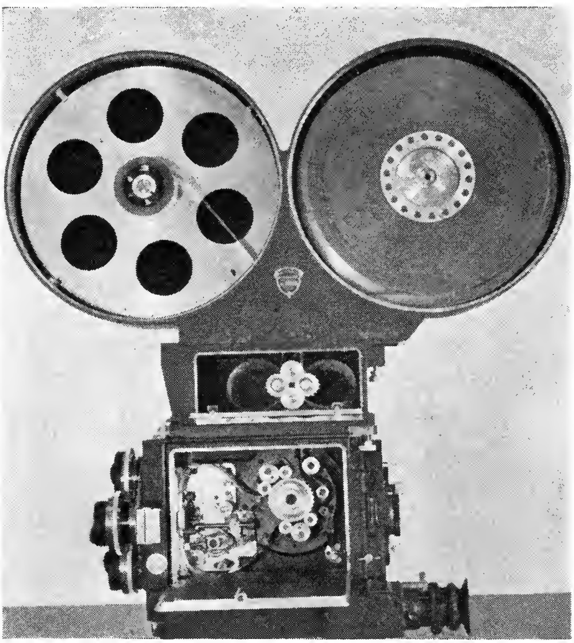

Fig. 3

(Fig. 2). In this relationship the films emerge from the adapter and enter the camera. After exposure the films return to the adapter, where they are separated by again looping and laterally displacing the orthochromatic film, and returned to a coplanar, side-by-side relationship. In this manner they emerge from the adapter and enter the magazine, where they are wound onto take-up spools.

The translatory loops are maintained in the adapter by means of an idler shaft carrying two concentric sprocket guides (*4*). Sprockets (*3*) are mounted on either side on a member which pivots to permit threading the film in the adapter. When in operating position, the sprockets are locked in contact with the guide rollers.

As is customary, only the take-up reels are driven. The supply reels are rotated by removal of the film, and since the speed of the take-up reel varies with the amount of film wound on the reel, a clutch is needed between the driving power and the reel to allow for overdriving, and to compensate for possible differences in length between two rolls of negative film.

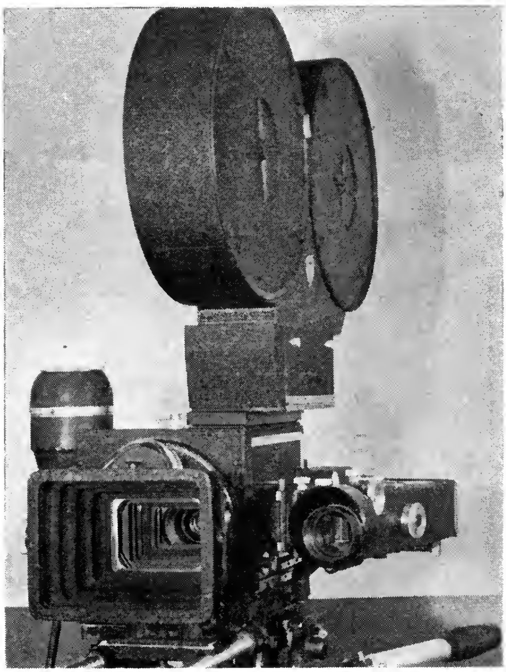

Fig. 4

A clutching device was desired which would not be too bulky, and would not overhang the camera outside the magazine. It was also desired that the clutch should not be completely enclosed within the magazine, thus making it impossible to adjust without opening the magazine. A pair of single-disk clutches within the take-up spool, arranged coaxially on the same shaft, was designed to meet these requirements. Ball-bearing surfaces reduce friction and increase the life of the drive.

The adapter-and-magazine unit has been extremely satisfactory in all tests. Runs of 1000 feet with no stops were made using a "wild" motor at an ambient temperature as high as 110 degrees Fahrenheit, without undue heating of the motor. During tests made at low temperatures (0 to 15 degrees Fahrenheit) the unit operated perfectly when it was so cold as to make it difficult to rack over the camera. In all tests made to date, the unit has never failed.

Tests run to date indicate that the unit is no more noisy than the standard 400-foot bipack magazine. Provisions have been made, nevertheless, for additional soundproofing of the adapter, should this be required. In order to use the unit with a standard blimp, it is only necessary to fabricate a slightly taller top for the blimp, an inexpensive and easy-to-do modification. This top can then be used interchangeably with the standard top permitting the blimp to be used either for color or black-and-white. The new blimp tops are being made at the present time, and it is expected that the 1000-foot magazine and adapter units will be in production use in the very near future.

Figs. 3 and 4 show the unit set up for operation.

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FORTY-ONE YEARS AGO

Middleport Frowns on Moving Picture Shows

Middleport, N. Y., May 1.—An edict has been passed by the city fathers of Middleport that moving picture shows are a menace to women and children who patronize them, and, consequently, all efforts of a party of Medina men to establish a nickelodeon here within the past few days have failed.

—*The Moving Picture World, May 16, 1908*

Cathode-Ray-Tube Applications in Photography and Optics*

By CARL BERKLEY and RUDOLF FELDT

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Summary—Cathode-ray tubes and oscillographs are ideal tools for the solution of many technical problems in the related arts of photography and optics. The methods described represent typical examples of the application of electronic-measurement techniques in such fields.

Applications considered and illustrated include:

1. Gloss measurement on photographic papers.
2. Goniophotometry of light sources.
3. Shutter, flashbulb, and synchronizer testing.
4. Cathode-ray-tube light sources for facsimile and stroboscopic work.
5. Scanning technique for television motion picture recording.
6. The combination of optical and electronic magnification for the study of gear and sprocket imperfections.
7. Automatic *H* and *D* curve plotting during film development.
8. Cathode-ray-tube sound on film recording systems.
9. The measurement of ripple in light sources.
10. Color studies in natural color reproduction and chromatic aberration in lenses.
11. Vibration studies of motion picture equipment.

The techniques and cathode-ray oscillograph accessories described will find wide application in other fields as well.

Mainly because of its rapid response and graphic presentation of results, the cathode-ray oscillograph has found wide application in the solution of many technical problems in diverse fields. In the course of their work, the authors and the members of the Applications Engineering Section of DuMont Laboratories have gained considerable experience in the application of the basic oscillographic techniques used in the solution of these problems. Since photographic and optical methods have become increasingly important in oscillography, a surprising proportion of the applications studies at the Laboratories have been in these fields. The techniques here described for photography and optics are basic and applicable to a much wider range of problems. To illustrate this point, it will be shown that many of the methods herein described will find direct application in the automotive industry. It is therefore felt that

* Presented November 5, 1948, at the National Electronics Conference, Chicago. Published in *Electronic Engineering* (England).

their description will be on interest and help to anyone concerned with a precise electronic approach to a measurement problem.

Shutter, Flashbulb, and Synchronizer Testing

One of the basic problems in photography as in many other industries is that of accurate short-interval timing. Photographic shutters are called upon to operate reliably and reproducibly over a wide range of speeds. Synchronizers and flashbulbs must be timed to operate within milliseconds of one another. This problem of proper adjustment is becoming more important with the increasing use of color films whose latitude does not tolerate the careless operation to which photographers using monochrome emulsions have become accustomed.

Shutter Testing

The obvious way to study and make these adjustments is by picking up the opening of the shutter by means of a phototube and light and displaying its output on an oscillograph. This procedure, was, in fact, tried many years ago using a string or mirror oscillograph with fairly satisfactory results.[1]

There are a number of advantages to be gained by the use of a cathode-ray oscillograph:

1. There is no practical limit on the shortest time that can be measured so that high-speed mechanical shutters or electrooptical shutters can readily be studied.

2. The image of the shutter characteristic appears instantaneously on the face of the cathode-ray tube, so that no waiting is necessary to view the record.

3. The shutter may be operated rapidly any number of times in succession, synchronized with the single sweep on the oscillograph, and any erratic operation easily observed by comparing each pattern with the previous one by means of a long-persistence cathode-ray-tube screen; by operating the shutter a few times and then observing the persistent image, an average value for the shutter speed may be obtained. This is of value in the case of simple shutters whose reproducibility is not such that a single reading suffices for calibration.

6. Various other electronic methods of testing camera shutters have been devised. These generally involve integrating the total light transmitted during the operation of the shutter, and expressing the result as a single reading on a meter. Such a reading fails to show any erratic operation of the shutter such as bouncing or slow opening

and closing which, while it may give rise to the same integrated value of light, represents improper operation of the shutter. Such improper operation is readily displayed on the cathode-ray tube.

Realizing all these advantages, many photographers today have devised elaborate oscillographic equipment to enable production testing of shutters.[2-9] Such equipments are now being used by most camera manufacturers to check their shutter operation.

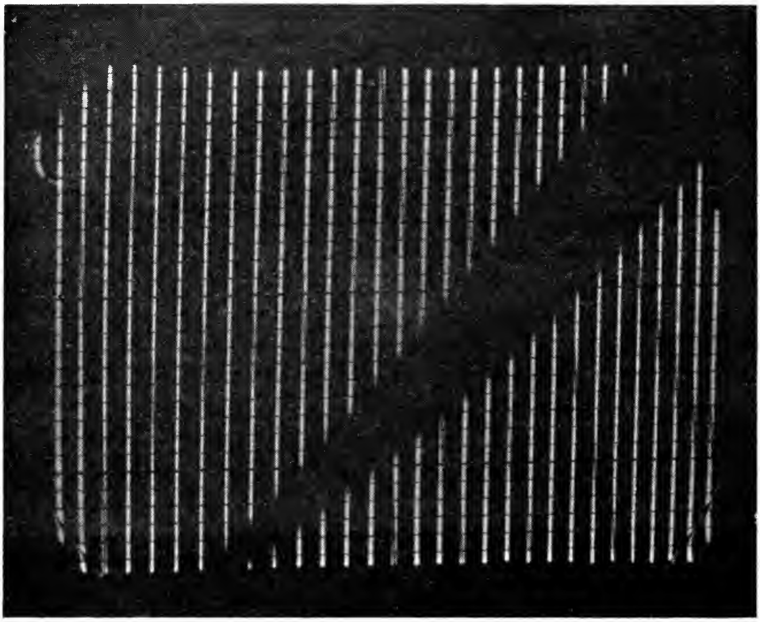


Fig. 1—Focal-plane shutter characteristics. Shutter speed $^1/_{20}$ second on a Graflex shutter—horizontal sweep approximately $^1/_{20}$ second.
(a) With low-frequency sweep approximately 600 cycles to show principle.

Our previous remarks have all referred to the testing of between-the-lens leaf-type shutters. The cathode-ray oscillograph has also been applied successfully to the testing of focal plant shutters by a technique described by Bullock.[2] This technique involves the photographing of a vertical oscillator trace on the cathode-ray tube and the sweep of this trace horizontally across the cathode-ray tube for a time somewhat longer than the operation time of the shutter. This pattern is then imaged in the focal plane. The sum of the cathode-ray-tube spot and focal-plane slit motions gives rise to diagonal areas from whose appearance the shutter opening characteristics may be evaluated. Figs. 1 (a), (b), and (c) show some typical examples of such operation on a Graflex shutter. Fig. 1 (a) was made with a rather low vertical-oscillator frequency in order to illustrate the principle. The horizontal distance represents the time during which a particular portion of the slit traversed the film. This time can be seen to vary from one end of the focal plane to the other,

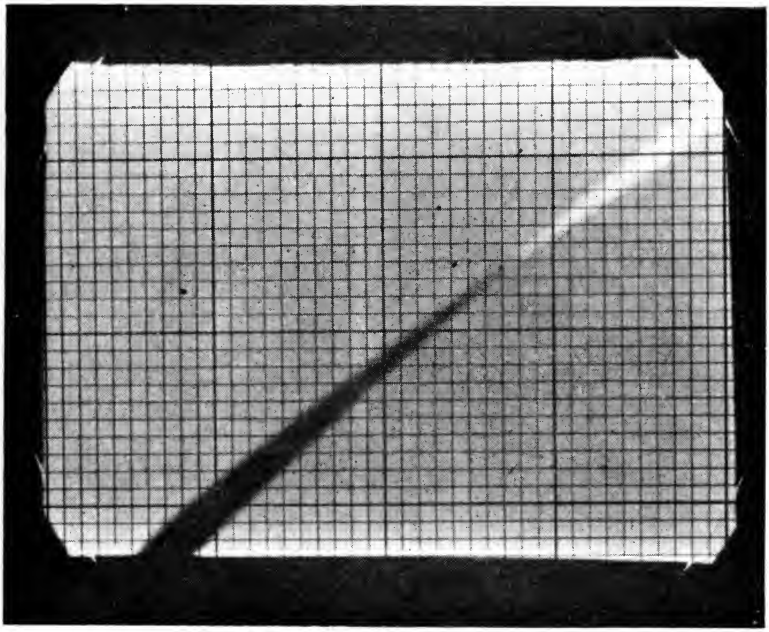


Fig. 1—(b) Same shutter with higher speed vertical sweep, showing change in speed of slit from top to bottom of focal plane.

indicating that the shutter did not move at constant speed. Fig. 1 (c) shows a properly adjusted shutter which moves at almost constant speed from one end of the image plane to the other.

Flashbulb Testing

Using almost exactly the same equipment, for example, an oscillograph and a phototube pickup, many other applications present themselves in photography. For example, the testing of photographic flashbulbs and their light-output-versus-time characteristics, may be accomplished readily. A method, using the same basic technique which was prescribed for shutters is now used as an American Standard for testing photographic flash lamps.[10] It is also possible to make recordings of the characteristics of a combustion type of flash lamp with a high-speed recording galvanometer. This equipment, however, fails when we attempt to measure the new gaseous-discharge microflash lamps, whose duration of light output may be of the order of a few microseconds; only a cathode-ray oscillograph can

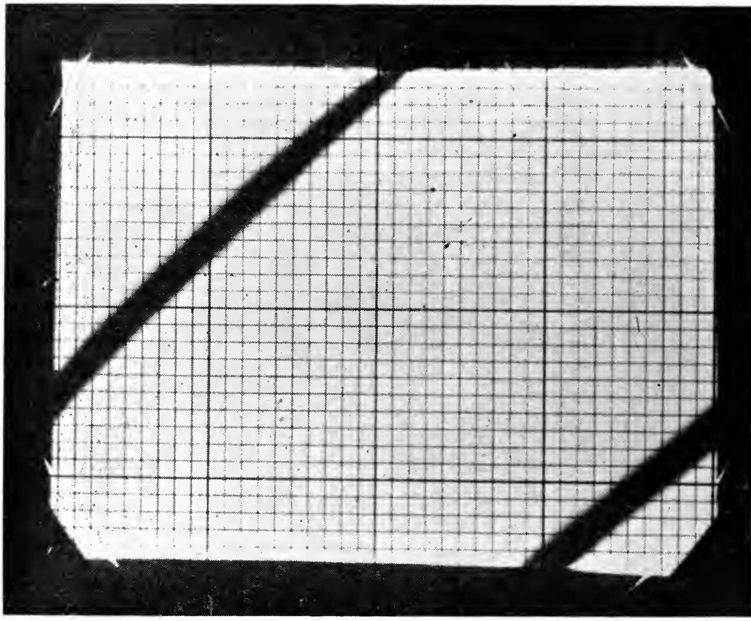


Fig. 1—(c) Same shutter properly adjusted for uniform slit travel.

measure times of such order conveniently. Fig. 2 compares relative duration of shutter and flash. The circuit for studying these phenomena can be a very simple one. The gas tubes usually have an accessory ignition coil operated from a trigger circuit, consisting of a small, cold-cathode, gas tube. The same pulse which fires the cold-cathode tube can be used to start the sweep of the oscillograph. There is sufficient delay in the initiating tube so that the sweep starts before the ionization in the flash tube becomes appreciable. Fig. 3 shows dual-beam oscillograms of such a photoflash tube in which a much higher shutter speed has been used, displaying the opening of the shutter and the flashing of the lamp unsynchronized and synchronized. These are made with a shutter that shows considerable rebouncing which, as mentioned previously, would not be indicated on an integrating type of shutter opening meter. The markers here are 25 microseconds apart instead of 1 millisecond.

Gloss Measurement

One of the basic problems in optics is the proper description of the visual or optical character of a surface, the gloss of the surface. For this reason, in many industries so-called "standards" of various degrees of gloss or surface finish are maintained. This problem is of importance in photography in connection with the proper specification of the surfaces on photographic papers. The so-called "feel"

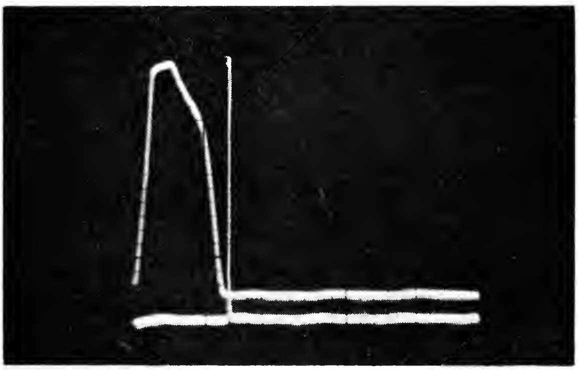
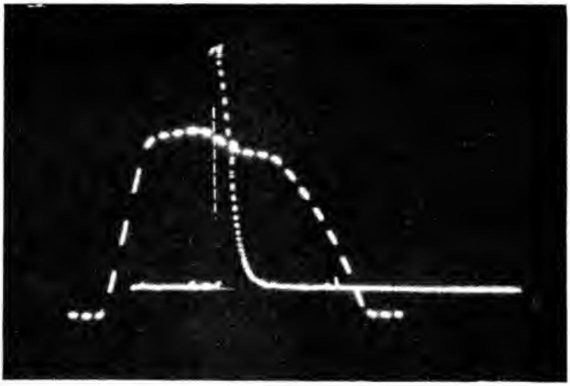


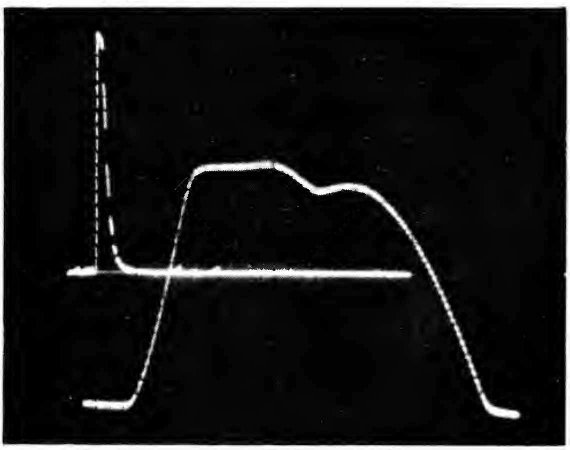
Fig. 2—Dual-beam recording of $^1/_{100}$ second shutter opening, plus electronic flashlight output. The time marking is given by a 40-kilocycle oscillator.

of the surface, being a subjective matter, is of extreme importance in the final effect that a photograph produces upon the viewer. However, no good method for specifying these surfaces, which assures uniform quality and reproducibility, yet exists. For this reason, in every photographic supply store, there will be found so-called standard samples of these various surfaces which serve as no specification whatsoever.

The only satisfactory way, to date, of specifying the gloss of a surface is by drawing its complete reflectance curve as a function of the angle of view of the surface under certain standardized lighting conditions. This graph preferably should be plotted as a family of curves in order to express the effect throughout a solid angle. For cases where the reflection is rotationally symmetrical about some point, a 2-dimensional curve such as the curve on a cathode-ray oscillograph, is sufficient and offers a very convenient means for obtaining



(a) Synchronized.



(b) Unsynchronized.

Fig. 3—Dual-beam recordings of high-speed shutter and electronic flashlamp with high-speed sweep and 40-kilocycle (25-microsecond) time markings.

these curves quickly. This can be done by many simple means. For example, this graph may be obtained in Cartesian co-ordinates merely by rotating the phototube around the sample illuminated in a standard fashion and expressing the output of the phototube on the vertical plates, and by expressing its position by means of a potentiometer geared to the phototube on the horizontal axis. This type of presentation has been duplicated by slower methods, such as pen recorders.

In some cases, however, it is desirable to do this very rapidly. For example, if we have a large number of samples, it is necessary, continually, to draw these distribution curves. This may be done readily by means of the following system, which also enables the use of a standard sample for comparison: two samples, one the standard and the other under test, are mounted back to back and spun by means of a synchronous motor about the axis of the motor. A phototube and light source are placed at some angle arbitrarily chosen, or at 90 degrees. As the samples are rotated by the motor, the angle at which the phototube alternately views the standard and the sample changes continuously. The phototube output displayed with a synchronous sweep on a cathode-ray tube is then a graph of light reflection as a function of the angle of view. Since the samples are presented alternately, the curves appear simultaneous and superposed to the observer.

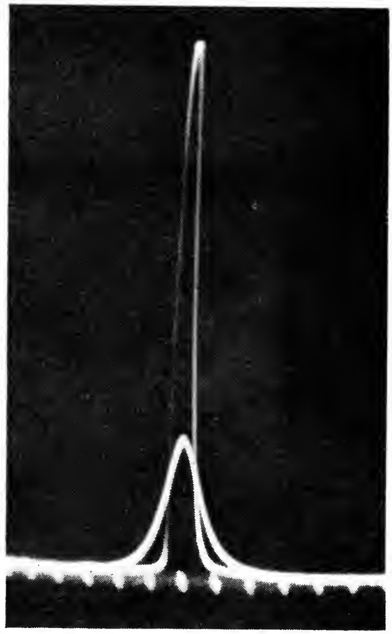


Fig. 4—Relative reflection versus angle for clear glass (tall spike) and matte-coated glass. Angle markers on baseline are 3.6 degrees apart.

Fig. 4 is a typical example of such a recording in which the reflection from a clear sheet of glass is compared with that of a sample treated with glare-reducing material. By means of intensity modulation, using a synchronized multivibrator, 3-degree angle markers have been put on the baseline which was recorded by double exposure. This technique, as mentioned previously, should find wide application in any industry where surface specification is desired. With this type of presentation, changes of reflectance characteristic during a drying process can be seen. This method may also be reversed by moving the phototube rapidly around the sample and drawing a great many curves as the sample dries.

Polar Presentations

It is more conventional in optics to express these light-distribution patterns in the form of polar rather than Cartesian co-ordinates. These patterns are generally used to describe the light distribution from lighting equipment such as photographic flood lamps. These patterns may be produced readily on cathode-ray oscillographs by simple means. Fig. 5 shows an instrument for this purpose, the Type 275 polar co-ordinate indicator. This instrument produces polar diagrams which are synchronized with the motion of any rotating object merely by attaching a small lightweight, two-phase generator to the rotating part.[11] If a phototube is placed on the rotating shaft its output can serve as a measure of the amount of light reaching a certain point from all angles by applying the output of the phototube to the radial-input terminal on this indicator. Similarly, the light source may be rotated and the phototube remain stationary. Fig. 6 (a) shows a Cartesian light distribution obtained from small flashlight bulb. Fig. 6 (b) shows a similar light-distribution pattern in polar coordinates on the Type 275-A indicator. Phototubes and cathode-ray oscillographs have also been used to scan the illumination of scenes being photographed to depict graphically the variation between high-light and shadow brightness so that, for example, the contrast range of the recording film is not exceeded.[12]

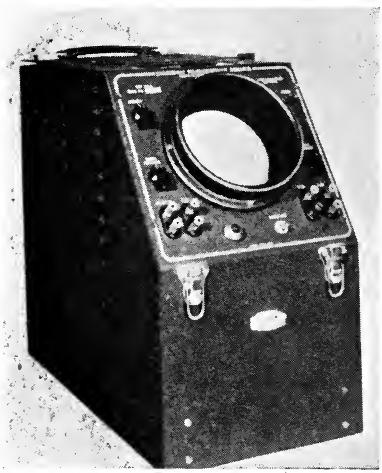
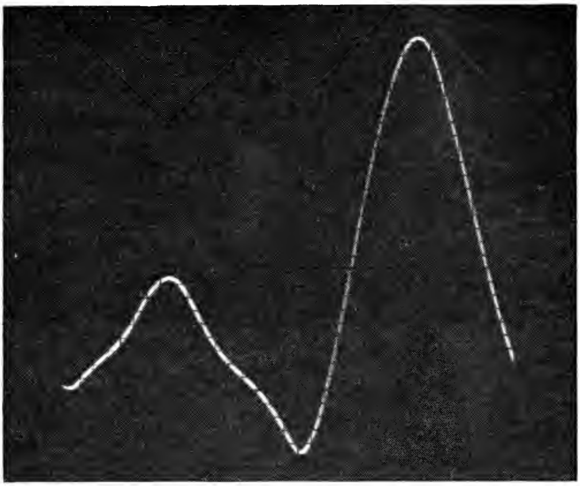


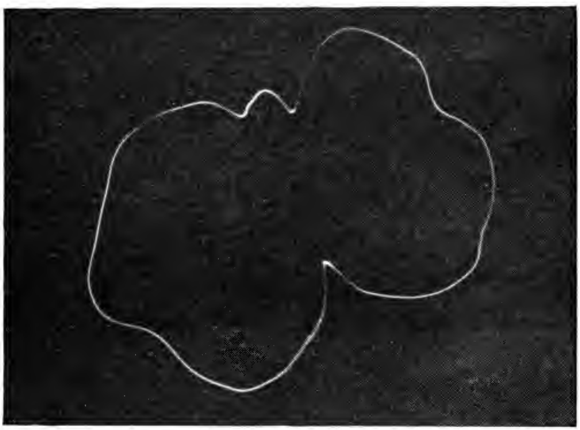
Fig. 5—Polar co-ordinate oscillograph.

Automatic *H* and *D* Curve Plotting

One of the best specifications for the behavior of a photographic emulsion is its *H* and *D* curve which relates the photographic density



(a) On Cartesian co-ordinates.



(b) In polar co-ordinates.

Fig. 6—Light distribution from small flashlight bulb.

to the logarithm of the exposure. These curves are generally produced by exposing either a stepped or continuously graded logarithmic variation of exposure along a strip of film, which is then processed in the usual manner. The dry film is examined by means of a densitometer and the results plotted on graph paper. This procedure is quite laborious and time-consuming. The shape of the *H* and *D* curve and its slope (the gamma) are affected widely by the conditions of development.

In cases such as in motion picture processing where it is desirable to develop to constant gamma in the face of increasing exhaustion of the developer, sensitometric strips are frequently included every few hundred feet so that the development may be checked constantly, at least visually. This check would be much more useful if the actual curves were drawn as each strip passed through the developer so that the development could be shortened or prolonged as required.

Such an *H* and *D* curve can be plotted easily by having the strips pass through an infrared light beam to a phototube while in the developer. The resultant variation in density is displayed on a cathode-ray tube.

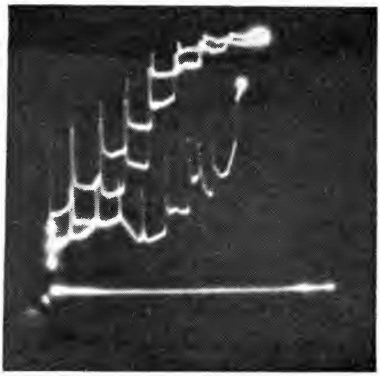


Fig. 7—Three triple-exposed *H* and *D* curves. The bottom curve shows the start of development and the top curve the final appearance of the strip.

We have produced such an *H* and *D* curve experimentally by examining the reflection from a sheet of paper exposed from an Eastman circular step wedge. The resultant *H* and *D* curves obtained at three different times during development are shown in Fig. 7. The exposed strip was mounted coaxially with a potentiometer, which produced horizontal positioning as the exposed sheet was rotated in a tray of developer. The wedge was illuminated by means of the vertical lamp which produced a small spot of nonactinic light on the paper. The reflection was plotted as a negative vertical deflection. The sharp peaks in the pattern are due to the black lines separating the various steps in the wedge.

CATHODE-RAY-TUBE LIGHT SOURCES

Present photographic flash lamps are gas-filled tubes and, therefore limited with respect to the shortest flash that they can produce, mostly because of the finite velocity of the gas particles. Since cathode-ray tubes are vacuum tubes, they are not subject to these limitations. By the use of phosphors having extremely short build-up and decay times, such as zinc oxide, it is possible to produce very short light pulses. Several experimental cathode-ray tubes for use in producing these short light pulses have been built in connection with the relaying of video information over light beams.[13] In order to demonstrate the capabilities and advantages of such cathode-ray tubes over conventional lamps for stroboscopy at high speeds, the light-output-versus-time characteristics of such a cathode-ray tube have been

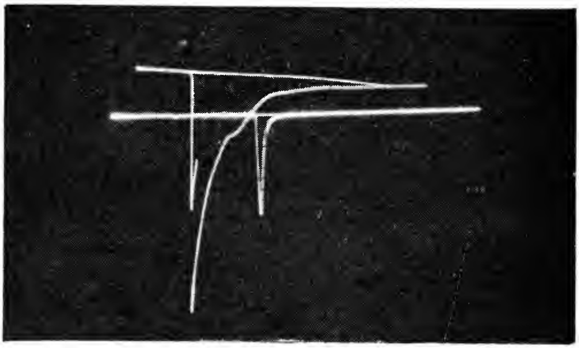
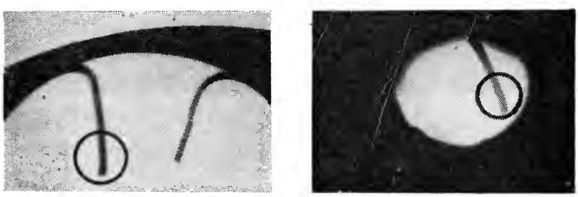


Fig. 8—Double exposures comparing light from stroboscope lamp with light from cathode-ray-tube light source.



(a) (b)

Fig. 9—Photographs of a wire rotating at high speed, made with (a) a stroboscope lamp, and (b) a cathode-ray-tube light source. The circle encloses the same wire in both cases.

compared oscillographically with that of the light from a gas stroboscope lamp. The results are shown in Figs. 8 and 9. Fig. 8 shows on the same time base, the oscillogram of a 2-microsecond flash from a cathode-ray tube (a small spike) and the comparatively long light output from a stroboscope. Not only is the stroboscope flash much longer in duration but it also rises and falls much less steeply and tends to oscillate. The effect of these light sources on a photograph is shown in Fig. 9. These two photographs are pictures of a wire being rotated at high speed by means of a synchronous motor. The picture taken by means of the stroboscope is seen to correspond roughly to the oscillogram and to have both leading and trailing edges blurred while the photograph made with the cathode-ray-tube light source is acceptably sharp. Such cathode-ray tubes, capable of being modulated with high frequencies, also have been used successfully to replace the gas-crater glow modulator tube which is capable of modulation up to only about 15 kilocycles. These tubes have been successfully modulated at frequencies up to 10 megacycles.

An oscillograph with a single-sweep beam-blanking circuit can be converted into a stroboscope of somewhat limited usefulness by the

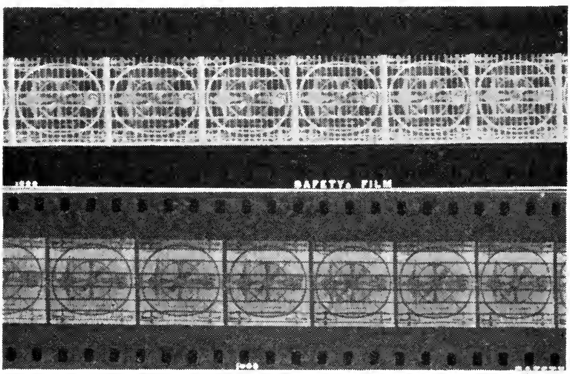


Fig. 10—Negative and positive television motion picture recording made with a continuous motion camera.

use of a short-persistence cathode-ray tube. The length of each light pulse may be controlled by setting the sweep speed. For studying electrical or other machinery, it is frequently possible to obtain a synchronizing signal, connect it to the synchronizing signal input of the oscillograph, and have a workable stroboscope for illuminating small areas. A further advantage is the possibility of using the cathode-ray tube, both as a stroboscopic light source and as a viewing tube to study simultaneously the electrical and mechanical characteristics of some machine or circuit. A further refinement lies in the use of a double-beam tube in which one beam acts as a stroboscopic light source, the other beam as a conventional cathode-ray oscillograph. The advantage here is that very much higher speed phenomena may be studied than is presently possible with gas-tube stroboscopes.

By the use of such short decay and build-up phosphors, it is also possible to make continuous recordings of television programs from a cathode-ray monitor tube, for example, merely by using the film motion as the vertical sweep and allowing it to spread a complete record of each frame of the television picture along the length of the film. Fig. 10 shows two recordings made in this manner with a Type 314 oscillograph-record camera. There are here no complications due to the differences in frame frequency and shutter frequency since no shutter is used on the camera. The same method is used in the present "Ultrafax" facsimile recording system.

GEAR AND SPROCKET STUDIES

One of the basic problems in the motion picture industry is that of obtaining accurate repeated sprocket teeth on motion picture camera and that of obtaining accurate repeated sprocket perforations on motion picture films and papers.

If these perforations or sprocket teeth are not properly made, then the final theater image will weave up and down or from side to side or jump erratically, as anyone knows who has seen prints of old motion pictures. The accuracy and reproducibility of these perforations and sprocket teeth may be studied easily by oscillographic methods. These methods involve a combination of optical and electronic magnification of the defects encountered. In order to display these defects on a cathode-ray oscillograph, a scanning technique is adopted in which the scanning element consists of a slit or small aperture placed in front of a phototube. The output of the phototube is then applied to the vertical plates of the oscillograph, after amplification, if necessary. In testing sprocket teeth or the gears on motion picture cameras, for example, the gear may be rotated at the operating speed and the outline of the gear tooth picked up by means of the scanning slit. Fig. 11 shows the optical setup just described.

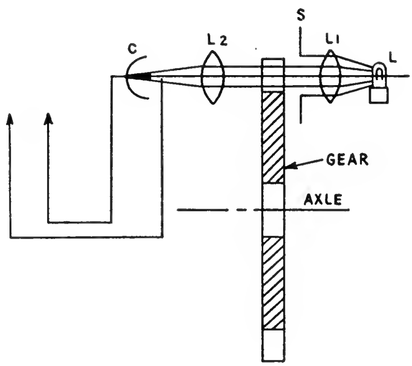


Fig. 11—Optical setup for gear testing.

If the sweep frequency on the oscillograph is equal to the time it takes for one tooth to pass the slit then a repeated image of each tooth appears on the oscillograph screen. This image may have been enlarged optically before reaching the slit and may then be enlarged further by means of the vertical and horizontal amplifiers on the oscillograph. Any eccentricity in the gear tooth, either angular or radial, may readily be seen and amplified to the desired value. As shown in Fig. 12, this method has the advantage that it tests the gear under operating conditions so that the effects of dynamic unbalance or bearing eccentricity are apparent. A vibration pickup

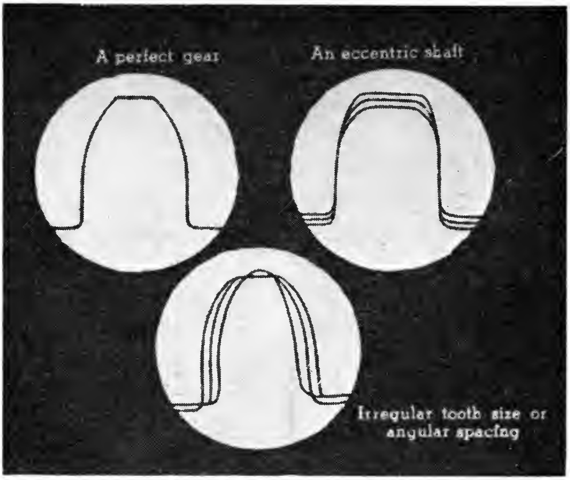


Fig. 12—Typical patterns obtained with perfect and defective gears. A perfect gear is shown in the upper left; an eccentric shaft in the upper right; and an irregular tooth size or angular spacing, below.

may similarly be used in a conventional manner on the oscillograph to determine which of the gears in a motion picture camera is causing a repeated noise in the sound track, for example, by correlating the frequency of repetition of the pattern on the oscillograph with the rate at which various gears move in the camera.

In the case of sprocket-perforation-accuracy measurements exactly the same technique is used, the scanning slit being similar to a sound-track slit. This technique of combined optical and electronic magnification will be illustrated by a very similar example, taken from another field, the testing of razor blades. Razor blades are manufactured in a continuous strip. The strips are sharpened on special grinding machines and are then honed and stropped. A microscope and phototube have been used to look at the edge of each blade as it passes by. Fig. 13 shows the optical setup used. The sweep frequency on the oscillograph is synchronized with the repetition rate of the blades. The resultant patterns are shown in Fig. 14. The dips between patterns are due to the gaps between blades. The sensitivity here is equivalent to a magnification of 1000:1, about 100 of this magnification being accomplished optically, the other factor of 10 accomplished electronically in the oscillograph amplifier so that a deflection of one inch on the cathode-ray-tube screen is equivalent to $^1/_{1000}$ inch on the razor blade. The pictures show a number of

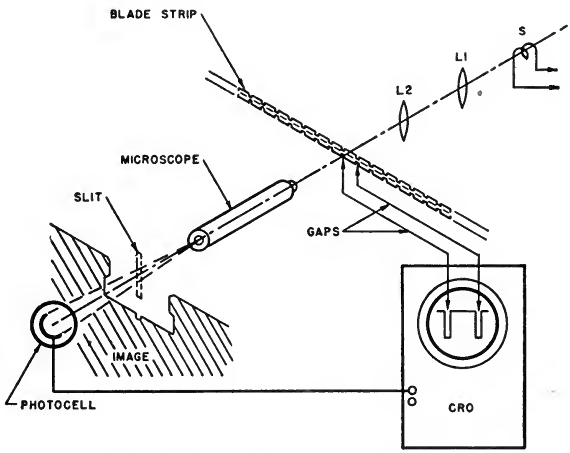


Fig. 13—Optical setup for razor-blade testing.

blades which are perfect and some blades which have nicks about $^1/_{2000}$th of an inch deep.

Automatic Printer Adjustment

One of the basic problems in the photofinishing industry is to obtain a properly exposed and developed set of prints from a widely varying series of negatives. This is usually accomplished by a hit-or-miss system which is based solely upon the judgment of the printer in the darkroom. This precludes accurate duplication of results from one photofinisher to another. Some attempts have been made to use electronic exposure controls which automatically adjust at least the exposure for these widely varying negatives. The darkroom operator still has to select the proper grade of printing paper.

A suggested approach to this problem is to print each negative to suit the personal preferences of the customer instead of attempting to make all pictures of uniform quality. These personal desires with respect to the artistic effect of the print may be determined by means of electronic equipment, operating as follows:

This machine, to be placed in the photofinisher's anteroom, consists of a simplified television imaging system such as a flying-spot scanner. When the negative is placed in the machine, a positive image appears on the cathode-ray-tube screen which shows how the final print will look. There may be only two adjustable controls on this machine, one controlling the gamma of the image and calibrated directly in contrast grade of the printing paper. The second control is a bright-

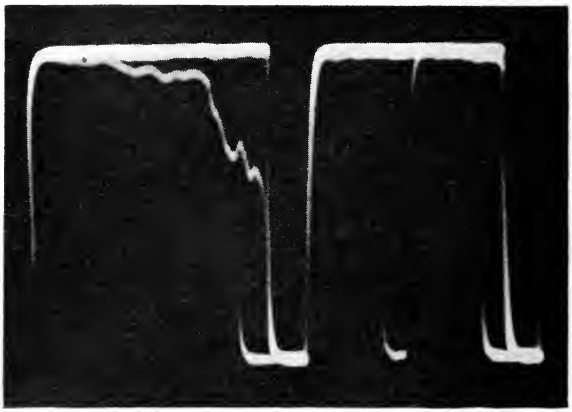


Fig. 14—Pattern obtained with razor-blade tester, showing a number of defective blades, compared with the edges of good blades.

ness control calibrated directly in exposure time required for the selected brightness. After adjusting the controls until a picture having the proper aesthetic effect is obtained, the print can be made under well-defined reproducible conditions.

Another and more serious problem exists in color-film printing. It is very difficult to make a good color print from a color negative without a trial-and-error process. Much of the guesswork can be taken out of this process by applying the above principles to it. Various methods have been proposed in the patent literature to enable an electronic viewing of a negative and a suitable phase and color reversal so that the appearance of a positive may be directly determined and the proper corrective measures taken.

Sound Recording

Since the earliest days of the cathode-ray tube, various types of tubes have been proposed for use as sound-recording elements in sound-on-film systems. One of the first to suggest this use and to build cathode-ray tubes for this purpose was von Ardenne,[14] who built the equipment and actually made such recordings. It is possible to make such sound recordings with perfectly standard cathode-ray oscillograph equipment and a continuous recording camera such as the Type 314 camera. Fig. 15 shows some examples of such sound

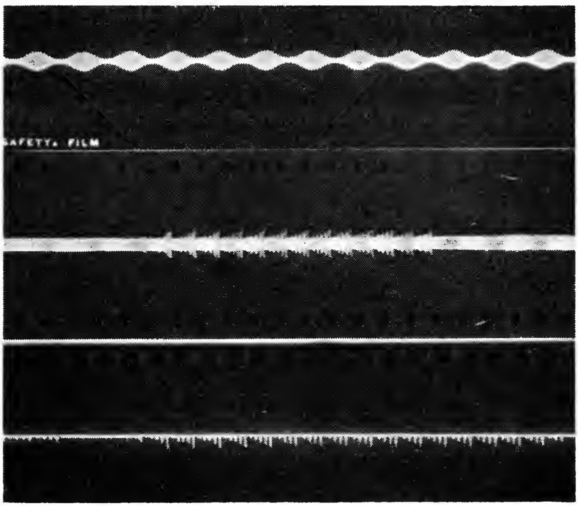
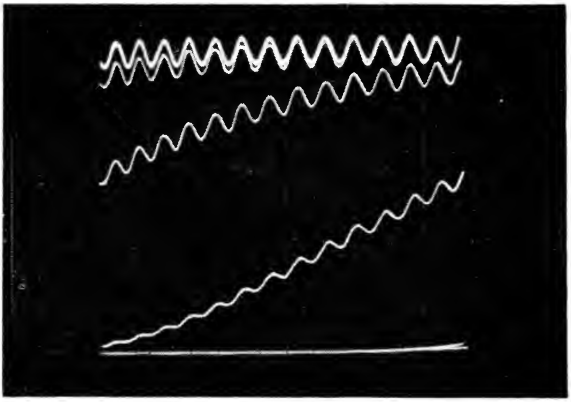
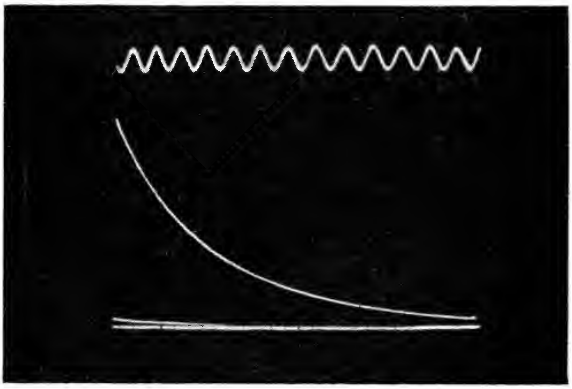


Fig. 15—Typical cathode-ray-tube sound-track recordings.

recordings made by voice-modulating a 100-kilocycle signal in a mixer tube and recording the result with the camera. These signals may be played back readily on the oscillograph by scanning them with an illuminated slit in a conventional manner. The advantage of the cathode-ray oscillograph here is that there is no limitation as to frequency response in the recording element itself, since modulating frequencies as high as desired may be recorded and played back. Obviously, a cathode-ray oscillograph is the best tool for properly studying, adjusting, and describing the performance of electronic motion picture sound equipment. Such phenomena as hum, cross modulation, and intermodulation may be recorded readily by standard techniques and many references appear in the literature to these methods.



(a) Showing incandescence.



(b) Showing nigrescence.

Fig. 16—Ripple in small alternating-current-operated lamps. These recordings made with repeated sweep.

STUDY OF LIGHT SOURCES FOR RIPPLE

One of the difficulties in illuminating a motion picture set with tungsten lamps is that the power supply must in many cases, be direct current in order to avoid a brightness flicker in the final image due to the 120-cycle variation in the light emitted from alternating-current-operated lamps. This variation causes an annoying beating of the frame frequencies with the ripple frequency and if a camera is to be operated at high speed, this flicker may become very annoying. Particular difficulty is encountered in cases where a motion picture has been made at high speed of a phenomenon illuminated by alternating-current-operated lamps and then the film printed on a high-speed printer also operated on alternating current. Occasionally, the dips in the exposing-light output and printing-light output become synchronous, with resulting light fluctuation in the final projected image. In recent years, many new types of filament construction have been adopted to minimize this defect and to produce as little ripple as possible. The best way to study this ripple is on a cathode-ray oscillograph equipped with a direct-current amplifier so that the ripple may be expressed as a percentage of the total light output. Fig. 16 (a) and (b) illustrates some typical examples of the ripple per-

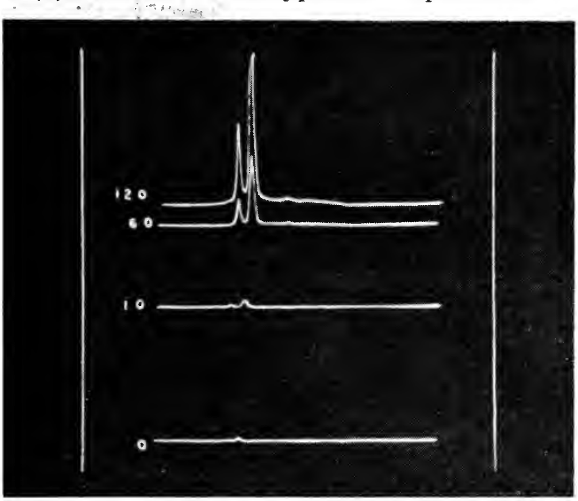


Fig. 17—Spectrograms of a low-pressure mercury arc at various times in seconds after starting.

centage of a certain lamp. In making these oscillograms, it was also of interest to determine which of these lamps lent themselves most readily to modulation for the transmission of information over light beams. The incandescence and nigrescence* curves can easily be seen and studied on these cathode-ray oscillograms.

Color Specification

Another problem in photography and optics is the proper description and specification of various colors. A cathode-ray-tube spectrograph for accomplishing this very result has been described by

* "Nigrescence" is defined as the process of becoming dark and refers here to the exact manner in which the light output of a lamp decreases after the current is suddenly cut off.

the authors.[15,16] Fig. 17 shows some typical cathode-ray-tube-produced spectrograms made with this apparatus. This instrument produces the color information required within $^1/_{120}$ second. The information may readily be put into other standard forms such as into International Commission on Illumination co-ordinates. To obtain the ICI co-ordinates requires certain standard integrations, additions, and divisions which may be accomplished electronically, by converting the information into digital form. To indicate these ICI co-ordinates, a cathode-ray tube again is a useful tool since a Universal ICI color diagram may be placed over the face of the tube, the position of the spot enabling reading of the co-ordinates directly. The output of a 3-filter photometer may also be shown in this manner instantaneously on the cathode-ray-tube screen.

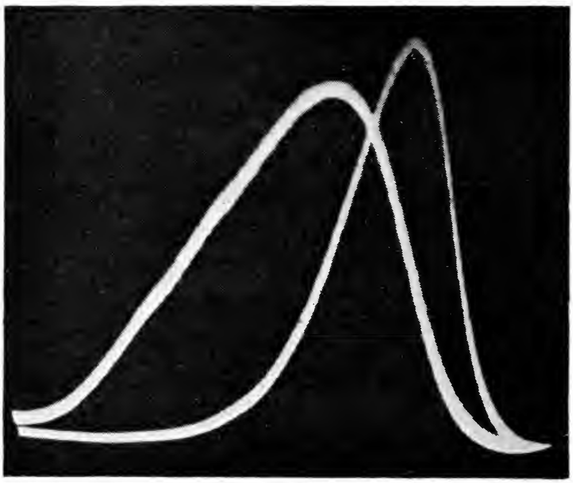


Fig. 18—Light distribution in image showing chromatic aberration. Pattern at left, at center of image; at right, at edge of image.

Another use of the cathode-ray tube spectrograph in optics is in the study of the color aberrations of optical systems. Fig. 18 shows the color distribution of the image of a rather poor lens along the axis, and the color at one of the fringes of the image. Many other uses for this instrument have already been described, such as the immediate drawing of filter-transmission curves or the reaction between chemical solutions, indicating, for example, when a developer has reached the exhaustion stage.

Conclusion

While it has not been possible to give here a complete description of all cathode-ray tube applications considered in optics and photography, it should now be obvious that cathode-ray tubes and oscillographs are valuable tools for solving many technical problems. Because of lack of space, we have not been able to consider many of these in the detail they deserve or to include many which have been developed outside of our Laboratories.

It is hoped that this brief consideration of some applications will stimulate the use of these oscillographic techniques in as wide a range of problems as possible.

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Objective Lenses of $f/1$ Aperture and Greater*

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Summary—**The factors involved in the design of large-aperture objectives are discussed and some of the general approaches to the reduction of the various aberrations are presented. Diagrams, classification, and source references of most objectives of $f/1$ aperture or greater which have been published are included. Both refracting and reflecting systems are considered, including objectives having spherical and aspherical surfaces and those employing the immersion principle. Applications, testing, and performance of extreme-aperture objectives are discussed. An extensive bibliography is appended.**

Introduction

During the past sixty years the relative aperture of a well-corrected objective for normal field of view has been increased from about $f/5$ to about $f/1.4$, some twelve times. The brightnesses of the carbon arc and the incandescent electric lamp have increased about six times and thirty times, respectively, in the same period, and new sources of great brightness such as the high-pressure mercury arc, the mercury-cadmium arc, and the condenser discharge flashtube have been developed. The sensitivity of the fastest film of today is more than fifty times that of the most rapid plate of the 1890's. As a result of these advances the lens-light source combination and the lens-film combination can be several hundred times more effective than they were when perforated film was first employed in cinematography. Film speeds and light-source brightnesses can continue to increase; with effective lens speeds the ultimate, while not attained, is at least clearly defined.

Illumination of the Image

The maximum light-gathering power of an aberrationless lens system is limited and in the case of a dry lens, i.e., one having both object and image in air, the greatest possible "speed" is $f/0.5$. Fig. 1

* Presented April 8, 1949, at the SMPE Convention in New York.

shows in cross-section portions of a fanciful objective having an aperture which approaches this maximum. The $f/2$ ray strikes the axis at the image plane at an angle of $14^1/_2$ degrees; the $f/1$, $f/0.7$, and $f/0.53$ rays strike the axis at angles of 30, 45, and $70^1/_2$ degrees, respectively. An $f/0.5$ ray would strike the axis at the limiting angle of 90 degrees, just grazing the image plane. The illumination E in foot-candles at the axis of an aberrationless image is

$$k\left(\frac{n'}{n}\right)^2 \pi B \sin^2\theta, \tag{1}$$

where k is the light-transmission factor of the lens, n' and n are the indexes of refraction in the image and object spaces, respectively, B is the brightness of the object in candles per square foot, and θ is the angle between the axis and the extreme, or marginal, ray reaching the image. An exceptionally lucid presentation of lens speed and of the factors involved is to be found in a paper by Kingslake.[1]

IMAGE DEFECTS AND APERTURE

As the semidiameter of the lens increases to approach the value of focal length as the limit, the rays passing through the outer zones are acted upon more and more violently by the refracting surfaces. Of the various unfortunate effects these refractions have upon the image, spherical aberration will be considered first. In a given system of large aperture it will be found that at any strongly curved surface, other than one which is aplanatic or zero-refracting, angular refraction will increase very rapidly with the height of the ray. The rays near the axis will be refracted an amount substantially proportional to their angle of incidence while the $f/1$, $f/0.7$, and $f/0.53$ rays will strike the refracting surface at greater angles of incidence with the consequence that the differences between the angles of incidence and the angles of refraction will increase disproportionately somewhat in the manner shown at surface 3 of Fig. 1. Consequently, the rays in the outer zones will intersect the axis at points displaced from the intersection point of rays in the more central zones unless corrected by refractions producing an equal effect of opposite sign. Spherical aberration reduces contrast and resolving power more or less severely depending upon the distance between the intersection points of rays being refracted by the various zones and upon their manner of distribution.

Reduction or elimination of this undesirable behavior of the light rays may be accomplished in part by utilizing shallower curves, employing aplanatic and zero-refracting surfaces, increasing the indexes of refraction of the glasses, and by "bending"—changing the shape factor of an element without altering its power. The necessity for employing shallower curves logically suggests the use of more elements, and the practice of substituting for a single element two others, each having half the power of the single element, can reduce the spherical aberration by $^3/_4$. Application of these principles in designing objectives of large aperture will usually reduce spherical aberration to an acceptable level.

Axial, or longitudinal, chromatic aberration may also be reduced to a level where it is not objectionable in view of the large variety of glasses available to the designer; for a given refractive index there are

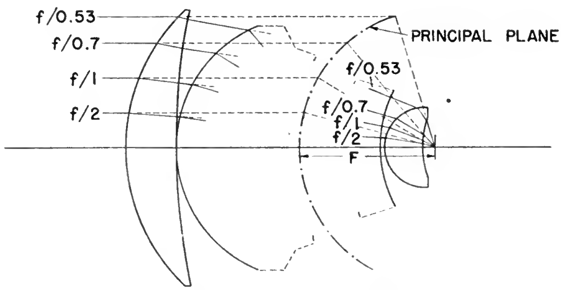

Fig. 1—Refraction at large apertures.

usually several, and occasionally a half-dozen glasses of different dispersion. Lateral chromatic aberration does not present too great an obstacle to the design of extreme-aperture objectives and can be reduced to a point where it is far less objectionable than, for example, astigmatism and curvature of field. Usually slight changes of spacing are sufficient to balance the v numbers* and spacing and powers of the elements before and behind the stop.

Distortion, resulting in variation in magnification across the image surface, is corrected in a manner not unlike that employed in correcting lateral chromatic aberration; that is, by balancing powers and separations on each side of the stop.

The remaining aberrations, i.e., coma, astigmatism, and curvature of field, are severely aggravated by the conditions accompanying large

* The v number of a glass is the reciprocal of the dispersive power; it is equal to the index for the sodium D line minus one, divided by the index difference for the hydrogen F and C lines.

relative aperture and require other treatments for their correction, and it is the difficulty of reducing these extra-axial aberrations which has generally led to the lens types and modifications to be discussed below. For example, the reduction of coma is most expeditiously effected by designing for approximate symmetry about the stop; this accounts for the presence among extreme-aperture objectives of those of the Gauss type. Reduction of astigmatism and curvature of field requires a low Petzval sum which can be accomplished by introducing appreciable air spaces among the components, by utilizing high-index, high-v crowns, and by adding a negative lens (field flattener) close to the image plane. Since all of these bendings, spacings, choices of indexes and dispersions, and distributions of power cannot be effected simultaneously because one action precludes or is only partially compatible with another, every design is a compromise of aberrations favoring the intended application of the objective, with the concessions as little damaging as the skill of the computer and the budget of the latter's employer permit.

The refinement of photographic objectives has been gradual and steady, principally through the small contributions of many workers and only occasionally through a new concept. The recent history and development of the photographic objective has been recorded and classified in papers by Taylor and Lee,[2] Lee,[3] and Kingslake[1,4] and in texts by Merte[5] and Leistner.[6,7] A consolidation here of the results of these efforts as they pertain to extreme-aperture objectives shows to what extent the limit has been approached, by what means and with what results. The only designs to be considered comprise those objectives of *f*/1 aperture or greater, including refractors and reflectors utilizing either spherical or aspherical surfaces, for which data are obtainable in the literature, or which have actually been issued. The selection of *f*/1 as the smallest aperture to be considered is arbitrary; designs of *f*/1.3 to *f*/1.5 aperture exist which may be quite capable of being produced in apertures of *f*/1 or faster.

REFRACTING OBJECTIVES—SPHERICAL SURFACES

A substantial number of large-aperture refracting objectives follow the Petzval design, outstanding for its excellent correction over a small field. In its fundamental form the Petzval lens is essentially a pair of widely spaced achromats, each approximately corrected for spherical aberration. The earliest of these modifications is the Ziess R-Biotar *f*/0.85, Fig. 2a, computed by Merte[8] which in the 4.5-centimeter focal length covers most of the 16-mm frame reasonably well.

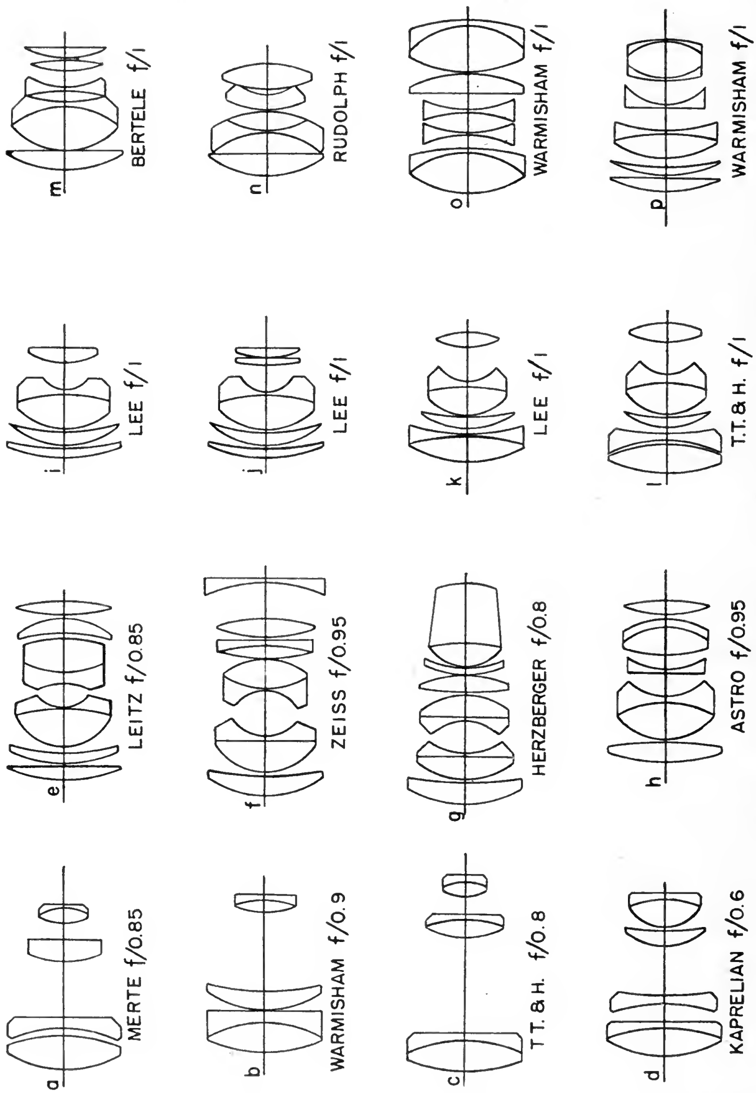

Fig. 2—Refracting objectives having spherical surfaces.

In this design the creation of an air space between elements 1 and 2 of the original Petzval lens and provision of another collective element (3) have provided the necessary additional degrees of freedom. Another design, Fig. 2b, of aperture $f/0.9$, has been developed by Warmisham,[9] in which the large aperture is obtained by the addition of a collective meniscus immediately following the first doublet, a procedure favorable to the reduction of spherical aberration. Fig. 2c shows the Taylor, Taylor, and Hobson $f/0.8$ radiographic lens,[10] a design in which the rear component of the basic Petzval configuration is split into two doublets, again taking advantage of reduced spherical aberration through dividing. The $f/0.6$ lens of Kaprelian,[11] Fig. 2d, adds another element to the R-Biotar upon which it is based in an attempt to obtain better spherical and chromatic correction and to increase the back focal length by a shift in power.

Another group of large-aperture objectives is based upon the excellent six-piece Gauss type, the principal defects of which are higher order astigmatism and oblique spherical aberration. Leitz,[12] Fig. 2e, has utilized a modification of the Gauss type which comprises the addition of two crown elements, one before the dispersing menisci and one after the menisci, to extend the aperture to $f/0.85$. The 7.5-centimeter Leitz objective has an acceptable field of about one inch diameter and covers the 35-mm frame for cine fluorography. An $f/1$ lens produced by Wray for radiography is of the same general type; here the additional collective element has been provided only at the long conjugate end and the second dispersive element appears as a singlet. The Wray lens, in common with most objectives intended for radiography, is especially corrected for use at short conjugates.

An $f/0.95$ Gauss-type objective of Zeiss[13] provides additional power through the provision of a second rear crown and includes a field flattener close to the focal plane, Fig. 2f. Herzberger[14] has designed an objective, Fig. 2g, of $f/0.8$ aperture which utilizes a front group comprising a complete, well-corrected Gauss objective followed by a rear-collective group of three elements based upon a system originated by Luboshez.[15, 16] The Herzberger objective provides for generally good correction. The Astro Tachon $f/1$ of Bielicke[17] utilizes the front components of the Gauss type in combination with rear components derived from the air-space type. Bielicke's $f/1$ design has been modified by the addition of another element to produce the $f/0.95$ Tachon, Fig. 2h.

Another group of extreme-aperture objectives derives from the Gauss type to form a separate and distinct class which results when the second dispersive meniscus is removed, the last element made strongly collective, and a meniscus introduced between the front element and the dispersive meniscus. Lee,[18] Fig. 2i, achieves an aperture of $f/1$ by this approach and in another form, Fig. 2j, also of $f/1$

aperture, the rear element is split in two without altering the first six radii or changing glasses. Lee[19] has also produced an $f/1$ design, Fig. 2k, in which the front element of this general arrangement is replaced with a cemented doublet to provide additional surfaces. Closely following this latter arrangement, Fig. 2l, is the $f/1$ Taylor and Hobson[10] radiographic lens in which an air space has been introduced between the first two elements.

Other lenses not directly identified with the above type groupings include an $f/1$ modification of the Ernostar by Bertele,[20] Fig. 2m, in which the rear crown has been replaced by a pair of crowns; a variation of the Plasmat by Rudolph,[21] Fig. 2n, for which an aperture of $f/1$ is claimed; and two $f/1$ designs, Figs. 2o and 2p, by Warmisham,[22,23] the first of which is derived from the four-piece air-space Dogmar design while the second is a modification of the Speed Panchro. Hopkins, Evans, Covell, and Feder[24] have described a six-piece $f/1$ objective based upon a microscope objective, or Petzval, design in which the well-corrected image falls upon a curved field to which the film is deformed pneumatically.

Of historic interest is an early and unusual design of Minor[25] for which an aperture of $f/0.5$ is claimed. Minor's design began with the computation of a four-piece air-space objective providing for the addition, later, of three more elements, one in front and two behind the basic objective to obtain increased aperture with the apparent utilization of specific surfaces to correct for specific aberrations. The final large aperture claimed was to be obtained by adding to the existing system a pair of rear elements which was intended to constitute a large-aperture rear attachment.

Of these twenty designs, six are currently, or have at some time been commercially available. Another, a Petzval lens, nominally of $f/0.99$ aperture, has not been considered here because its actual effective aperture is about $f/1.4$. Objectives which do not appear even approximately to fulfill the sine condition, such as one dry objective of $f/0.3$ aperture,[26] have been omitted from the present paper. Other large-aperture objectives having only partial corrections[27] or intended for nonphotographic uses,[28] may be of interest in some applications.

Refracting Objectives—Aspherical Surfaces

The use of aspheric surfaces in large-aperture refracting objectives permits substantial reduction of spherical aberration and coma while maintaining an economy of the number of elements employed or allowing the other elements to be applied to the correction of other aberrations. At present, aspheric surfaces of glass having the accuracy necessary for use in photographic objectives cannot be mass-produced; the high cost of hand-figuring and the difficulty of testing during manufacture have prevented extreme-aperture photographic objectives with aspheric surfaces from appearing commercially. The probability that methods and techniques for the production of such surfaces on a large scale may be developed in the near future, possibly through the use of materials other than glass, warrants the design and study of these objectives.

Lee[29] has shown, Fig. 3a, an $f/1$ design similar to that of Fig. 2i in which concave surface 7 is aspheric, changing from a sphere at its central zones to a conicoid at the outer zones. Djian[30] discloses

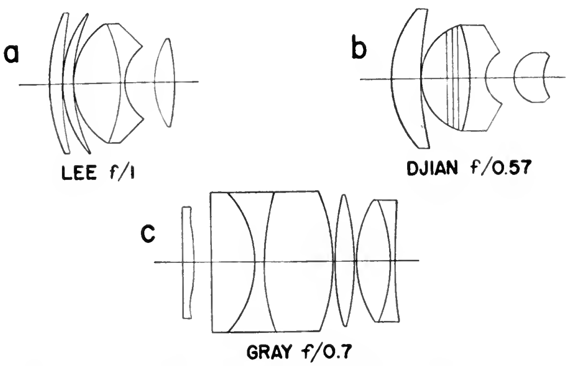

Fig. 3—Refracting objectives having aspherical surfaces.

several modifications of much the same type, one of which, Fig. 3b, attains the aperture of $f/0.57$. Djian aspherizes a convex surface (3) by constructing the second element of four pieces of the same type of glass cemented together, each succeeding piece in the light path extending beyond the previous piece and presenting aspherical front surfaces of increasing radius to the rays in the outer zones.

Another approach is that of Gray,[31] Fig. 3c, in providing an objective with an aspheric correcting plate at the long conjugate end to provide a 1-inch $f/1$ objective of $f/0.7$ aperture which is capable of satisfactorily covering 16-mm frame size.

Reflecting Objectives

Reflecting systems offer a variety of advantages for large-aperture applications which are bound to tempt the computer. By comparison with a refractor of the same power, the spherical reflector has a longer radius, it can have a more favorable Petzval sum, and it has a small fraction of the spherical aberration. There is a complete absence of chromatic aberration in the front-surface reflector and by placing the entrance pupil at the center of curvature of a spherical reflector, coma, astigmatism, and distortion can be reduced to zero. Reduction of spherical aberration and appropriate flattening of the field are the principal goals in the utilization of mirrors as photographic objectives.

The first large-aperture reflecting system of extended field is that accredited to Schmidt,[32, 33] Fig. 4a, which utilizes a spherical reflector and an aspheric corrector plate. It is generally well corrected except

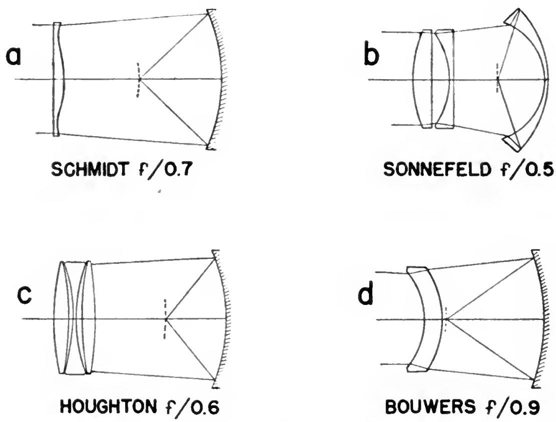

Fig. 4—Reflecting objectives.

for curvature of field. The Schmidt system has had numerous applications and has been modified in a variety of ways even though the image falls inconveniently between the mirror and the correcting plate and though the latter is not readily or inexpensively produced at present.

A logical next step was the elimination of the aspheric correcting plate. This was done by Sonnefeld,[34] Fig. 4b, who utilized a dispersing corrector comprising a positive and a negative element having spherical surfaces to correct the image formed by a Mangin mirror rather than by an ordinary front-surface spherical mirror to achieve an aperture of $f/0.5$. Mangin-mirror arrangements of $f/0.9$ and $f/0.6$ apertures are described by Flugge,[35] and Martin, Flugge, and Roll[36] have utilized a Mangin mirror in combination with refracting elements to produce a system of $f/0.8$ for television projection without the use of aspheric surfaces. Houghton[37] obtains an aperture of

$f/0.6$ by combining a dispersive air-spaced triplet with a front-surface spherical reflector, Fig. 4c.

Use of a substantially zero-power concentric meniscus lens, which is also concentric to the mirror which it corrects, has been made by Maksutov[38] and by Bouwers,[39, 40] Fig. 4d, to obtain large fields with large apertures, the aperture being limited only by zonal aberrations and longitudinal chromatic aberration. For those applications requiring extreme aperture where curvature of field to a radius approximately equal to the focal length is not objectionable, systems of this type may be preferable to straight refracting objectives in the present state of the art. The simplicity of concentric systems from the viewpoint of both construction and computation, axial tracing and design suffice for the entire field of view, makes these objectives attractive. Application of this principle to television projection has been made by Bennett[41] who has obtained an aperture of $f/0.8$. Bouwers[42] has further improved the corrections obtainable with the concentric system by providing an aspherical correcting plate in an arrangement in which the mirror is corrected by a substantially concentric double meniscus. Baker[43] has utilized as the correcting means in one modification of the concentric system of $f/0.6$ aperture a pair of menisci with their concave surfaces facing an aspheric correcting plate of very weak curvature. A similar approach, but without a corrective plate, has been presented by Wynne.[44] Gabor[45] has disclosed a reflecting system of $f/0.9$ aperture based upon the same general principles as that of Maksutov and Bouwers. In Gabor a secondary mirror permits the more convenient positioning of the image just at the rear of the primary mirror. Henyey and Greenstein[46] have described a concentric system of about $f/1$ aperture for photofluorography which utilizes an achromatized correcting meniscus. In another report[47] by these investigators, additional systems of various configurations are shown.

The parabolic mirror is ideal for telescope imagery but suffers so badly from coma that it cannot be employed for photography where both large aperture and extended field are requisite. Warmisham[48–53] has succeeded in combining spherical and aspherical mirrors with and without aspheric correcting plates to produce a family of large-aperture objectives, some of which are suitable for photography.

It should be noted that in each of these mirror systems there is vignetting either from the photographic film or from a secondary mirror which has the effect of blocking the light from the central zones responsible for much of the sharpness in a lens. The rays from the outer zones which contribute most of the aberration in any system form the image in these systems and must therefore be highly corrected. Because of the location of the image between the corrector and mirror, many of these objectives do not lend themselves to ready utilization as taking lenses caused by shutter problems, nor are they adapted for use in ordinary projection systems.

IMMERSION OBJECTIVES

The brightness of an image depends upon the ratio of indexes of refraction in the image and object spaces as well as upon the angle of the extreme ray (equation (1)). Thus the use of an immersion fluid of index 1.5 between the focal plane and the rear element of an immersion objective more than doubles the "speed" of the lens. It is thereby possible to obtain relative apertures of $f/0.4$ or slightly faster with the accompanying advantages or disadvantages of increased theoretical resolving power and reduced depth of focus.

The difficulties and inconveniences associated with the immersion principle limit its use to very few applications. Bracey[54] employed an enlarged oil-immersion microscope objective of $f/0.36$ aperture for astronomical photography. One form of the Djian[30] objective not dissimilar to that shown in Fig. 3b, is especially adapted for immersion use and attains an aperture of $f/0.54$ through oiling the film to the rear plane surface of the system. A variety of high-speed Schmidts, including solid modifications, have been described by Hendrix and Christie[55] and an aperture of $f/0.3$ has been attained by Baker[56] utilizing a solid system. Nicoll[57] has shown an immersion Schmidt system of large aperture applied to picture taking and to television projection. Solid Schmidts and solid concentric systems of approximately $f/1$ aperture or greater are to be found in Henyey and Greenstein.[47] In those applications where the ultimate in light-gathering power is essential and the inconveniences of the immersion systems are secondary considerations, these systems represent the only purely optical means whereby this extreme lens speed may be attained.

APPLICATIONS

There are a number of reasons to account for the fact that very few extreme-aperture objectives are available commercially: they require extensive design time, are costly in view of the complexity of construction and the limited production for a specialized market, and the performance at present of all-refracting objectives having spherical surfaces only is at best mediocre in comparison with well-designed objectives of $f/1.5$ or $f/2$ aperture. An $f/0.85$ objective may resolve 15 to 20 lines per millimeter on the axis and only 5 to 8 lines per millimeter at the corner of the 16-mm frame while at least one recent mass-produced *f*/1.4 lens can resolve 60 lines per millimeter and 45 lines per millimeter at the center and edge, respectively, of the same field on the same high-speed emulsion. Extreme lens speeds are valuable in those applications where object brightness is low as in cine fluorography, where exposures are extremely short as in ultrahigh-speed photography, and in those situations where short exposure times are necessary at locations of low light level where the use of lamps is objectionable. They may also be useful in projection where exceptionally high levels of screen illumination must be obtained or where a given high screen illumination must be maintained with an economy of light-source power or with light sources of relatively low brightness.

An optical disadvantage of these extreme-aperture objectives, aside from lack of high resolution, is the extremely shallow depth of focus. In order to realize the full resolving power of an *f*/0.8 objective capable of separating 40 lines per millimeter the emulsion must be positioned within 0.016 mm (0.0006 inch) of the image plane. Clearly the taking or projecting equipment intended for use with an objective of such aperture must be properly designed and fabricated. It is also important to recognize the low light-transmission factor in refracting objectives, where, notwithstanding the use of low reflection coatings, there still will be considerable light loss at the 10 or 12 glass-air surfaces in addition to significant loss due to long glass paths. For those applications where a considerable amount of the light is at the violet end of the spectrum there may be a disproportionately large loss due to the use of extremely dense flint elements in the design.

Testing of extreme-aperture taking lenses is best performed by photographic means, preferably utilizing the subject contrast and type of emulsion with which the objective is to be employed. Visual tests on an optical bench are convenient, although evaluation is difficult because of the high magnifications which accompany the use of large numerical-aperture microscope objectives and partly because the observation is subjective. It is essential that the numerical aperture of the microscope objective used on the optical bench be at least as great as that of the objective under test. In testing an objective of *f*/1, *f*/0.85, or *f*/0.6 aperture, the numerical aperture of the microscope objective must be not less than 0.5, 0.59, or 0.83, respectively, otherwise the observed image will be that formed by the objective when stopped down to the aperture corresponding to the numerical aperture of the microscope objective. Projection means utilizing a projection test slide may also be employed for testing these objectives, provided the projector condenser is of an aperture capable of filling the objective with light.

For those photographic applications where even the great light-gathering power of an extreme-aperture objective is insufficient or where the speed of such an objective must be maintained while enjoying the greater depth of focus, higher contrast and higher resolving power of an objective of more modest aperture, an electronic stage such as an image tube or an image orthicon, or other intermediate means such as phosphors, provide the next obvious step for increasing the amount of energy in the image.

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66th Semiannual Convention
SOCIETY OF MOTION PICTURE ENGINEERS

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HOTEL RESERVATIONS AND RATES The Housing Committee, under Watson Jones, chairman, will make reservations for members and guests. Inform him at 1560 North Vine Street, Hollywood 28, California, of the accommodations you desire. He will book your reservations and confirm them.

TRAVEL Make your train or plane reservations early because West Coast travel in October normally is quite heavy.

LADIES AND GUESTS Members are encouraged to invite their friends to attend the convention. There will be eleven Technical Sessions open to all who wish to be on hand, and for the ladies who accompany their husbands, the Ladies' Committee is arranging a week of sight-seeing and special events.

RECREATION The identification cards issued to members and guests who register for the convention will permit them to attend Grauman's Chinese and Egyptian Theaters of the Fox West Coast Circuit, the Hollywood Paramount, the Pantages, and Warner Theaters, all of which are located on Hollywood Boulevard and near the hotel. Convention Headquarters will have a wealth of information on places to visit in or near the Los Angeles area.

PAPERS PROGRAM Authors who plan to prepare papers for presentation at the 66th Convention should write at once for Authors' Forms and important instructions to the Papers Committee member listed below who is nearest. Authors' Forms, titles, and abstracts must be in the hands of Mr. Grignon by August 15 to be included in the Tentative Program, which will be mailed to members thirty days before the Convention.

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Edward Auger

Edward Auger, lifelong friend of the theater and retired employee of RCA Theater Equipment Sales, suffered a heart attack on April 4, 1949, while attending the Convention of the Society of Motion Picture Engineers at the Statler Hotel in New York City.

Mr. Auger got his start in the theater during the days of silent films and was an early independent producer of "Westerns." He joined RCA Photophone at its inception and remained with Theater Equipment Sales until his retirement in 1947. His widespread knowledge of the theater and friendships with exhibitors across the country made him a natural good-will ambassador for the Radio Corporation of America, and he became National Office Field Representative soon after his start with the company. He maintained contacts with exhibitors everywhere, and his liaison work was principally with chain-theater operators.

On many occasions Mr. Auger was called out of retirement to handle special assignments for both RCA Theater Equipment Sales and RCA Theater Service. His co-operative efforts were well known among his many friends throughout the company.

He joined the Society of Motion Picture Engineers as an Associate on April 3, 1934.

Book Reviews

Comparative List of Color Terms

A Report of the Inter-Society Color Council. Published, January, 1949, by the Inter-Society Color Council, Box 155, Benjamin Franklin Station, Washington 4, D. C. Paper Bound. $8^{1}/_{2}$ by 11 inches. 94 pages. Price, $1.00 to members and delegates of the ISCC; $2.00 to nonmembers.

This pamphlet is not intended as a final report on definitions; instead, it is meant to provide the basis for a thorough study of the subject among the member bodies of the Council and lead to a revision of this list that will provide official definitions upon which all can agree.

Certain terminology, as applied to color, has taken on meanings peculiar to the art and science to which it is applied. Such meanings are, in some cases, not the same among various societies and have led to misunderstandings. This glossary lists the use of such terms and indicates to which group the meanings and definitions apply. Terms and phrases are listed alphabetically, followed by the definition, with references.

This report is well written and is edited by well-qualified people in each field of color. It should be helpful to anyone working in the color field.

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Physical Aspects of Colour, by P. J. Bouma

Published (1948) by N. V. Philips Gloeilampenfabrieken, Eindhoven, The Netherlands. Distributed by Elsevier Publishing Company, Inc., 215 Fourth Ave., New York 3, N. Y. 263 pages + 12 pages + 13 pages tables and symbols + 19-page bibliography + 4-page index. 113 illustrations, $6^{1}/_{4} \times 9^{1}/_{4}$ inches. Price, $5.50.

Dr. Bouma's introduction to the physics and the measurement of color is a worth-while addition to our literature. In a book of some 300 pages, including a lengthy bibliography and competent index, the writer traces the subject of color from its fundamentals to its present position of international importance. The steps, the techniques, and their importance are clearly stated. This is followed by a regrettably brief mention of the relation of these subjects to the various fields of application.

Dr. Bouma is at his best when he is discussing the historical background of the various controversies with which the subject has been burdened. Perhaps because of the lack of a clear-cut theoretical basis, the subject of color has been much given to hearsay, whim, and casual discourse. All these are taken in the writer's stride. He recognizes the contribution from both sides to an argument and is not deterred in his purpose, that of setting down the facts wherever they may lead.

To American audiences the book will recommend itself chiefly by its rather complete and straightforward statement of the European point of view. Many people have thought on the subject of color and many different points of view have been expressed. It is good to find a writer who has set down the opinions in fair fashion with relatively little of judicial attitude.

It could be wished, in some sections, that a little broader realization of the psychological implications were present, even in a book deliberately restricted to the physical point of view. Nevertheless, it is good to see a book which is restricted to this phase which at the same time recognizes other possibilities and other means of access to the subject.

One regrets that its author is no longer with us. There are too few authors whose writings criticize the currently accepted ideas and at the same time freely state an opinion based on careful thought and deep historical knowledge. The book is definitely recommended reading for all who aspire to become familiar with the peculiar but important and rapidly expanding field of color as a science.

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Better Color Movies, by Fred Bond

Published (1948) by Camera Craft Publishing Company, 95 Minna Street, San Francisco 5, Calif. 156 pages + 3-page index. 70 black-and-white illustrations, 16 color plates. $6^1/_4 \times 9^1/_4$ inches. Price, $5.00.

Fred Bond, who wrote a good book for still photographers entitled "Kodachrome and Ektachrome from all Angles," has written one for the amateur motion picture maker called "Better Color Movies."

The book becomes rather technical in places for the average amateur, but the professional cameraman (and there are a number of them shooting 16-mm professionally) will find the book misleading in a number of places. Most amateur motion pictures consist of baby, family, and travel pictures. The amateur cinematographer will have little if any control over good or bad color schemes, and few of them will have any idea of the Munsell system of denoting color even after he reads the book.

A good job has been done on the chapter, "Determining the Exposure," if the user can remember all the tables given, or consult the book before taking pictures. If he follows all the instructions for guessing the exposure, as explained by Mr. Bond, undoubtedly he will feel that he has used the mental-calculation method which is also described.

The importance of color temperature is mentioned in a number of places throughout the book. Color temperature is important, but there are so many variables in color photography today that the amateur or even the professional can do little about it. The amateur is warned not to use old photofloods and to be very careful with line voltage to avoid the brick-red flesh tones. Those professionals who have made accurate experiments with Kodachrome will not agree with Mr. Bond on all of these points. The majority of the amateurs taking motion pictures still have a great deal of trouble in securing correct exposures, even with the relatively simple exposure meters on the market, and if he attempts to calculate color temperature as well as exposure the average motion picture maker will probably become somewhat confused.

I feel that Mr. Bond has made the mistake of many still photographers who have turned to motion pictures. He constantly makes still pictures instead of motion pictures. In fact, a number of the illustrations are pictures used in his book on still photography entitled, "Kodachrome and Ektachrome and How to Use It." Most of the illustrations on lighting are very good for still pictures, but are not suitable if any action is to take place. Unless there is action, it is not a motion picture. You get the feeling all through the book that he is trying to tell the motion picture maker how to take a number of beautiful photographs with no thought of continuity in action, writing, or composition.

A chapter is devoted to theatricals and indoor sporting events. Mr. Bond also gives some rather definite exposure suggestions. Shots of theatricals and indoor sporting events have made the film manufacturers a great deal of money, but the number of bad pictures or no pictures far outnumber the good ones. For example, there are a few basketball courts in the country with enough light to obtain good pictures with the fastest black-and-white film. There are probably basketball courts somewhere in the country where color motion pictures can be shot, but we have seen it tried on a number of courts in black-and-white and we have even taken motion pictures for the National Tournaments. There is not any too much light for black-and-white even on these courts, which are supposed to be ideal. We, therefore, feel that color motion pictures on most courts is simply out of the question for the average amateur and the average basketball court. The average theatrical is just as hard to shoot.

Anyone doing color photography and who likes to read will enjoy the book, even though he does not agree with it entirely. He should get some ideas, although we cannot say it is a "must" for every movie maker.

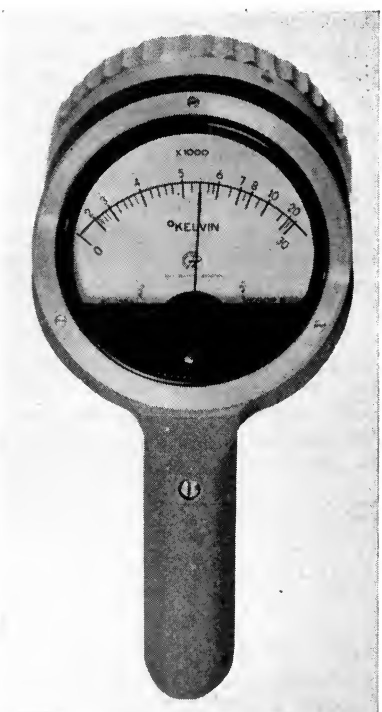
Lloyd Thompson
The Calvin Company
Kansas City, Mo.

New Products

Further information concerning the material described below can be obtained by writing direct to the manufacturers. As in the case of technical papers, publication of these news items does not constitute endorsement of the manufacturer's statements nor of his products.

Spectra Direct Color Temperature Meter

Photo Research Corporation, 15024 Devonshire Street, San Fernando, California, announces the Spectra Direct Color Temperature Meter, developed by Karl Freund. Color temperature of incident light is measured by pointing the side containing a photoelectric cell toward the camera or source of light, and turning the diaphragm ring until the meter needle comes to a reference mark. When a trigger is pressed, the color temperature is indicated directly on a scale reading from 2000 to 30,000 degrees Kelvin.



Automatic Tristimulus Integrator

General Aniline and Film Corporation, 230 Park Ave., New York 17, N. Y., and **Librascope, Inc.,** Burbank, California, recently introduced an automatic tristimulus integrator to be used with the General Electric recording spectrophotometer.

The primary elements in the mechanical computer are ball and disk integrators. Wavelength and reflectance, or transmittance, of the sample are fed into the computer by servomechanisms. The only modification required on a standard spectrophotometer is the installation of two Selsyn transmitters, the removal of a section of panel, and installation of two rails. Normal operation of the spectrophotometer is not affected.

While a sample is being measured in the spectrophotometer at either high or low speed, the integrator automatically computes the tristimulus values to a precision of about ±0.0005. When the curve is completed, the values are read from three counters on the computer, the counters are reset to zero, and the next sample may be run. Thus tristimulus values are obtained with practically no additional time beyond that normally required for drawing the spectrophotometric curve.

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Society of Motion Picture Engineers

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Engineering Techniques in Motion Pictures and Television*

By ALFRED N. GOLDSMITH

Consulting Engineer, New York 17, New York

In the following brief summary it is feasible only to outline problems and processes, and primarily to stimulate discussion. Actually the subject matter of this short commentary would require, for adequate treatment, a number of large and impressive volumes.

Properly handled, the television broadcasting of a film presentation should be identical (so far as the audience is concerned) with a live-talent program. There are some incidental technical and economic advantages inherent in the use of film. These include ease of repetition of the program, the possibility of ready cutting and editing, the certainty of program quality, the predictability of the program, and the like.

Adequate film presentations in television imply, however, that the film picture and sound shall exceed in general quality the capabilities of the television system. In other words, the bottleneck in performance should reside in the television transmission and reception, not in the film recording. Accordingly the film images must have resolution and gradation range superior to that of the television system. The sound recording similarly must excel in fidelity and in low noise level.

Available data indicate that 35-mm film, used for pictorial purposes, would be more than adequate. Sixteen-millimeter pictures, made as reductions from original 35-mm negatives, are largely satisfactory. More nearly marginal are 16-mm positives made from 16-mm negatives, particularly if these negatives are derived directly from a television system by kinescope or picture-tube recording.

So far as sound reproduction is concerned, 35-mm records running at 90 feet per minute are satisfactory. Sound reproduction from 16-mm film, under existing circumstances, fluctuates about an adequacy level.

* Presented April 4, 1949, at the SMPE Convention in New York.

The preceding comments refer specifically to 16-mm and 35-mm film used by available personnel in everyday available equipment, under normal circumstances, and with routine commercial processing of the film negatives and positives. That is, these comments apply to everyday conditions as now experienced.

Once a film transcription of picture and sound is available, it can be used to modulate the image transmitter by one of several available methods. Thus, the pictures may be intermittently projected upon the screen of a camera tube, using as required a regime suitable for converting 24 frames per second on the film to 60 interlaced fields per second of the television transmission.

Alternatively, the film pictures may be scanned by a flying light spot, which is itself a focused image of a raster-forming spot on a low-persistence, high-intensity picture tube.

It has also been suggested that nonintermittent projection of the film upon the camera tube photosensitive surface be used. This process has not as yet found commercial exploitation.

The film transcription itself may be made in a variety of ways, two of which may be mentioned. The most obvious and direct method of producing a film transcription is by actual photography of the face of a monitor picture tube or kinescope which is reproducing the program to be recorded. This method has the advantages of high speed, simplicity, and low cost. It has the limitations that the record necessarily can be no better than the image produced by the electrical portions of the television system up to and through the monitor kinescope. Further, it lacks any capabilities of cutting, editing, or substantial and flexible revision of the recorded material. As a result, this method is a present-day expedient. It produces program material fluctuating around an acceptable level.

Presumably direct kinescope recording could be improved if certain fairly radical steps were taken. For example, if high-resolution and wide-gradation-range television systems were used between the studio camera and a precision monitor kinescope, the picture available for photography would be adequate or more nearly so. Such a procedure might well justify the use of 35-mm film for recording the picture, at least for the transcription negative. This would enable the full capabilities of such an evolved television system to be realized and would provide film transcriptions which might well be, as previously suggested, better than the conventional television broadcasting system over which they were later to be transmitted.

A second method of producing film transcriptions is the obvious one of direct photography in the studio along more or less conventional motion picture lines. One necessary exception to this statement would be the requirement that economy of operation would necessarily be stressed to a far greater extent than is customary in motion picture practice. Studio photography of the program yields superior picture quality, greater ease of cutting and editing, enhanced flexibility in production, and the possibility of retakes as required. However, production costs will, at best, be considerably increased when this method is used, and the speed of production will be appreciably reduced.

Considering comparatively both 35-mm and 16-mm films, as used in television, there is something to be said in favor of each of these. The obvious ease of handling 16-mm films, and the correspondingly lower equipment, film, and processing costs are definitely advantageous. On the other hand, the improved quality, increased reliability, and the more highly developed 35-mm techniques as contrasted with those available for 16-mm film swing the scale back toward, or even beyond, a level position.

It will, therefore, be interesting to observe the future developments in this "millimeter contest," so to speak. So far as the recording of actual program material is concerned, this struggle may be vigorous enough. It will likely be even more strenuous in relation to the customary and much cherished commercial announcements which, of necessity, are the "sponsor's pride."

It is urged that present-day practices be not regarded as crystallized and permanent. It is rather suggested that alternative methods for the production of film transcriptions on various sizes or gauges of film be thoroughly and continuously explored. It may thus result that television, five years in the future, shall continue to please its audiences and shall utilize programs on film most effectively and economically, all factors being considered.

Motion Picture Laboratory Practice for Television*

By ARTHUR J. MILLER

Consolidated Film Industries, New York 19, New York

The use of motion picture films in television has brought with it a variety of problems, both for the producer or the user and for the laboratory making prints for such use. These remarks will be confined to the subject of picture quality on 16-mm films for use in television.

There are three controllable factors which can be considered in the production of an acceptable film for this use: definition, contrast of the print, and print density.

The definition of the print is first governed by the definition of the material from which the print is made. No print can be sharp if the original material used is lacking in definition because of improper focus of the camera, dirt, or moisture on the lenses, or any one of many factors.

Assuming that we have a negative or other original material which has as good definition as can be obtained, then the factors controlling the ultimate definition of the print used for television are limited to the equipment used in the laboratory, and the inherent limit of definition in the stock used for the print.

If the print is made by reduction from a 35-mm negative, it is essential that the printer used for this purpose be maintained in the highest state of mechanical and optical perfection.

Two types of printers are commonly used when making contact prints. One is the continuous printer which is most commonly used in all production work and in which the negative and positive films are moved continuously past an aperture during exposure, while being carried on a sprocket.

Contact and definition in this type of printer are dependent largely on the shrinkage of the negative in relation to the positive and the amount of curl inherent in the two films. Tension is applied during printing to keep these effects at a minimum, and it goes without

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saying that the sprocket on which the films are printed must be cut to the highest degree of mechanical perfection possible.

Unless all these factors of shrinkage and curl happen exactly to match with each other and the design of the sprocket, it is possible to secure better definition on prints made on a step printer, in which each frame is printed separately, and in which the negative and positive films are held in tight contact during exposure.

The other main factor, in securing high definition, is the maximum resolving power of the positive film used. It has been remarked that if this resolving power is greater than that of the television system the other factors are immaterial. It is not believed that this is the fact, but that all of the definition possible should be saved in each of the steps necessary in bringing a motion picture to the television screen.

Some of the prints shown were made on continuous-type printers and others were made on highest definition step-type printers. Some prints on each type printer were made on fine-grain release positive, and some were made on fine-grain duplicating positive, which has the highest resolving power of the commercially available motion picture films.

This film also has the advantage of producing excellent quality when developed in the manner that these prints were made, that is, to a gamma of approximately 2.10, producing a good tone range on varying types of scenes.

Sound-on-Film Recording for Television Broadcasting*

By CLYDE R. KEITH

Western Electric Company, New York 5, New York

These remarks are confined for the most part to problems of sound on 16-mm film, since such films are of greatest economic importance to the television broadcaster.

There are three principal bottlenecks tending to degrade the quality of sound obtained from 16-mm films in television broadcasting.

1. 16-mm film processing is generally inferior to 35-mm processing, resulting in more noise and distortion than would be present if equally good processing were available for 16-mm films. This is shown by the tendency of Hollywood studios to record sound on 32- to 35-mm film so that it can be processed in 35-mm developing machines.

2. 16-mm printers frequently introduce distortion and flutter. Good 16-mm printing requires a higher degree of precision in the printer than is required for 35-mm printing.

3. Most 16-mm sound-and-picture projectors do not have the electrical, mechanical, and optical accuracy required to give the best results, or the mechanical sturdiness to maintain optimum adjustments over a long period of steady use.

Most of the above deficiencies arise from cut-price competition in the amateur and educational fields. Considerable improvement should result if methods and equipment used in the 35-mm field are adopted.

Effect of Lack of Adjustment of Reproducer on Sound Quality

1. Frequency Response

Some commercial 16-mm reproducers are built with excessive loss at frequencies over 3 to 4 kilocycles. The output at 5 kilocycles may be as much as 10 to 15 decibels below that at 1 kilocycle. This droop may be introduced intentionally on the assumption that the reproduction

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of noise and distortion products above 4 to 5 kilocycles degrades the sound quality more than it would be improved by reproducing the signal uniformly up to say 7 kilocycles. While this may be a reasonable assumption for many 16-mm films in circulation today, it does not allow for improvement as better recording and printing techniques are developed. It would be preferable to use a scanning system and amplifier which would provide essentially uniform response to at least 7 kilocycles and then use a suitable low-pass filter whose cutoff frequency could be adjusted depending on the noise and distortion on a particular record. This is similar to the practice used in broadcasting phonograph records. A test film such as Z22.44–16-mm Multifrequency Test Film should be used for determining reproducer response.

2. Scanning-Beam Focus

An out-of-focus condition reduces high-frequency response. Some reproducers focus in the center of the film to take care of both standard and nonstandard emulsion positions. This means neither position is quite right and may give a loss of about 3 decibels at 7 kilocycles depending on the optical system. Out-of-focus by thickness of film may cause a loss of 10 decibels at 7 kilocycles.

The projector should have quick change of focus between front and back surface of film. Focus should be checked periodically with Z22.42–16-Mm Sound Focusing Test Film, 7000-Cycle Laboratory Type.

3. Scanning-Beam Azimuth

Azimuth error causes loss at high frequencies similar to loss caused by slit width. It also introduces wave-form distortion in reproducing variable-area sound records. For example, if azimuth is out by width of slit (0.5 mil), second harmonic of 3600 cycles would be about 12 per cent for area tracks. Azimuth should be checked with above Z22.42 Test Film.

4. Scanning-Beam Position

Improper position of scanning beam relative to sound track may cause noise on density films or both noise and distortion on area films. Scanning beam too close to the edge of the film causes random noise while beam too far from the edge may produce 24-cycle noise caused by picture-frame lines.

With variable-area sound tracks, displacement in either direction will also cause severe distortion at high amplitudes because of sharp cutoff of wave peaks. Track position should be checked by means of Z22.57–16-Mm Buzz-Track Test Film.

5. Uniformity of Illumination

Nonuniformity of scanning-beam illumination has no effect on a variable-density track, but may introduce considerable distortion in variable-area tracks. Harmonic distortion may be shown to be quite low for any reasonable nonuniformity of illumination. For example, with a bilateral track and symmetrical (parabolic) nonuniformity 20 per cent brighter in the center than at the sides, the second harmonic is about 3 per cent and the third about $^1/_2$ per cent. However, intermodulation of high and low frequencies is much higher. With the same light distribution intermodulation would be 15 to 20 per cent.

In some machines distortion is also produced in area tracks by nonuniform sensitivity of the cathode of the phototube. This occurs where the optical system is such that the illuminated area of the cathode varies as the width of the track. Intermodulation as high as 60 per cent has been measured because of this effect. No standard test film is now available to measure intermodulation caused by scanning deficiencies, but such a film can be made without difficulty.

6. Flutter

One of the most noticeable defects in the reproduction of films over television at this time is flutter. The flutter frequently is very much greater than would be tolerated in even the smallest theater. While it is possible that the flutter may be in the film, it may also be in the 16-mm reproducer. This need not be the case since it is possible to build machines in which the flutter is consistently below audible levels. Although methods of flutter measurement have not been finally standardized, methods and equipment are well known in the film industry. A flutter test film Z22.43 is available for this purpose.

Television-Film Requirements*

By G. DAVID GUDEBROD

N. W. Ayer and Son, New York 20, New York

The printed material describing this forum mentions industrial, educational, institutional, commercial, and promotional films as well as entertainment films. It implies that they are all frequently used for television programming. Actually, however, straight industrial or institutional films are so unadaptable and so specialized that in the author's opinion they can be safely ignored as a factor in television programming. In order to clarify and simplify things a little, the films covered in this paper are primarily entertainment films—the type of films sought when building a television program to sell goods for a sponsor.

Motion picture production requirements—so far as television is concerned—are almost like any other film requirements: first, the films must have box-office appeal; second (and this is a variation), continuity; third, technical excellence; and fourth, the price must be right.

These four main qualifications must be examined from an advertiser's standpoint—an advertiser who is looking at television as a new medium of mass communication.

An advertiser is going to insist that his television films have box-office appeal for the very simple reason that he wants a big audience—the larger the better. No clients have ever complained about having too large an audience, but television must have a very special sort of box-office appeal. The film must be created to speak to three or four people in a living room. It must have a certain warmth and intimacy. Films for theatrical distribution depend to a great extent on awakening a crowd reaction. A television film plays to no crowd. It does not even have a studio audience to lean on. It must reach directly into the home and sing a song or spin a yarn to three or four people, not three or four thousand.

How can one tell whether a television film has this type of box-office appeal? Probably no one can do it consistently, but one must keep trying to capture it when possible.

* Presented April 4, 1949, at the SMPE Convention in New York.

The second qualification is continuity. Box-office appeal gets the audience, continuity holds it! Advertisers have long since learned that the audience likes to have something familiar in their entertainment week after week. To the author's knowledge a successful radio or television program has never existed without continuity of one kind or another. Sometimes it is no more than a make-believe theater such as the Kraft Television Theater, The Philco Playhouse, or the Ford Theater. Still another type of continuity is achieved by the use of a single recurring character such as the Bookshop Man in the current Lucky Strike series. And sometimes there is a continuity of story and cast as in the live Goldbergs or the filmed Adventures of Eddie Drake. In any case, there is a need for some*thing* or some*one* which the audience can remember from week to week.

Now for the third point—technical excellence. Here again, it is thought that there is a difference in technical excellence for normal theatrical use and technical excellence for television use. One is not of lower quality than the other, they are merely different. Since 1939 N. W. Ayer has been using films in television—with varying degrees of success. At first the Company was forced by economies to cut up old prints and splice odds and ends together to tell a commercial story. This brought a number of horrible experiences, and many a conference was held with television engineers trying to find out what was wrong. The lesson was learned the hard way, simply because in those days there were somewhat less than five thousand sets in the whole United States, and no advertiser could afford to spend more than print costs to try this medium. The approach being made here today to the problems of lighting, sound recording, and printing for television films is one of the best things that can possibly be done for television. Without this sort of approach, films never will become as important a factor in television as they should. To be technically excellent a television film must be made for television in the first place. That means that the writer, director, cameraman, cutter, and laboratory technician must work to new standards, television standards.

Finally, there is the question of price. Two years ago with a brashness born of enthusiasm for the film medium in television, the author suggested in a forum meeting that films for television could be produced at a considerably lower price than most people thought possible. The basic idea was to recognize the limitations of television, the slower pace, the difference in lighting and finally to preplan films on a sort of assembly line. At that time, the suggestion was regarded, in certain quarters, as heresy and high treason. Today, it is being done.

The advertiser is vitally interested in price. He generally knows how much he can afford to spend to reach a thousand prospects, and he watches this cost per thousand with an eagle eye. In the author's opinion it will be found that it is going to be worth more to reach a thousand customers via television than it is to reach them by other media.

Someone is going to say "What is the right price?" And the only answer that can be given is an evasive one, "That depends!" It depends first of all on how much an advertiser can afford to spend to reach prospective customers. It depends on how widespread will be his use of the film. It depends on what television can do for his business. All of these variables must be taken into account by any good advertising man before he can say "This film is a good buy for Client A."

In the author's opinion the Lucky Strike series of films has all four requisites for good television film production—box office, continuity, technical television excellence, and a proper price.

The twenty-six stories which comprised this series were chosen from world-famous anthologies. They must be good box office, people must like them, because they have been selling well for years, read and reread by hundreds of thousands of people.

And here is continuity in the Bookshop Man, a warm and intimate person whom you grow to like after a while. Sure, he's a bit of a character but no doubt people like him just because he is a character.

Technical excellence for television? The author thinks so, although in the early films of the series there were troubles with halation and edge flare and too much contrast and bad lighting. But those things are being corrected.

And the price? It is as right as any television price can be today. With the show running each week in 29 markets and with its rating in the thirties, the cost per thousand is satisfactory.

Will Film Take over the Television Commercial?*

By JOSEPH A. MORAN

Young and Rubicam, New York 17, New York

People in the advertising business are convinced that the amount of film used for television commercials will be determined largely by the way film does its job. Any commercial is supposed to sell goods, and to sell goods over television, many of the same things are done that sell goods over the counter or from door to door or over a desk. As many contacts as possible are made with prospects. They must be interested in what a product can do for their welfare. Show them the product. Demonstrate the way it works. And if possible, try to make friends while doing this.

The interest in television at present is so great that probably it is easy to make contacts with prospects. But unless television commercials start with good showmanship, the very intensity of interest may work against them.

When the commercial flickers on, that CAN be the cue for Dad to tell Mother about the funny thing that happened to him on his way to the office—or ploughshed—today—or for sonny to sneak the dial over for a minute to see how Cassidy is hopping along—or even for someone to leave on an errand. So it helps if the television commercial flows smoothly into the program.

For instance, most people would agree that film gets a black mark when the quality does not even remotely resemble live camera pickup. That tips off the commercial and cuts down listening and viewing. Also, the quality is often worse, and something, maybe the film projector, sometimes causes electrical differences that seem to throw off the pattern on the viewer's set.

Of course, these technical matters, such as contrast and density, should be studied carefully by experts if advertisers will continue to use film commercials.

Skillful leads into a commercial and a good commercial itself are

* Presented April 4, 1949, at the SMPE Convention in New York.

very important, but they will not help if listeners *see* a commercial coming. One of the fascinating things about television, viewers say, is the idea that it is happening right before your eyes. Film that is obviously film may spoil that illusion.

If more and more film is to be used for television commercials, the first thing to concentrate on is technical quality, and this means not just film that looks well on a motion picture screen, but film that will look well on the customer's set. There is a big co-operative job to be done here between the advertising agency, the film experts, and the television engineers.

Now that contact has been made with a customer, he must be sold. Interest him in what is to be sold, then show it to him. Right here, says the advertising man, is why television was born, and why he is looking to film for the best pictures possible. To the advertiser, those three minutes of commercial are three golden minutes. They are the reason for the whole show, and the entire investment. So the product has to look just right, and again that means films that televise right.

After the product is shown, probably it is to be demonstrated. That is where film has certain advantages. The demonstration CAN go wrong if the commercial is live. And *has*. On one show, for a horrible example, the high-pressure hose did not squirt and it was only the foresight of a production man who had provided a bottle of seltzer water that saved everyone an embarrassing moment. Things have always gone wrong in radio, and television is no exception. But with film, the mistakes go on the cutting-room floor. This dependability of film will help make it popular for television commercials.

Before television, advertisers kept saying that radio was great, but that one thing it could not do was show the product. With television, the skeptics are asking if television can show the product as clearly and as beautifully as printed advertising.

There is no color, but probably everyone will agree that at times the best television reproduction is nearly equal to good magazines for tones. Advertisers will turn to film only if it gives them a picture every bit as good and better than the live pickup.

The author was asked about what the advertiser and his agency consider important in film commercials. Probably product plus people is one thing, good pictures of the product in action in relation to people, and the other is showmanship plus salesmanship, good staging plus good selling.

The author also was asked about the *length* of television-film commercials. The networks have established this rather closely. Spots, commercials made and run independently of sponsorship of a program, are usually fixed for television at twenty seconds for short spots, one minute for long spots. The twenty-second length is becoming more and more popular, probably because it can be put in between the important programs; and because its position can be guaranteed and not be pushed off when a sustaining show becomes a sponsored one.

On programs, the usual total time is three minutes for an evening half-hour show. Normally there are two main commercials of a little over a minute each and a short opening and closing. The openings usually will not run more than fifteen or twenty seconds because the opinion of most television men is that it is very important to get a show off to a fast start. The main commercials and the openings and closings together use up the total three minutes. Three minutes is about 10 per cent of the program time and, with slight differences, that proportion holds for almost all radio and television programming. Therefore it is important to make every second of commercial count.

There has been some discussion of using one long rather than two short commercials on television programs but the eventual outcome of this is unknown. In *radio,* the Nielsen charts show the way in which customers tune in and out of a program and prove that more people will be reached if the three minutes of commercial are broken into several units and distributed at different points throughout the program. Probably this will hold true for television, too, and the single long commercial will not be used very frequently by advertisers.

One question is about the re-use of film commercials, because film commercials are expensive to make, especially good ones. Some commercials, of course, can be used again and again in exactly the same way. Some never can be used again. Probably most advertisers would be satisfied to make but three commercials in the course of a year, and then repeat the group three or four times to cover their program period.

Anyone who wants to do a little mathematics can decide what this means in terms of film footage. At the present moment television stations in New York, which is the most highly developed area, are on the air an average of forty-seven hours per week. If this increases to something like twenty hours (1200 minutes) a day of operation, and if

5 per cent (60 minutes) of the twenty hours a day are represented by commercials on film, then in 365 days, at 90 feet per minute and divided by four to allow for repetition, 200 stations will use 98,550,000 feet of film. (The station count is low because it is assumed that many commercials will be transmitted by network.) At the present moment, New York stations are using an average of 26 per cent film, but this includes old film run as entertainment.

From the advertiser's standpoint, the physical characteristics of film commercials will become important. Safety film is a great convenience. Thirty-five-millimeter film shows some signs of becoming standard because of the extra quality it provides. At the present moment *screenings* for agency personnel and for clients are usually done by means of 16-mm prints which can be shown in any office. Perhaps this will continue to be easier than providing the more expensive 35-mm projection equipment.

Finally, whether it is on film or live, the television commercial is not just on the screen, it is also on the spot. New research measurements are already being developed to tell whether the commercial is doing this job. These are the like and dislike charts made by groups of people holding little electric switches that show how they react to every single minute of a program, including the commercials.

There are tests for remembering, and for the extent to which television viewers have a better notion of products advertised to them. There are methods available for making direct checks in the homes of listeners and measuring the ultimate effectiveness of the commercial. This means there must be a whole new technique for film commercials, and that television technique undoubtedly will need the services of dozens of specialists just as specialists are needed to get the best quality in magazine reproduction. Television is a new field, but it comes into action against highly developed competition, and that means there must be top results right away. There is apparently not going to be in television a long period of infancy such as there was in radio. We all must work together to make film commercials technically and creatively the equal of any other type of advertising.

It is certain that the same kind of ingenuity, inventiveness, research, experience, and judgment which made radio commercials so effective so quickly, will make them even more effective in television, even more quickly.

Note: After the delivery of the papers on the Television Forum, Moderator Hyndman called for discussion. As this issue of the Journal goes to press, the paper by Richard Blount, "Studio Lighting for Television," and that by Edmund A. Bertram, "Motion Picture Laboratory Practice for Television," are not yet available, but it is expected that they will be published in later issues.

Discussion

Mr. Rockmore: Mr. Gudebrod mentioned the amount which the advertiser can afford to pay. Should not the comparative effectiveness of television versus other media be considered in considering price?

Mr. G. D. Gudebrod: I think I indicated we suspect from an advertising standpoint that it is going to be worth more to reach any given thousand people in television than by any other medium. Currently, however, I do not believe there is enough qualitative information of that kind to say what that factor is, whether it is $1^1/_2 \times$ or $2 \times$ or $3 \times$. As the medium grows up a little, I think we shall have more concrete figures so we can say instead of, as an advertiser will say, $6.00 a thousand, maybe we shall say he should pay $10.00 a thousand. As yet we have not gone far along the road.

Dr. Alfred N. Goldsmith: We have some data on sponsor identification and product identification ratios as compared, for example, to those for standard radio, and the like, and we are beginning to get adequate data. And they do indicate a distinct superiority in impact value of television.

Mr. E. F. Zatorsky: This is directed specifically to the Technical Committee. When are they going to set up specifications on the television apertures and the like so we shall not be penalized the same as we are in standard motion picture aperture so far as the microphone goes, in order to make motion pictures cheaper for television, which would be the answer to Mr. Gudebrod's specification.

Moderator D. E. Hyndman: Unfortunately, there is no direct answer at present but work on standards is in process.

Mr. Zatorsky: Do you not think the Technical Committee ought to set up a recommendation?

Moderator Hyndman: It has been discussed, and I believe that would be in the hands of the Committee on Television. John Maurer, Engineering Vice-President, is here; perhaps he will choose to answer.

Mr. John A. Maurer: I should like to point out that in the booklet on films for television which was issued a short time ago by our Television Committee, and which has by now been rather widely circulated, there is specific mention made of the ratio of the motion picture frame that is to be expected to be utilized by the television picture. At the moment, I do not remember just what the figure is, but it is in there in quite a specific form. It has not as yet received the sanction of a standard, but doubtless it will work that way in the future.

I should like to add a couple of footnotes to some of what Dr. Goldsmith said and likewise to Mr. Hyndman's remarks with reference to the projection here.

Dr. Goldsmith made the comment that as television improves, and when a wider frequency range may be transmitted to the television tube that is being photographed for transcription purposes, the time might arise when it would be desirable to go to 35-mm film for the negative, at least in order to get better definition. The footnote I should like to add is that at the present time in practice the lenses that are being used for this type of work by no means exhaust the resolution capabilities of the 16-mm film that is being used, and there are lenses available commercially at the present time from several manufacturers which would permit coming very much closer to the limits of the resolution. That they are not placed in service, I presume, is just one of the inevitable examples of technological lag that occur when many people are busy doing a job and do not have too much time to spend thinking about improving their apparatus.

With reference to projection lenses, a similar situation exists, on what I believe to be reliable information, that in the majority of projectors which are used to throw the image on the film into the kinescope for broadcasting, the lens is the same lens that normally is supplied in the amateur trade, which is far from exhausting the detail possibilities of the picture, and here I will be specific. Lenses which will do that job are commercially available from at least two reputable manufacturers, Bausch and Lomb and Kollmorgen, and the fact that they are not put into use for the projectors in the television stations is one of those things that requires a little explanation.

Likewise, with respect to our projection here, I think that it is unfortunate we cannot have a lens of that type on the projector used for the Society; however, I should like to make this comment about the film that we saw. From long experience of the idiosyncrasies of 16-mm films, it looked pretty obvious to me that the titles which were spliced into that reel were not on the same stock as the individual scenes, and the curl of the film in the gate was not the same; also that the projectionist was focusing on the title, and the picture was actually out of focus. It certainly was not doing justice to what was on the film.

MR. W. H. OFFENHAUSER: Recently we have seen some advertising of some of the newer receivers. The little Hallicrafter 7-inch tube receiver that has a tricky type of masking on it is one. I do not know what the rest of it may be, except I would rather expect it would limit the picture area to something like 40 or 50 per cent of the normal standard area. Has there been any trend as far as television receiver production is concerned, to guide that or limit it to meet the suggestions that have been placed in the SMPE booklet?

DR. DEANE R. WHITE: It is on the agenda for our committee during the meeting. The question whether we should take it up has been subjected to some discussion by the officers of the Society, because it was not at all certain it was an engineering problem as much as it was a commercial problem. I do not know what action the Television Committee will take because it is fairly obvious if you are going to use them on television and throw them away on peculiar masking and receivers, things will not fit, but there are certain commercial aspects of the problem entirely separate from the engineering. I would not attempt to predict how they would fit into the picture. We can certainly enter into the engineering aspect and find out what is wrong and find out what has occurred and whether or not we can change them or exchange them.

MR. PAUL J. LARSEN: I agree with Dr. White to a degree but not completely. I believe that it is an engineering organization's responsibility to at least establish standards by which the industry can be guided. As an example, when the 16-mm film is in question, we should establish an aperture size that should be adopted by the broadcasters, and likewise establish a standard as to what the aspect ratio of the picture should be. If someone wishes to change that, then he is not abiding by standards adopted.

MR. R. M. MORRIS: I should just like to throw in for consideration the fact that the same problem of aspect ratio exists with respect to our nonrecorded presentations in broadcasting just as much as it appears in the matter of the presentation of recorded picture transmission. The aspect ratio of 4×3 is set by the Federal Communications Commission regulations at the present time, and unless it is approached from that standpoint, I do not know that it is a matter especially for an SMPE or any other engineering society standardization. It has been considered by the Commission, and unless there is good reason to change, I suspect that that is one of the things that we can consider fairly well established.

The matter of masking shape, I think we all considered was more or less well established until two or three manufacturers, apparently for commercial reasons, chose to try to make the receiving tube more efficient in its utilization of area rather than making the system efficient from the utilization of bandwidth, and I think it is obviously something which some organization is going to have to make recommendations on to the end that there be a standard receiving picture mask established. It is a thing in which the broadcasters, of course, are as much interested as anyone else.

MR. EDWARD P. SUTHERLAND: I have seen many motion pictures via television, and it was only recently that I noticed the Lucky Strike series. It is my personal opinion that the picture and sound quality are about the best, and I was wondering if Mr. Gudebrod or anyone else here could tell me first of all whether it is a projection print of 35-mm or 16-mm and also what the gamma is.

MR. GUDEBROD: I am not enough of an engineer to tell you what the gamma is. The network is fed by 35-mm print, 16-mm prints being made available for all nonconnected stations.

We have had as I indicated, some considerable argument about the contrast range or gamma of the prints which we are using. We have finally prevailed upon the producer and some of the engineers on the West Coast to reduce the contrast more in keeping with what we think, by rule of thumb, is right for television transmission. About the first six or eight films of the series were pretty harsh. We got edge flare. We got halation. We had troubles with it. The later ones in the series we think we got pretty well corrected. We have seen them on closed circuit, but that, of course, is an ideal situation. It varies considerably when you get it actually on the air.

DR. NORWOOD L. SIMMONS, JR.: I should like to add to Mr. Gudebrod's answer regarding the series of productions which were made by Grant-Realm Productions for the Lucky Strike show. These pictures were produced in Hollywood and the 35-mm negatives were developed to a gamma value of 0.65 to 0.70. The 35-mm prints were made on regular release positive film, developed to a gamma of about 2.40, until recently. Then an experimental print was made on fine-grain master positive film, developed to a gamma of about 1.40. The printing density used for the low-contrast master positives is light, not as would be used for ordinary motion picture duplicates, but rather in the nature of those shown by Mr. Bertram.

Mr. Moderator, I should like to ask Mr. Blount if the visual luminosity curve he showed was based on equal energies or on tungsten at 3000 degrees Kelvin.

MR. RICHARD BLOUNT: Equal energies.

DR. SIMMONS: Is it not then true that the visual-luminosity curve, in order to be fairly compared with the product curve of the tube sensitivity multiplied by the light-source-output curve, should also be multiplied by the relative output curve for the particular light source being considered?

MR. BLOUNT: In both cases, to be highly accurate we should have used fluorescent lamp or the 3000. I do not feel that for the basis of this presentation that degree of accuracy is warranted.

MODERATOR HYNDMAN: Dr. Simmons, do you not think that there has been confusion here this afternoon, with some in the television industry and some in the motion picture industry continually talking about controlling contrasts by controlling gamma, when we think of gamma as applying to a development factor only? Literally the problem is, in the majority of motion picture films produced, there is a brightness latitude greater than the television system or chain is capable of accommodating. For illustration, a latitude brightness range of 1 to 40 in a motion picture film may be common, and the television system has about 1 to 20, then television-image distortion of tone occurs regardless of gamma or density.

DR. SIMMONS: I quite agree with you. I was extremely interested in Mr. Bertram's samples and should like to congratulate him on an excellent set of tests and to tell him that had we had such a set of tests in Hollywood at any time in the last six months, it would have straightened out a great many people. I am thinking of the nontechnical people involved in making these films for television, and we have tried to straighten them out without the aid of such tests. This was a very illuminating test to me.

I think it is important, though, to point out that, at least as I saw it, the 1.70-5302 print appeared less "contrasty" on the screen than the 1.25 fine-grain master positive which is because we are dealing with toe portions of the characteristic curve. If we consider that the fine-grain master positive has a steeper and shorter toe than regular release positive film, then, in consequence, the true contrast of the screen image is not in proportion to the gamma values as read.

Therefore, it behooves us to consider the curve shape. I may be deviating somewhat from your question, but I did want to mention that in Hollywood the National Broadcasting Company and others have given thought to that matter of curve shape. That is cutting it rather fine possibly, but since there is less toe on the fine-grain film, therefore, we have more high-light contrast relative to middle tone and high-density contrast. Some people think that helps. Personally, I do not think the art or science of television has advanced far enough to allow us to see any difference yet, and I agree with you, Mr. Hyndman, in saying that at the present time the contrast of the print provided is of secondary importance.

MR. EDMUND A. BERTRAM: To answer Dr. Simmons' question or agreeing with him, it is too bad I do not have time to make a slide of the curve characteristics, but I do have all the characteristic curves of the particular films shown in the 35-mm form. The print at gamma 1.70 is made on a high-contrast film, and printed on 5302, developed in negative developer in which we tried to develop a shadow density well up on the curve to produce transparencies in the black and at the same time bring up the toe.

Progress Report—Theater Television*

By BARTON KREUZER

RCA Victor Division, Camden, New Jersey

Summary—In connection with a theater television demonstration of an instantaneous theater television projection system, a chronological record of the early development and current progress of theater television is presented. References are made to both instantaneous projection and the kinescope-photography methods. The demonstration consisted of the projection by theater television of lantern slides for the paper, live action, and film reproduction fed from the anteroom of the auditorium together with broadcast television programs received by radio transmission and telephone circuits from a near-by television station.

It has been the practice of the Radio Corporation of America to report at intervals on the continuing developments in theater television. These reports have taken the form of various technical papers[1–4] of the Society of Motion Picture Engineers, some accompanied by demonstrations, discussions, and demonstration before the last two annual conventions[5,6] of the Theater Equipment Supply Manufacturers Association, a talk at the *Televisor* Magazine's Television Institute[7] in April, 1948, and a very complete demonstration and explanation by Warner Brothers and RCA engineers at the joint meeting of the SMPE and the National Association of Broadcasters held in the Warner Brothers Studio in May, 1948. This report and exhibit of operating theater television equipment is another progress report in this series.

The foundation for this work by RCA goes back a long time, as age goes in this new art of television. The first work, started in 1928, culminated in a demonstration in January, 1930, in the RKO-58th Street Theater in New York City. The system provided a 60-line picture with reasonable brightness on an approximately $7\frac{1}{2}$- × 10-foot screen, using a rotating-lens disk, Kerr cell, carbon-arc method. The need for further work was indicated, about ten years' more!

This led to the famous 1940 demonstration which some members of the SMPE witnessed at the New Yorker Theater in New York. (See Fig. 1.) Here a 441-line picture was shown with low brightness.

* Presented April 4, 1949, at the SMPE Convention in New York.

on a 15- × 20-foot screen using Schmidt-type reflective optics. Further development was interrupted by the war.

Following the war, the RCA Laboratories reconditioned this same system, introduced an improved kinescope, revised circuits to operate on the new 525-line standard, and used the equipment in the summer of 1946 to show the Louis-Conn fight to an estimated audience of 3000 on the lawn of the Laboratories in Princeton.

Fig. 1—Equipment used in New Yorker Theater Demonstration, 1940, 15- × 20-foot picture.

1947 provided a $7\frac{1}{2}$- × 10-foot television picture demonstration both at the TESMA Convention in Washington, D. C., and at the SMPE Convention in New York using equipment previously described.[1-4]

In 1948, the demonstrations increased in picture size to 15 × 20 feet. Demonstrations were made by Warner Brothers in Hollywood[8] for the SMPE-NAB meeting with equipment described in the same papers,[1-4] and by Twentieth Century-Fox at the Fox Theater in Philadelphia on the occasion of the Louis-Walcott fight.[9] The equipment, stripped of its base, was mounted on the front of the balcony. The audience who paid admission that night saw the first program to be carried from one city to another on a microwave relay system especially for showing in a regular motion picture theater.

These two demonstrations were both made with reflective optics

Fig. 2—Projector with 20-inch mirror and 21-inch plastic lens, demonstrated in 1948 at TESMA Convention, St. Louis.

systems employing 42-inch spherical mirrors, because of their size dubbed "Behemoth—Mark I."

In September, 1948, the RCA demonstration of a 15- × 20-foot television picture, exhibited to approximately 1200 persons at the TESMA Convention in St. Louis, used a smaller equipment with comparable results (Fig. 2). The optics had now been reduced from the

500-pound, 42-inch mirror, and its 21-inch glass lens, each of which had required months of grinding, to a 20-inch mirror and a $15^1/_2$-inch plastic molded lens weighing only 50 pounds!

This equipment, although smaller than previous equipments projecting the same size picture, was nevertheless relatively bulky as it contained power supply and video amplifiers in the base of the unit. Subsequent developments, in addition to improving performance, have made it possible to separate the optical barrel from the balance

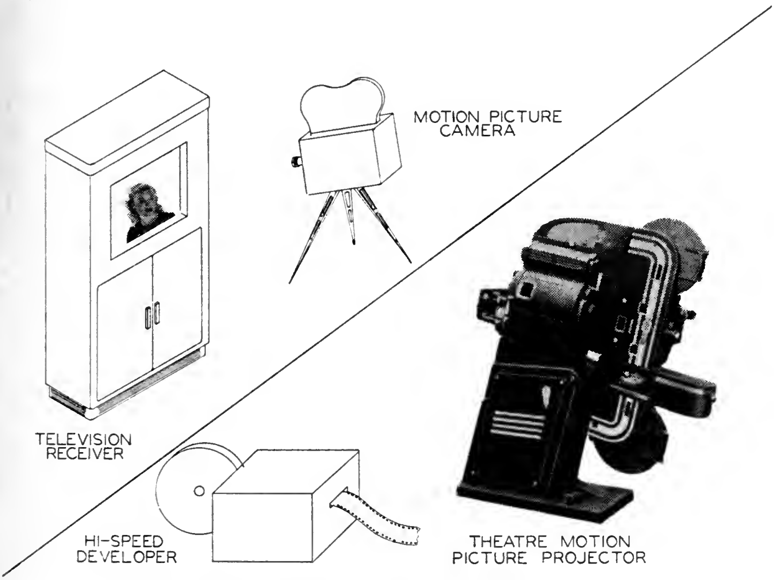

Fig. 3—Schematic of kinescope-photography system.

of the equipment. Hence, the smaller barrel (30 inches in diameter and 36 inches long) is now the only element of equipment required in the theater auditorium. It may be mounted from 40 to 65 feet from the screen by using appropriate projection lenses, at which distances it will project a 15- × 20-foot picture. This particular demonstration is limited to 11 × 15 feet by the room dimensions.

While this development has been taking place the parallel field of broadcast television has also developed. Some impression of its rapid progress can be drawn from Table I, particularly when it is remembered that the average television receiver frequently has more than one viewer; literally, an audience running into the millions!

TABLE I

	Cities	Stations	Sets
Eastern network	8	21	730,800
Midwest network	8	14	200,600
Non-network	16	20	152,700
	32	55	1,084,100
Stations not operating	5	2*	95,900
	37	57	1,180,000

* Now testing; start regular operations in March. 2-26-49

The discussion thus far has related solely to the instantaneous type of television projector. An alternate type of some merit has also appeared on the scene, the kinescope-photography system, also called the "film-storage" method, or the "intermediate-film" system. In

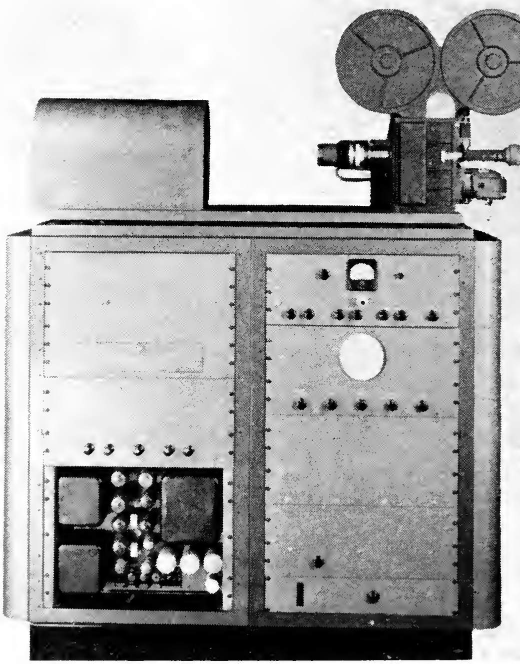

Fig. 4—Kinescope-photography system as supplied to Twentieth Century-Fox and Warner Brothers.

this method, a kinescope television picture is photographed on motion picture film, rapidly developed, and, if desired, fed continuously into a regular motion picture projector. Diagrammatically, this system functions as shown in Fig. 3. Systems of this type, shown in Fig. 4, have been supplied to Twentieth Century-Fox and Warner Brothers for evaluation of this method. A number of such systems have been sold to television broadcasters, not for theater projection use but for

Fig. 5—TLS-86 projector for use in theater lobbies and lounges, approximately 7- × 9-foot picture.

"storage" of television programs for later repetition or for syndication purposes over other television broadcast stations. These kinescope-photography systems are in daily use; very likely many members have witnessed film from them on television programs. At the NAB Convention early in April, 1949, in Chicago, just such a system adapted for broadcast use was demonstrated.

Theater television programming appears to fall into two broad classes: (1) Use of regular television broadcast material; and (2) so-called "closed-circuit" performances in which a privately originated program is fed to one or more theaters.

In the second case, some examples of originating sources might be: (A) *live action* in a studio, from the stage of a theater, or from some public gathering such as a sports arena or a political event; and (B) *motion picture film*, either produced in more or less regular fashion, or by kinescope photography to "store" some program such as those described above.

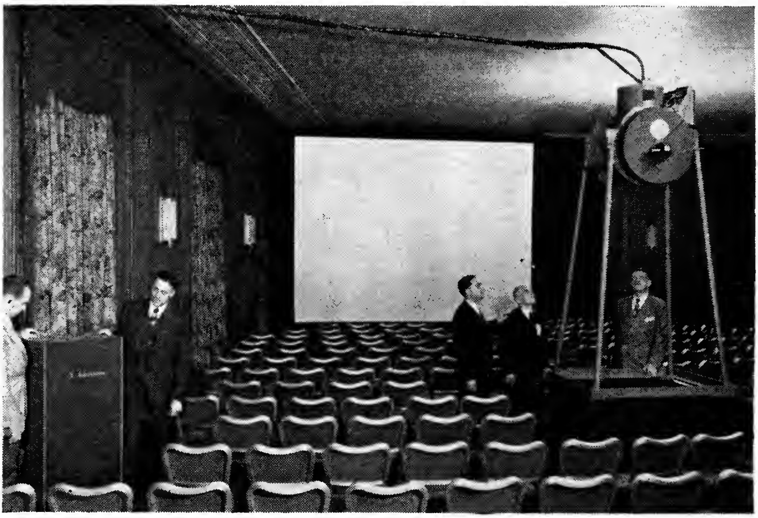

Fig. 6—Theater television protector optical barrel mounted near ceiling with amplifier system in left foreground. Demonstrated at SMPE Convention, Hotel Statler, New York, April, 1949.

In any case, program transmission might be by microwave relay, equalized telephone lines, or by coaxial cable, or some combination of these as adequately covered by our own SMPE bulletin on Theater Television.[10]

In the theater, such programs can be projected in lounges and small auditoriums by commercial equipments such as the RCA TLS-86, shown in Fig. 5. For regular theater auditoriums, professional equipment will also be available in the near future. RCA expects to be in a position to manufacture theater television equipment, based upon the prototype system demonstrated at this time, in pilot-run quantities possibly by the end of 1949. It is expected that the price for a single unit without stand-by facilities would be less than $25,000.

ACKNOWLEDGMENT

Thanks and grateful acknowledgment are due many for the work leading up to the demonstration which was presented as part of the paper, and for the demonstration itself. Among these are Messrs. E. I. Sponable and H. J. Schlafly of Twentieth Century-Fox, Colonel

Fig. 7—Equipment used in the demonstration at the Hotel Statler ballroom with an actual television picture on the screen. The picture originated in an anteroom of the ballroom and was fed to the television projector by direct cable connection.

Nathan Levinson and Dr. B. R. Miller of Warner Brothers, Mr. R. D. Kell of RCA Laboratories, Messrs. J. E. Volkmann, R. V. Little, F. G. Albin, R. C. Wilcox, L. L. Evans, and K. E. Palm of the RCA Victor Division of RCA, and Mr. Cy Keen of the RCA Service Company.

NOTE: The demonstration (Figs. 6 and 7) included viewing of the lantern slides used by theater television. This was followed by instantaneous theater television of program material including both live action and regular motion pictures. Some of the live action was regular program material from NBC television station WNBT of the National Broadcasting Company, and the balance was picked up by a television camera in the anteroom. The broadcast material was received both through the air by radio transmission and by means of an equalized telephone line. The latter is of particular interest since it demonstrates one means of intracity transmission, one which does not require licenses from the Federal Communications Commission. The motion pictures were scanned on equipment also located in the anteroom. Both the screen and the film used were supplied through the co-operation of Twentieth Century-Fox. The screen was directional, of the embossed type, with a brightness gain in excess of 2.0 over that using a matte surface.

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DISCUSSION

QUESTION: How does the screen brightness here compare with the standard set by the Society of Motion Picture Engineers?

MR. BARTON KREUZER: Though it is materially improved since the last demonstration, it is still below par. It is at the level of brightness which, unfortunately, you still find in many motion picture theaters.

MR. H. EMERSON YORKE: May I ask when we may reasonably expect large-screen television in the theaters?

MR. KREUZER: Some time toward the very end of this year or early next year.

Television Pickup for Transparencies*

By ROGER D. THOMPSON

Allen B. DuMont Laboratories, Passaic, New Jersey

Summary—**Scanning an opaque subject or photographic transparency with a moving spot of light found application in the early days of television. A modern version, using a short-persistence cathode-ray tube as the light source, can produce television pictures of excellent quality. Equipment restricted to pickup of transparencies can be of simple and reliable design. A motor-driven slide-changing mechanism accommodating as many as twenty-five 2- by 2-inch glass slides is described. Esthetic transitions possible include automatic picture fading preceding and following the slide change as well as unblanked changes to give the effect of instantaneous change-over. Artistic effects, particularly adapted to the flying-spot device, extend its flexibility.**

Since the earliest attempts to transmit pictorial information between remote points by electrical means, scanning subject material with a small spot of light and projecting the transmitted or reflected light upon the cathode of a phototube has received attention.[1] The first television systems employing this principle utilized mechanical methods of scanning. With the advent in 1934 of electronic means for producing television pictures, the flying-spot method became less popular than the use of the image dissector, the iconoscope, and later the orthicon and image orthicon. The competitive position of the older scheme has been favored, however, by the recent development of cathode-ray tubes having very short-persistence screens. When an electron-multiplier-type phototube is utilized for translation, a simple pickup device is possible.[2]

Achieving a pleasing picture by the flying-spot principle in a direct pickup of live talent seems difficult when compared to present camera practice. The use of photographic transparencies is more convenient because the problems of depth of field and intensity of light are greatly simplified.

A practical adaptation suitable for televising 2- by 2-inch glass slides is outlined in Fig. 1. A television raster is formed on the face of the 10-inch cathode-ray tube, which is magnetically focused and

* Presented April 5, 1949, at the SMPE Convention in New York.

deflected. An amplifier is provided for blanking retrace lines to produce black reference. Light from the raster is focused by an $f/1.9$, 50-mm lens upon a slide and the transmitted light is projected upon the cathode of the phototube by a condenser lens composed of two plano-convex lenses $2^1/_2$ inches in diameter and having focal lengths of $3^1/_2$ inches. The resulting electron displacement from the cathode surface is multiplied by dynode stages of the phototube about 40,000

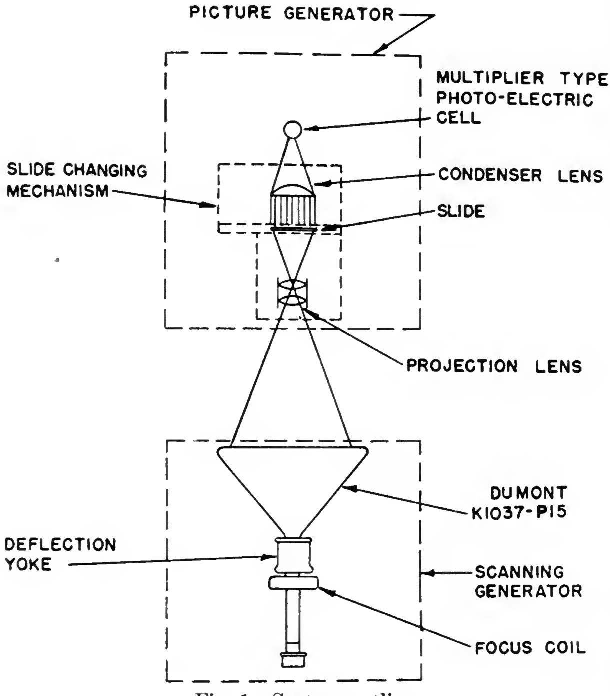

Fig. 1—System outline.

times to produce a signal of 0.2 volt which is applied to the multistage amplifier shown in Fig. 2.

Because of the persistence of the screen of the cathode-ray tube, the scanning spot would have a cometlike appearance if it could be viewed while in motion. About 0.8 microsecond is required to excite the phosphor to 70 per cent of its maximum intensity, and 1.2 microseconds is required for decay to 30 per cent after the electron beam is cut off. Fortunately, both of these effects can be corrected by the use of two simple networks, one located in the anode circuit of the phototube, the other in the plate circuit of one of the amplifier stages. An inverter accommodates the use of either a positive or a negative slide by reversing the polarity of the video signal.

A gamma corrector in the form of a remote-cutoff pentode amplifier operated with large signal input to cause nonlinearity provides increased amplification of gray steps near black compared to those near white. This transfer characteristic compensates for distortion introduced by reproducing monitors and receivers.

To permit adjustment of picture black relative to blanking level in the output signal, blanking is emphasized by an inserter stage and then clipped at the desired level by a series diode arrangement. A

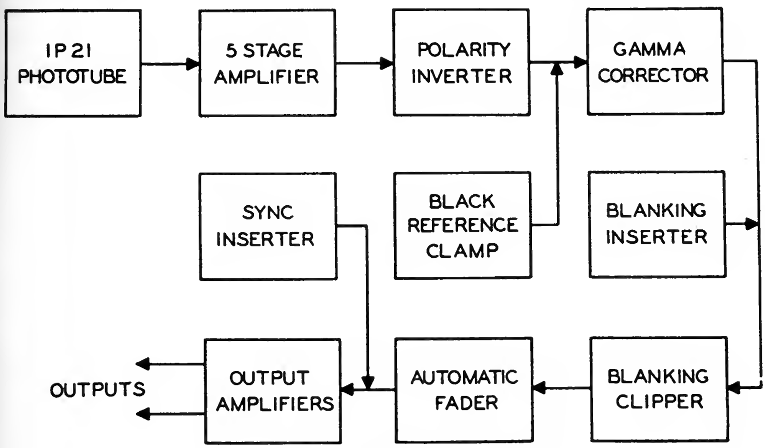

Fig. 2—Block diagram of video circuits.

clamp on the grid of the gamma corrector sets its proper operating point and maintains the blanking level after clipping independent of picture content.

Standard synchronizing signals specified by the Radio Manufacturers Association may be added by an inserter stage.

The versatility of a scanner for program service can be extended by the use of the remotely controlled slide changer shown in the photographs of Figs. 3 and 4. A capacitor-type motor is geared through a worm reduction to a disk on which a connecting rod is pivoted near the rim. A flat plate with a thickness approximately that of a 2- by 2-inch glass slide is driven by the connecting rod in a reciprocating motion. A slide is positioned between the objective and condenser lenses on the forward stroke of the plunger and the next slide to be used drops into place at the end of the retracting stroke. Thus the slides are gravity-fed from the hopper on the left to the slide track, are positioned by the plunger, and finally are pushed by the next

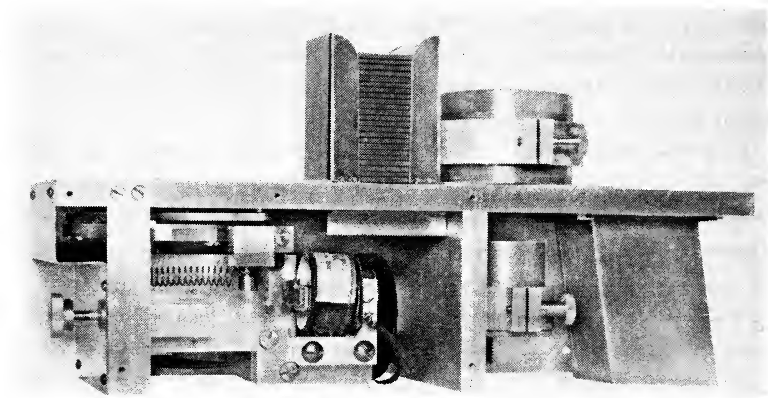

Fig. 3—Exposed view of slide changer.

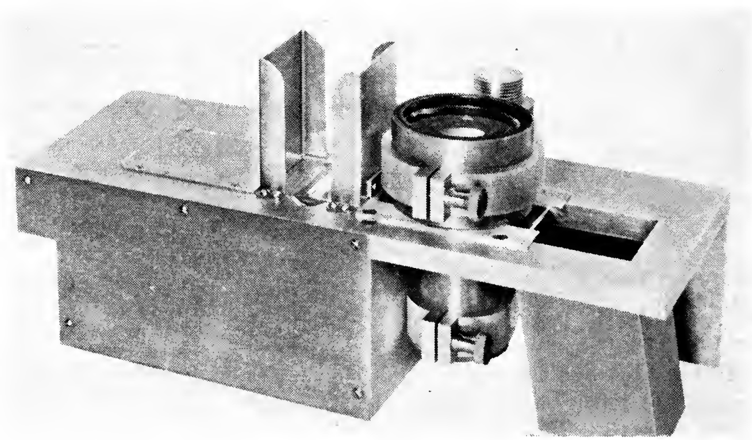

Fig. 4—Slide changer with cover.

slide into a receiving hopper. The unit shown uses a 3000-revolution-per-minute motor, has a 16-to-1 reduction system, and completes a slide-change cycle in about 0.4 second. The motor picks up speed rapidly, and since the beginning of the cycle is chosen well ahead of the forward stroke of the plunger, it is operating at full speed during the time each slide is positioned. The actual change-over time then is less than 0.2 second, and the effect of an instantaneous change-over is imparted to a casual viewer. The friction of springs contacting the slide being positioned dissipates the momentum imparted to the slide. Coasting is further minimized by the sine motion of the plunger, which decelerates to zero velocity at the end of the stroke; and indexing of the slide is controlled entirely by the dimensions of the linkages. A mechanical brake held in contact with a cam raised on the rim of the crank disk by spring tension prevents excessive coasting of the mechanism after the motor is de-energized. The brake is released by a solenoid which is wired in parallel with the motor for simultaneous operation. A limit switch depressed by cam action at the end of the forward stroke completes the cycle.

To supplement the instantaneous change-over, an automatic control circuit has been developed to fade the output video signal of the scanner to black, whereupon a slide change is made and a fade-in of the next slide follows. Either of two rates of fading can be selected, and the switch accomplishing the selection, the switch initiating the cycle, and all other operating controls can be remotely located.

An attribute of the flying-spot device is the possibility of attaining good geometrical linearity; as little displacement of a point from its true position on the raster as 1 per cent of the picture height is possible with production units. The evenness of illumination is good. Shading is almost entirely due to the optical system and is not objectionable even when using a negative slide, in which case the gamma corrector exaggerates intensity variations. Resolution of 500 lines in the horizontal direction, measured by RMA methods, is readily attained. Vertical resolution is limited to about 450 lines by the number of active scanning lines in the raster.

The use of color slides for reproduction in black and white is entirely feasible and preliminary tests do not reveal adverse effects despite the fact that the cathode-ray-tube output and the phototube sensitivity are largely confined to the green portion of the spectrum. Because of the density of color slides, the signal-to-noise ratio is inferior to that obtained by the use of good black-and-white slides.

Since the raster is sharply focused in the plane of the cathode-ray-tube screen, transparencies may be placed on the face of the tube with only slight defocusing resulting from the thickness of the glass. In this way, two transparencies may be superimposed. An effective device utilized by WABD, New York, is that of a special clock made of transparent parts placed upon the face of the tube. Another innovation is the use of a pointer on the face of the tube to attract attention to particular portions of the picture.

There is evidence that cathode-ray-tube scanners will find acceptance for many applications where simplified sources of test and program material are desired.

Acknowledgment

Acknowledgment is due the Research Division of the Allen B. DuMont Laboratories for development of the cathode-ray tube, to Mr. A. J. Baracket for supervision of initial circuit development, and to Mr. A. L. Olson for slide-changer and scanning-generator design.

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FORTY-ONE YEARS AGO

Atlantic City.—Managers of local playhouses will be asked to have a hymn sung at each Sunday performance as a compromise with members of the local W.C.T.U., which threatened to close the moving picture shows given Sunday evenings.

A special committee of women that visited the shows brought back a report that it had discovered nothing objectionable in the performances, but recommended that hymns take the place of "illustrated songs," with the audience taking part.

—The Moving Picture World, January 25, 1908

Saloon Men Fight Shows

Tamaqua, Pa. April 27.—The saloon proprietors are now agitating against the moving picture shows. These attractions, the saloon men say, are taking the crowds from their places of business.

Throughout this section there is not a town having a population of over 3000 that does not boast of at least two of these shows, while some have as high as four, this town being one of the latter class. All these shows are well patronized. Men and boys who would otherwise frequent the saloons go there, making the rounds of the shows each evening.

The saloons in some of the towns are endeavoring to have the shows taxed in the same manner as circuses and opera houses.

—Moving Picture World, May 9, 1908

Use of 35-Mm Ansco Color Film for 16-Mm Color Release Prints*

By REID H. RAY

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Summary—In commercial motion picture production, there is often a need for both 35-mm and 16-mm color prints. In this field color serves the purpose of product identification, and therefore a three-color system is required. In the specific work described here, locations were widespread and demanded specific dates for shooting. Therefore, several cameramen had to cover location assignments almost simultaneously and available 35-mm professional photographic equipment had to be used. How both 35-mm and 16-mm color release prints were quickly processed from one three-color original is described.

The history of color in motion pictures, at least up to 1949, can be summarized in these 13 words: Kinemacolor, Prismacolor, Agfa color, Dufay color, Gaumont color, Technicolor, Cinecolor, Multicolor, Gasparcolor, Magnacolor, Kodacolor, Kodachrome, and Ansco color.† Perhaps this list may slight some color process, but in the main, these names embrace color motion picture history.

Those of us who have been associated with the production of motion pictures for the past 25 years have continually had the "color problem" confronting us. Since 1938, when sound Kodachrome duplicates were announced, the industrial producer has really become color conscious because black-and-white picture production gave way to a large percentage of color production, even faster than the producer actually preferred. Color plays a more important role in business films than in the theatrical film. The client who pays the bill wants the color of his product in motion pictures to be as nearly like

* Presented February 17, 1949, at the Central Section Meeting, Chicago.

† It is interesting to note that the first Ansco color 35-mm release won an Academy Award. It was a 2-reel short released through Monogram titled, "Climbing the Matterhorn" and was shot in 1946 by Irving Allen, while producing a feature picture in Switzerland. In 1947, "16 Fathoms Deep" was made in Florida, a 9-reel feature in Ansco color, also released by Monogram. A third film, "Alice in Wonderland," has just been completed and will be released in 1949, through the J. Arthur Rank Organization. In 1948, A & T Productions produced in Paris, France, the picture, "The Man on the Eiffel Tower."

the actual product in real life as possible. While in a theatrical release, if the color of the dress of the heroine is a shade or two different from the original, the color director may object but usually the "front office" will remark, "What matters—it is still 'color by Technicolor.'"

When a color production is ordered and only 16-mm prints are required, the print job is comparatively simple. Shoot 16-mm commercial Kodachrome, make 16-mm contact duplicates, and you have your best possible release prints. However, when the client asks for 35-mm *and* 16-mm prints in three-color, there has been actually only one process the industrial producer had to turn to, Technicolor. Technicolor production, as everyone knows, is not geared especially to industrial production budgets; besides, very often, industrial location work is complex and camera equipment must be as mobile as possible with minimum crews for extensive traveling. This paper does not purport that Technicolor does not meet the requirements, but that Technicolor is not an economical color process for certain types of industrial color production which this paper presents.

Of course, two cameras, one 16- and one 35-mm, might be used simultaneously on all shots, but this calls for an extra crew, extra equipment, extra film cost, lighting problems, and double editing, conforming, and handling all through the production. The purpose of this paper is to present a method one production company used to solve the request for 35- and 16-mm color release prints and to do it in an economical manner.

The basic 35-mm color film used was Ansco color camera film, Type 735, which is an integral subtractive color film of the reversible type. Introduced in 1946, this camera film is balanced for exposure by daylight and the best color rendition on exteriors is obtained in bright sunlight.[1] For interior work, high-intensity arc lamps with Y-1 filters are recommended for key-lighting with the fill light supplied by white-flame arc broads, such as Duarcs, or "CP" lamps filtered with MacBeth Whiterlite filters.

In our studio we have obtained good results with incandescent lighting equipment, using CP lamps with MacBeth Whiterlite filters, although extremely high total wattage must be used as an exposure level of 1000 foot-candles at $f/2$ with color temperature of 5400 degrees Kelvin is required. That is better understood when one knows that the film speed is rated thus: ASA Exposure Index 6; Weston, 5; and General Electric, 8. Ansco UV-15 or UV-16 filter or the Wratten 114A filter is recommended for all exteriors and interiors.[1]

Ansco color camera film, Type 735, may be used in regular 35-mm professional cameras without any conversion and, therefore, Bell and Howells, Mitchells, or even Eyemos are satisfactory for production work. That fact was very important in the requirement of the industrial production job to be described. There were assignments to be met within three months' time, scattered from California through Colorado, Texas, Kentucky, Mississippi, Illinois, Iowa, Minnesota, North Dakota, and Oregon; and half a dozen cameramen, with a wide variety of equipment, had to be assigned to shoot the color footage under a great variety of field conditions. These varied from flying over the great wheat fields of the Pacific Northwest with an Eyemo in order to climb the steep hillsides to film the harvest; to standing in almost knee-deep water in the rice fields of Mississippi, no place for heavy cumbersome color cameras, and the Eyemos and lighter Bell and Howells came in handy and turned in creditable color photography. In some locations cameras had to be secured on top of moving machines, and one Mitchell was even tied down inside the grain tank atop a huge combine moving over rough ground.

No photography was planned before 10:00 o'clock in the morning, and seldom after 4:30 in the afternoon, and bright sunlight was a prerequisite. As a result, a fairly evenly exposed original camera film was obtained. Approximately 15,000 feet were shot during those three months. It is recommended that one single-emulsion number be used on each production as there is, as in all color processes, some color-balance change in succeeding emulsion runs. It was also found that pleasing effects and good definition in dark areas were obtained with cross, and even partial, backlighting. Naturally extra caution was taken in exposure reading and our camera crews carefully considered the subject before deciding on a lens stop.

After the original camera film was exposed, it was shipped to the Houston Color Laboratories in West Los Angeles for developing and printing a "daily." During the past 10 months this laboratory has been processing approximately a half-million feet per month of Ansco color film, and is equipped to turn out a daily print within 48 hours. The processing of Type 735 camera film is almost identical to a description by Forrest,[2] except for a somewhat shorter developing time in both the first developer and the color developer.

In making a daily print from the original camera film, each scene is not timed for density and color balance, but an over-all average printer exposure and an average filter balance are determined and the daily is printed. The printing stock is Ansco color release film, Type 732, also a reversible-type film of relatively low speed, very fine grain, and special sensitization for printing.[3]

When the daily print is received, it is edited as in black-and-white production, and the track is recorded. This step is followed by re-recording sound effects and musical background. At this point a word should be given about the type of track best suited for Ansco release printing. Excellent results with no loss in reproduction volume have been obtained using the direct-positive method of final recording. A studio recorder, Radio Corporation of America PR 23, was converted to handle either negative or direct-positive recording. Otherwise in negative sound recording, with a positive track furnished for printing, some method has to be devised to realign the track placement because the track must be on the opposite side of the film for printing a reversible type of color system.

Conformation of the original camera film with the edited daily work print follows and lap dissolves or other effects may be inserted as there is Ansco color Type 132 duplicating film and Ansco color Type 154 masking film available for making effects on optical printers. When conformation is complete and the re-recorded direct-positive film is synchronized, this material is delivered to the laboratory to prepare a composite print. In timing the original, the laboratory now times each scene for printing, as in black-and-white procedure, except that each *frame* of the timing strip has a different filter balance and there are several density balances made on each scene.[4] From these strips, a timing number and a filter combination are selected to print each scene. The first print from the assembled negative, known as the answer print, has scene-for-scene density *and* color correction. The Bell and Howell printers used have been remodeled to provide a light source of 3200 degrees Kelvin for printing the Ansco color release positive, Type 732, and for inserting filters into the light source quickly and for the rapid changing of these filters during printing. This answer print is shipped to the producer for approval and if color balance on certain scenes needs changing, a second answer print is processed. After an approval has been obtained, release prints are ordered and the 35-mm print requirements are supplied.

Making the 16-Mm Color Print

Each 35-mm release print is carefully inspected, and one is selected to be used as the master for the production of the 16-mm release prints by optical reduction to Kodachrome. The original camera film, Type 735, which is being used for 35-mm printing cannot be used inasmuch as available reduction printing equipment is not equipped to make filter changes scene by scene. However, the 35-mm release print is color-balanced scene for scene and, therefore, it can be used as the master for the 16-mm reduction printing. The 35-mm print is first carefully timed, although very few light changes are needed, and with the proper filter pack, customarily used in printing Kodachrome duplicates, a 16-mm reduction print is made. A Depue reduction printer, using a 250-watt lamp, with a blower added to dissipate the heat for filter protection, is used for this work. Although the print being used for the picture reduction work is a composite print with track, this track is not used for sound printing. A 35-mm direct-positive variable-area track with additional compression for 16-mm reproduction was recorded for this assembly immediately after the re-recorded track was made for the 35-mm prints. An RCA 35- to 16-mm optical reduction sound printer, running 180 feet per minute, prints the sound on the 16-mm Kodachrome print stock.

Although the resulting 16-mm Kodachrome release print is a second-generation print, it is quite acceptable, and compares favorably with 16-mm Kodachrome contact duplicates from 16-mm Kodachrome originals. This is, no doubt, due to the fact that the original was shot on 35-mm film and that a reduction print results in better quality than a 16-mm contact print.

Approximately fifty 16-mm reduction prints each of two 2-reel pictures were made by this method, and the 35-mm Ansco release print used did not show any noticeable scratches, shrinkage, or warpage from its runs through the Depue printer. Both 35- and 16-mm prints were released within three weeks after the day the last scene was photographed—an excellent record for fast service, and credit is due the two laboratory crews who helped make such a record possible.

In the production of commercial motion pictures, problems of location work, economy of operation, making the best of conditions as they are found in the field, and transportation of photographic equipment have a direct bearing on the increased use of business films. Therefore, a practical solution in producing commercial films in 35- and 16-mm color has been desired for a number of years. Although the method just described of how 35-mm Ansco professional color film Type 735 was used to produce 35- and 16-mm release prints may be improved in the future, the method still did make possible an acceptable color process, with distinct production advantages, to a large user of commercial films. It is the belief of the author that the "difficult can be done immediately; the impossible takes a little longer." An answer to the difficult was found; perhaps the "impossible" will be solved in the years ahead of us.

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Direct-Positive Variable-Area Recording with the Light Valve*

By LEWIS B. BROWDER

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Summary—**By reflecting light from the back surface of the light-valve ribbons and focusing the ribbon edges at the film plane a bilateral or unilateral type of direct-positive variable-area track is obtained. By relocating the recording lamp so that light is transmitted through the space between the ribbons a normal variable-area negative may be obtained.**

A new film recording machine designated as Type RA-1231 was described in the Journal[1] in 1946 employing the tight-loop, controlled-compliance type of film drive. As shown, the recorder was equipped with a small, variable-density type of modulator. Since then, there have been described a 200-mil push-pull density modulator[2] and a light-valve-type, double-width, push-pull variable-area modulator[3] both of which operate with the same basic film-pulling unit as was shown with the small modulator. In this paper is described the fourth in the series of modulators for use in the Type RA-1231 recorder; i.e., a simple, compact, standard variable-area modulator. As in the other modulators, the ribbon light valve is employed as the basic modulating element, the field of application of this device being extended in this modulator to the recording of direct-positive variable-area sound track as well as the standard negative variable-area track.

The direct-positive recording facility is of particular interest in connection with those black-and-white and color processes in which the composite prints are obtained by photographic reversal from positive sound track and picture films.[4,5] The direct-positive sound track thus eliminates the intermediate sound print which ordinarily would be required with such processes. The direct-positive sound track also holds promise in certain television applications where the tonal scale on the television screen is reversed electrically to give a positive picture on the film.

* Presented October 26, 1948, at the SMPE Convention in Washington.

PRINCIPLE OF DIRECT-POSITIVE RECORDING

For recording direct positive, the aperture between the light-valve ribbons must be projected on the film as a dark area so that it will develop out to clear film. The aperture image must, of course, be bounded by an exposed area which will develop out black on the film. Thus as the ribbon aperture is made smaller in response to noise-reduction bias, the percentage of clear area in the developed track becomes less and the ground noise in the reproduced film is correspondingly reduced. In principle, this reversal of clear and exposed area from the situation obtained with the standard negative recording system is accomplished as follows:

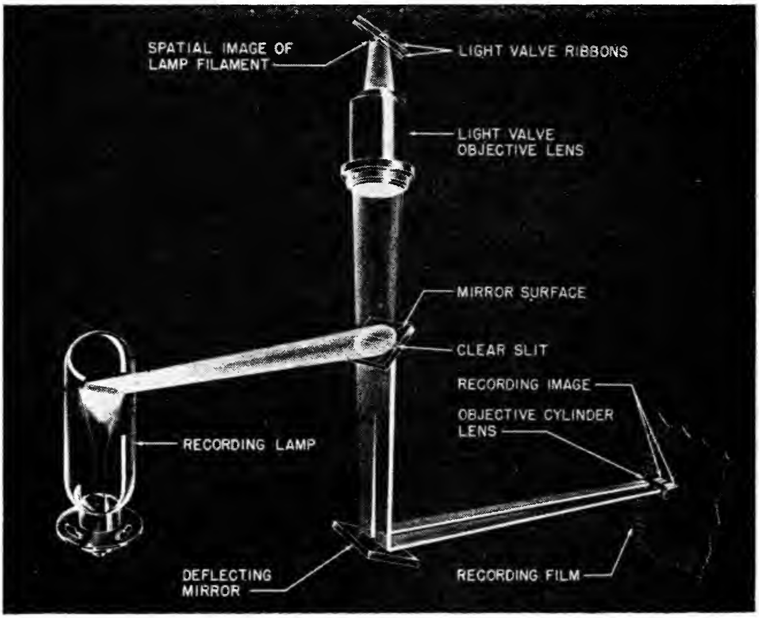

Fig. 1—Basic optical system for direct-positive recording.

As shown in Fig. 1, the light valve is equipped with a high-quality apochromatic objective lens. Light from the recording lamp is directed off the inclined slit mirror into this objective lens, the working distances being such that an image of the lamp filament is formed at the plane of the light-valve ribbons. As in previous light valves, the width of the ribbon is considerably larger than the thickness. This thin, flat ribbon is suspended in the fixed magnetic field so that electrical currents flowing lengthwise through the ribbon will cause it to move sidewise in the plane of the flat surface. For this light valve, the foil from which the ribbon is to be sheared is polished optically smooth and given a mirror-quality surface finish. When stretched between the ribbon clamp carriages, the ribbon appears as a thin strip mirror whose surface is perpendicular to both the optical axis and the axis of the lamp-filament image. The width of this strip mirror is defined by the accurately straight edges of the ribbon and is much less in extent than the length of the spatial image of the lamp filament, with the result that the actual area of illumination of the ribbons remains constant as the ribbons are modulated. There is thus formed by the polished ribbon surface a mirrored image of just that portion of the filament image which it intercepts.

Since the ribbon moves laterally across the filament image in response to modulation currents it, in effect, scans the image directing the reflected light back toward the light-valve objective lens. By means of optical expedients to be described later, the individual coils of the image of the lamp filament are made to blend with one another so that the filament appears as a uniformly illuminated rectangle of light. Thus each reflected element of the image appears identical to any other differing only in lateral position as determined by the instantaneous displacement of the light-valve ribbon.

Two of these reflecting ribbons are employed in this light valve. They are arranged side by side and accurately adjusted so that their reflecting surfaces are coplanar. These ribbons may be connected to record either a bilateral or a unilateral type of variable-area sound track.[6] In the unilateral case one of the ribbons is connected to move in response to noise-reduction currents while the other moves in response to speech currents. As seen from the light-valve objective lens there appear two brightly illuminated patches, the inner edges of which move in response to speech and noise-reduction currents to define the lateral extent of the embraced dark area. This situation when projected onto the film is correct for the recording of direct-positive variable-area sound track. The inclined mirror by which the light from the recording lamp is directed into the light-valve objective lens contains a narrow, rectangular, clear slit extending across its width through which the light can pass to the film.

As shown in Fig. 1, the light proceeds from the recording lamp to the inclined slit mirror which directs all but that lost through the slit upward to the light-valve objective lens. This lens forms a spatial image of the lamp filament at the plane of the light-valve ribbons. The reflecting surfaces of the ribbons in turn form virtual images of sections of the filament image, which virtual images are limited in extent by the width of the ribbons and are located also at the ribbon plane. The light-valve objective lens then picks up these reflected images and reprojects them, this time through the clear slit in the inclined mirror and to the film. The cylindrical lens located near the

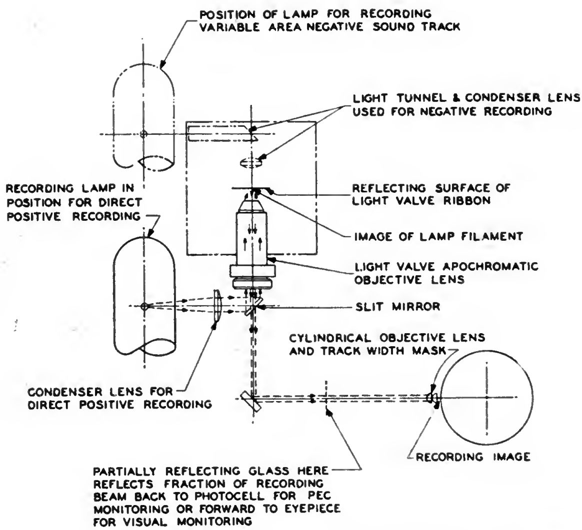

Fig. 2—Optical system schematic of variable-area modulator.

film gathers the beam of light from the slit and converges it to the narrow line required for the recording image.

OPTICAL SYSTEM

The complete optical system of this modulator is depicted schematically in Fig. 2. The recording lamp is of the prefocused type rated at 5 amperes and 10 volts having a single-helix, curved, horizontal filament. The axis of the filament is rotated at 45 degrees to the optical axis which has the effect of reducing the pitch of the filament helix to the point where there are no dark spaces between the coils and the whole length of the filament appears uniformly bright. Some gain in optical efficiency and a considerable saving in space is achieved by locating the lamp fairly close to the light valve employing an auxiliary lens to throw a virtual image of the lamp filament back to the proper distance for projection by the light-valve objective lens to the ribbon plane. In order to maintain the recording lamp in its normal vertical operating position the light valve is located immediately above the slit mirror with the light-valve objective lens facing downward. The slit mirror is a front-surface, aluminized, glass mirror with a clear slit across its width. The width of this slit together with the reduction afforded by the objective cylinder lens determines the height of the recording image. The clear slit in the mirror casts a shadow which disappears at the ribbon plane but reappears in the reflected beam from the ribbons in such a way that the slit ordinarily would be in its own shadow and no light would be available for recording. By displacing the slit from the optical axis through slightly more than half its width, the shadow is thrown to the opposite side of the optical axis making the full-intensity beam available for recording. The mounting of the apochromatic objective follows previous practice in that it is located within the light-valve structure. Since the light valve is intended to be a readily replaceable component, this arrangement confines any slight, mechanical misregistration of the light valve with its mounting to the image space of the objective lens where such displacements are not subject to optical magnification.

The reflected light from the ribbon passes through the clear slit to a front-surfaced plane mirror whose function is to turn the recording beam through 90 degrees to a horizontal axis. The objective cylinder lens is located near the film and is adjusted to focus an image of the clear slit in the above mirror onto the emulsion of the recording film. Separation of the cylinder lens into two components is resorted to as shown in order to minimize the cylindrical equivalent of spherical aberration.

Recording of a standard negative track is accomplished by bringing the light in through the edge of the light valve as shown in Fig. 2. Upon reaching the optical centerline of the valve, the beam is deflected downward by a prism to the condenser lens. An image of the lamp filament is focused by the condenser lens slightly beyond the ribbon plane in order to minimize the effects of the filament striations further. The rear-illuminated aperture between the ribbons is then projected by the light-valve objective lens through the slit and to the film. As in the direct-positive setup, the cylinder lenses focus the slit onto the film emulsion to define the height of the recording image.

Light for phototube monitoring is obtained from the horizontal section of the recording beam by a thin, inclined, clear-glass wafer which subtracts a fraction of the beam by Fresnel reflection directing it back to the monitoring phototube. In the viewer a similarly located but oppositely inclined mirror throws the reflected fraction of the recording beam forward allowing the spatial image of the light-valve ribbons to be inspected wih a microscope eyepiece.

THE LIGHT VALVE

The folded-magnet structure employed in previous variable-area light valves[3] is used here, as are the beryllium-copper ribbon clamp carriages with their adjustments for ribbon spacing, height, and tuning

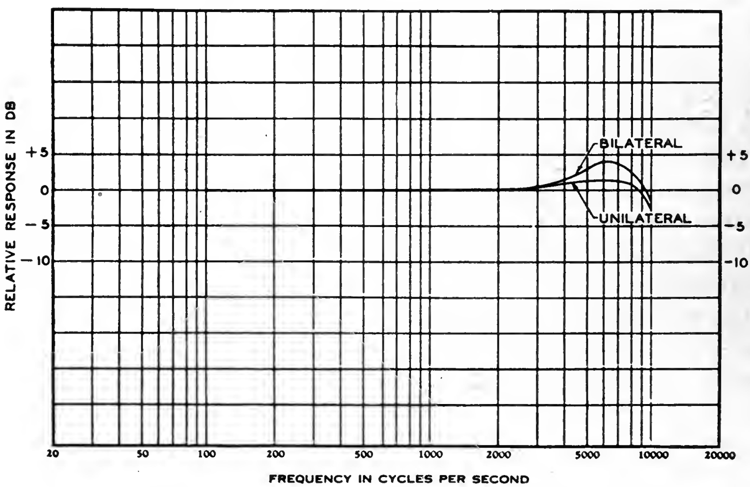

Fig. 3—Frequency response of light valves.

tension. A box-shaped Alnico magnet comprises the main body of the case with Permendur pole-pieces closing the ends and carrying the magnetic flux to the center of the valve where the ribbon gap is located. One of these pole-pieces supports the objective lens as well as the clamp carriages while the other contains the condenser lens and the prism arrangement by which light is directed to the ribbons for negative recording.

The surface quality of the light-valve ribbons used for direct-positive recording must, of course, be quite good. Of the several materials suitable for use in the fabrication of the light-valve ribbon, aluminum offers definite advantages from the standpoint of electrical performance[7] although unfortunately its softness presents some problems in the achievement of a satisfactory surface finish. However, by careful maintenance of the rolls with which the foil is worked, excellent foil surfaces have been obtained comparable in reflectance to an aluminized mirror.

The relationship between the amplitude of ribbon displacement and applied voltage at the 600-ohm primary of the light-valve matching coil is shown in Fig. 3. The somewhat higher peak exhibited by the bilateral light valve is due to the use of a series resistor in the Simplex noise-reduction circuit with which this valve is used. The light valve looks back into a circuit of relatively high impedance so that the effectiveness of the electromagnetic damping is somewhat

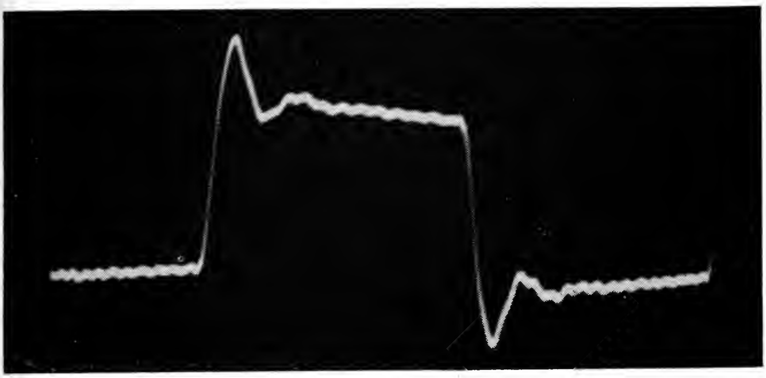

Fig. 4—Square-wave response of light valve.

reduced. The unilateral valve, on the other hand, looks back directly into the low-impedance secondary of the matching transformer with a consequent improvement in the electromagnetic damping characteristic. Fig. 4 shows an oscillogram of the monitoring phototube output as the unilateral valve is driven through its matching transformer with a square-wave generator having a fundamental frequency of 800 cycles per second As used in a recording system, the resonant peaks are usually flattened by means of a light-valve equalizer which improves the square-wave response also.

MECHANICAL ARRANGEMENT OF THE MODULATOR

The only mechanical difference in the setup for recording negative track and that for recording direct positive is in the manner in which the light from the recording lamp is conducted into the light valve. By mounting the recording lamp on a movable slide, it becomes possible to effect this change merely by moving the recording lamp from one position to the other. Fig. 5 is a photograph of the modulator with the light valve in place and the lamp moved up to the position for recording negative sound track. Fig. 6, in which the modulator is mounted in its recorder, shows the lamp moved down in position to record direct-positive sound track. The lamp bracket is mounted in a dovetail slide equipped with adjustable stops at each end of its travel. After the stops have been adjusted and locked for a particular lamp, the transition from direct-positive to negative recording may be accomplished in a matter of seconds merely by moving the lamp.

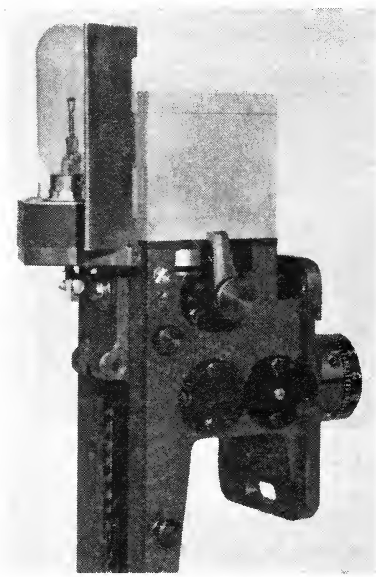

Fig. 5—Modulator and light valve.

The light valve is a completely self-contained component of the modulator, the mounting being arranged so that it may be removed readily from the modulator proper for inspection or replacement. Registry of the face of the light valve with the modulator mounting plate is accomplished by constructing this plate of soft steel so that the leakage magnetic flux from the valve serves to hold the valve face tightly against this plate. A single milled slot in the valve face and a dowel in the mounting plate locate the valve in the right and left directions while registry tabs at the back of the mounting plate bear against the rear edge of the valve to locate it fore and aft. After the valve is pushed home against the registry tabs, a clamping lever is swung into place and tightened to augment the magnetic clamping force further. Release of this lever then allows the valve to be slid across the steel mounting plate and finally lifted clear.

The objective cylinder lenses are mounted in a cylindrical cell which is spring-loaded against a threaded ring. Calibrations on the periphery of this ring serve as a reference in making film tests to establish the optimal focus setting. Provision is made for a limited range of adjustment of this cell about its longitudinal axis for setting the azimuth of the recording image to the precision required in variable-area recording.

The monitoring facilities are designed as self-contained accessories which may be installed into the modulator in place of the right-hand small circular cover seen in Fig. 5. The phototube monitoring attachment is an assembly of deflecting glass and a field lens for producing a variable-intensity spot on the plate of the phototube. This assembly

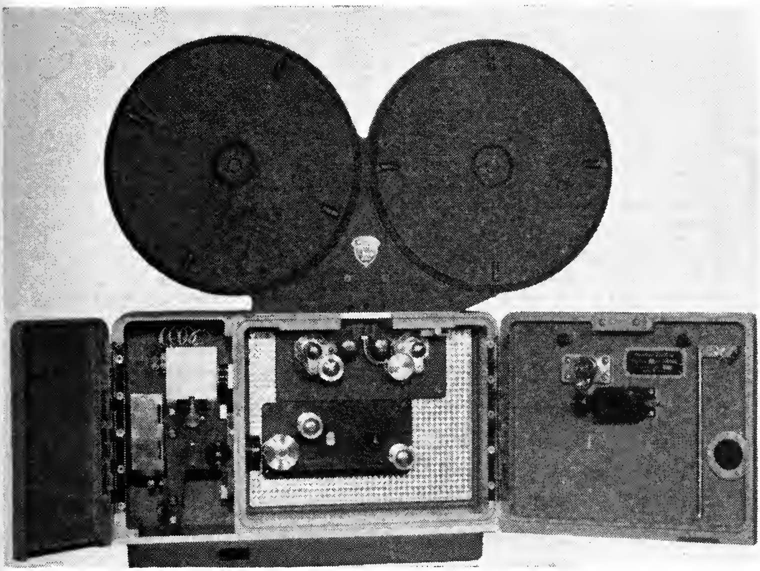

Fig. 6—Modulator and light valve in recorder.

and the chassis containing the monitoring phototube and amplifier constitute the complete phototube monitoring unit. The visual monitoring accessory consists of a microscope eyepiece with its mounting for installation into the modulator. A graduated scale is located in the focal plane of this eyepiece which enables the setting of the noise-reduction current to obtain a given width of bias line.

PERFORMANCE

Both the unilateral and the bilateral light valves require an input level of +20 dbm* into the primary of the matching transformer for operation to 100 per cent modulation. This figure applies, of course, for either direct-positive or negative operation.

* Decibels with respect to 0.001 watt.

For direct playback of the direct-positive track, maximum cancellation of the cross-modulation products is obtained by exposing EK-1372 or EK-5372 variable-area film to a total density[8] of 1.3. A frequency film recorded at constant modulation of the light valve and exposed to this optimal density exhibits a frequency characteristic as shown in Fig. 7 for both the 35-mm modulator and the 16-mm version which uses a narrower recording slit to improve the frequency response.

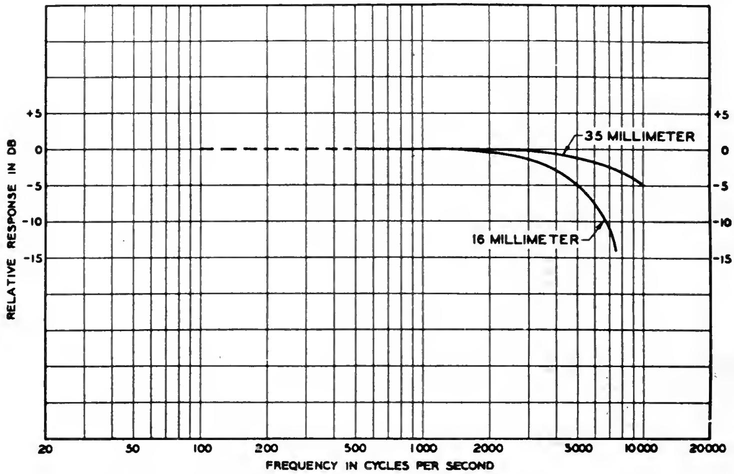

Fig. 7—Frequency response of direct-positive film.

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35-Mm and 16-Mm Portable Sound-Recording System*

By E. W. TEMPLIN

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Summary—**A new low-cost portable sound-recording system suitable for recording a standard variable-density sound track on 35-mm or 16-mm film in synchronism with a motion picture film is described. The basic system includes a two-channel mixer, a main amplifier including associated noise-reduction circuits, a compact recorder, and a power unit for operating the entire system from a 115-volt, alternating-current supply. An optional inverter providing for operation from 96-volt batteries and an alternating- and direct-current multiduty motor-control unit are also available. The various circuit facilities and the performance of the components and system with respect to sensitivity, signal-to-noise ratio, harmonic distortion, and flutter are discussed in detail. The mechanical and electrical design of the equipment make possible a high-quality sound product for both speech and music recordings, the performance specifications being consistent with the requirements and standards of major Hollywood studios.**

General Description

A new low-cost lightweight portable sound-recording system suitable for recording a standard variable-density sound track on 35-mm or 16-mm film in synchronism with a motion picture film is now available in the Western Electric 300 Type recording system. The assembled system, as shown in Fig. 1, consists of three electronic units, a mixer, amplifier, and power unit, each assembled in an attractive duralumin case, plus a compact recording machine also well adapted for portable application.

Although limitations on weight and size are imposed by the portability requirements, the equipment retains a frequency-response range and freedom from distortion consistent with the high-quality requirements of major studio production. In addition, variable equalization facilities are incorporated for controlling the frequency response in the low-, medium-, and high-frequency ranges to obtain the best possible sound product for either speech or music recordings on both 16-mm and 35-mm film, and for the wide range of pickup conditions found in the studio and on location.

* Presented April 24, 1947, at the SMPE Convention in Chicago.

The electronic components operate from a single-phase 50- to 60-cycle, 115-volt power source with a total drain of less than 2 amperes. The recording machine motor may be either a 3-phase, 220-volt synchronous type, a conventional 3-phase alternating-current interlock, or a 96-volt direct-current multiduty motor, depending on the type of power source provided for driving the motors of the associated cameras. Alternatively, by means of a supplementary electronic inverter, shown dotted in Fig. 1, the entire system, including the recorder and camera motor, may be operated from 96-volt batteries.

Five 6-conductor-shielded cables terminating in Cannon type "P" connectors are required for connecting the components together. Additional cables are required for the microphones and for connection to the power source. Six varieties of the "P"-type connectors are used in order to minimize the possibility of mispatching cables. The assignment of terminals on the connectors has been arranged to prevent damage to components in the event cables are accidentally connected to the wrong receptacle.

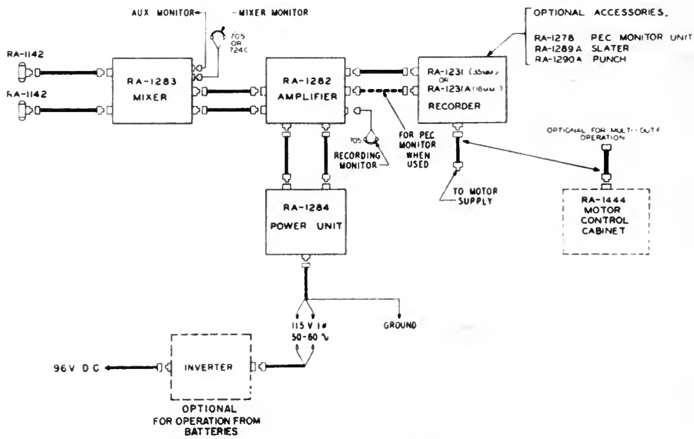

Fig. 1—Basic 300 Type recording system—block schematic.

The microphone cables normally are 100 feet long. The system will also accommodate a 100-foot separation between mixer and amplifier. The amplifier, recorder, and power unit are intended to be located close together so that all may be under the operating control of the recordist. The power-supply cable may be as long as necessary, providing the terminal voltage at the power-supply input is within the range of 100 to 130 volts.

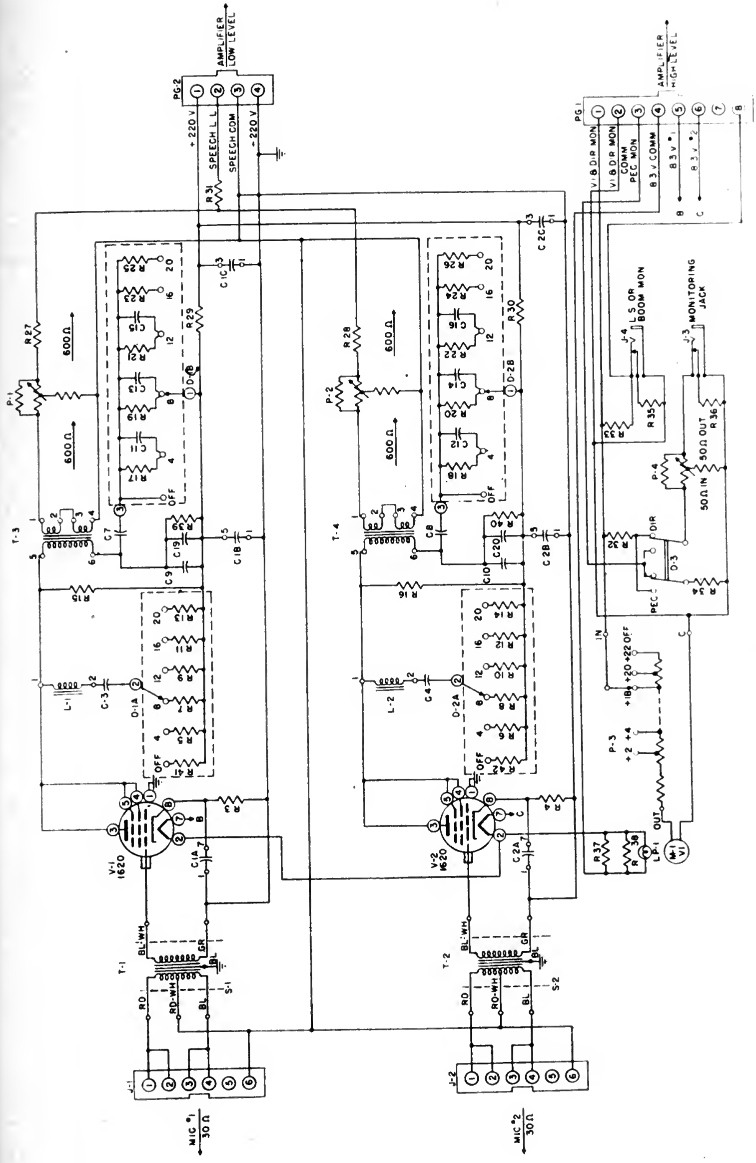

Fig. 2—RA-1283 mixer—schematic.

MIXER

The RA-1283 mixer is shown schematically in Fig. 2. Two microphone inputs are provided, working into separate preamplifiers. These amplifiers are arranged to operate from microphones having a 30-ohm impedance such as the Western Electric RA-1142 (cardioid) type. The preamplifiers have a gain of 33 decibels, an overload level of 0 dbm* for 1 per cent total harmonic distortion, and a background noise level of −93 dbm at the amplifier output.

Separate variable dialog equalizers are provided in each preamplifier. This feature is desirable not only to provide greater flexibility but because of special requirements in a low-cost system that it be possible to use the original film for release negative rather than undergo a costly re-recording process. In applications of this type, background music might be recorded simultaneously with the picture and the low-frequency equalization for the music would generally be considerably less than for the dialog. As another example, in a two-microphone setup where acoustics differ markedly in the two positions, the equalizers may be adjusted so that they are balanced in the original recording, thus eliminating the necessity of frequency-response readjustment during a subsequent re-recording process.

The desired equalization characteristic is obtained by series and shunt elements in the plate circuits of the preamplifiers. The relatively high impedance of the plate circuit allows a smaller space and weight for the components than would be possible in the 600-ohm output circuit. The dialog-equalization characteristics are described in detail in a later portion of this paper.

Separate mixer potentiometers follow the preamplifiers. These are standard 600-ohm bridged-T type having $1^1/_2$ decibel per step ($^3/_4$ decibel per step when bridging two contacts) and tapered to full cutoff at the maximum counterclockwise position. The mixer potentiometers terminate in a combining network, the output of which is carried to the mixer output terminals.

Either phototube or direct monitoring may be selected by the mixer operator providing the optional RA-1278 phototube monitor assembly is installed in the recorder.

A volume-indicator, direct-monitor line is bridged from the main amplifier output. The volume-indicator circuit includes a high-speed meter and a control switch providing a range from +2 to +24

* Decibels with respect to 0.001 watt.

dbm for 0-decibel meter deflection. Direct-monitor level for the mixer operator is adjustable by means of a bridged-T continuously variable attenuator which provides a level from −10 dbm to cutoff for 100 per cent modulation of the light valve. An auxiliary direct-monitor circuit, at a fixed level of −18 dbm for 100 per cent light-valve modulation, is provided for the microphone-boom operator.

The RA-1283 mixer requires 0.6 ampere at 8.3 volts direct current for the vacuum-tube heaters and the volume-indicator meter lamp, and 5 milliamperes at 220 volts direct current for the plate supply.

A front view of the mixer, with cover removed, is shown in Fig. 3. The mixer potentiometer and dialog equalizer for one microphone channel are on the left and for the other on the right. In the central

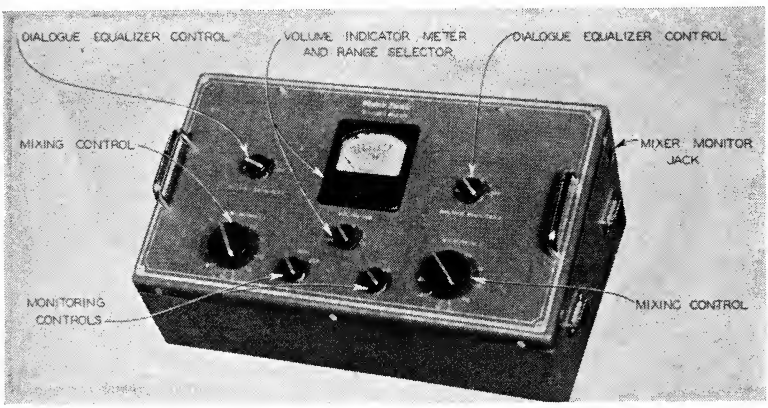

Fig. 3—RA-1283 mixer—front view.

portion, below the volume-indicator meter, from left to right, are the phototube, direct switch, volume-indicator range switch, and monitor volume control.

A rear view of the mixer is shown in Fig. 4. On the left side is the mixer monitor jack. On the rear are receptacles for two microphone cables, low- and high-level interconnecting cables to the RA-1282 amplifier, and auxiliary monitor.

The cover, not shown in the photographs, can also be latched to the under side of the mixer when the equipment is in use, thus avoiding the possibility of its being left behind as the mixer is moved about from one setup position to another. The mixer is $15^3/_4$ inches long by 6 inches high by $8^1/_2$ inches deep, including cover, and weighs $17^1/_2$ pounds.

AMPLIFIER

The RA-1282 amplifier is shown schematically in Fig. 5. This unit contains the main system amplifier, a 1000-cycle test oscillator, variable low-, middle-, and high-frequency equalization, a noise-reduction circuit for automatically biasing down the light-valve spacing in accordance with the envelope of the modulating signal, a volume-indicator circuit, and the recorder lamp-control circuit.

The amplifier section is a 3-stage unit having either 60, 70, or 80 decibels gain. By connecting an internal strap the gain may be increased 5 decibels on each of the above steps. The power output is +18 dbm for 1 per cent total harmonic distortion and +22 dbm for 5

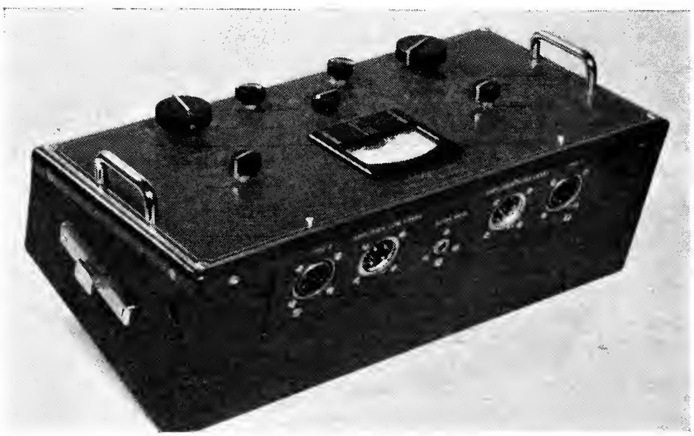

Fig. 4—RA-1283 mixer—rear view.

per cent total harmonic distortion. A maximum output of approximately +25 dbm prevents damage to the light valve under conditions of excessively high input signals. The background noise level at the amplifier output with the mixer turned OFF is −56 dbm on low gain, −51 dbm on medium gain, and −41 dbm on high gain. Under normal operating conditions the signal-to-noise ratio of the amplifier is 65 decibels or well above that of the mixer preamplifiers.

The first stage of the amplifier uses a 403-B or -C vacuum tube connected as a pentode with cathode feedback. The feedback may be reduced by installing the short-circuiting strap mentioned above to raise the amplifier gain by 5 decibels. This strap is located conveniently on the subpanel on the top side of the main chassis. The

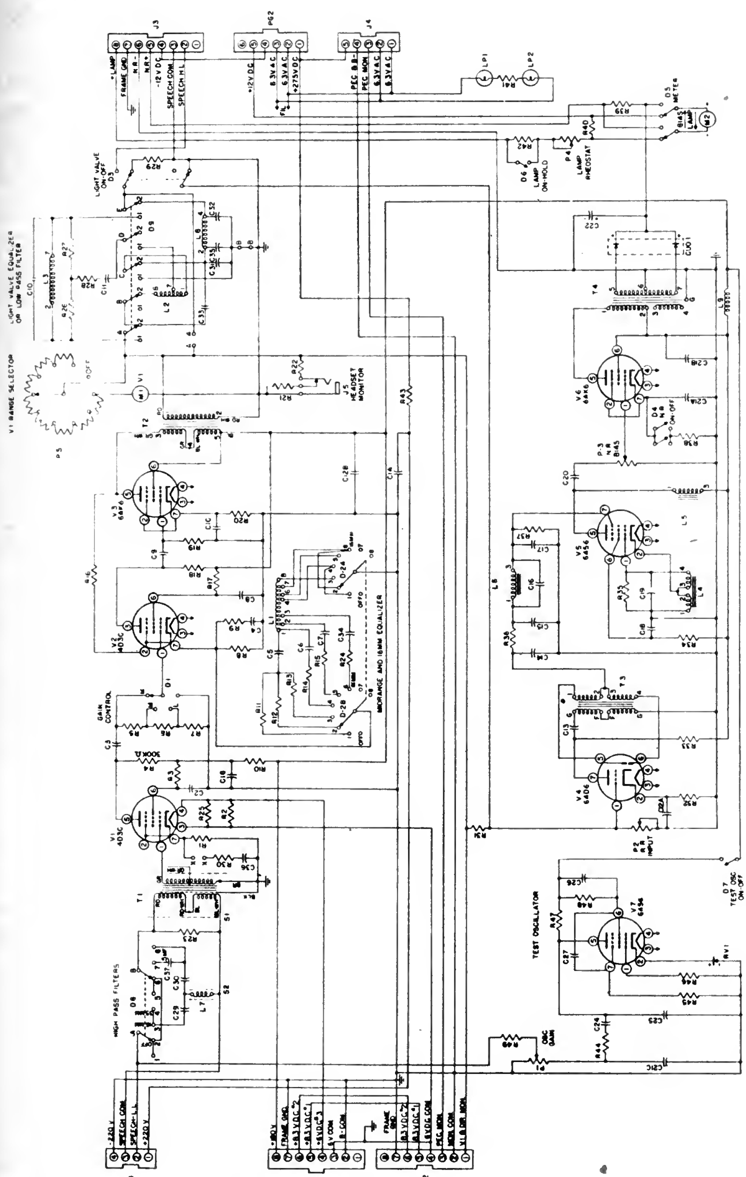

Fig. 5—RA-1282 amplifier—schematic.

first stage of gain is resistance-capacitance-coupled to the second stage, the latter having a grid pot for controlling the gain in three 10-decibel steps. This control is located on the front panel.

The second and third stages utilize a 403-B or -C and 6AK6 Type vacuum tube, respectively, with feedback around the two stages from plate to cathode.

A high-pass filter, located at the input to the first stage provides optimum low-frequency cutoff for either 16-mm or 35-mm recording or may be switched out of the circuit. An inductance-capacitance resonant circuit in the cathode of the second stage provides adjustable mid-frequency equalization. High-frequency equalization is located in the 600-ohm output circuit of the amplifier. These will be described in detail later.

The test oscillator is used to check continuity, to determine light-valve overload level, to set noise reduction, and otherwise align the system. It uses a 6AS6 vacuum tube in a modified Transitron circuit. A Western Electric 400A germanium crystal is used in the cathode circuit of this tube, its steep resistance-versus-current characteristic acting to stabilize the oscillator. The oscillator frequency is approximately 1000 cycles per second and its output level sufficient to overload the light valve on medium-gain step. Continuously variable oscillator output control is provided. The oscillator heater is paralleled with those of the other tubes so that the test tone is available immediately when the oscillator OFF-ON switch supplies plate voltage to the oscillator. The noise-reduction circuit comprises three tubes used as audio amplifier and rectifier, carrier oscillator-modulator, and modulated-carrier power amplifier, respectively.

The first stage uses a 6AQ6 duo-diode-triode. The triode section amplifies the signal input, which is bridged from the main amplifier output. An input potentiometer serves as a noise-reduction margin control. An isolating resistance between the amplifier output and the noise-reduction input allows the latter to be short-circuited without affecting the main amplifier output when the light-valve switch is in the OFF position. This prevents noise-reduction signals from modulating the valve when unmodulated biased and unbiased test tracks are being made at the end of a take. The duo-diode portion of the tube serves to rectify the signal. This is then filtered to provide a varying direct current proportional to the envelope of the input signal. The attack and release times of the noise-reduction system are also established by the elements of this filter.

In the second stage is a 6AS6 tube operating in a 30-kilocycle Hartley oscillator circuit, with suppressor-grid modulation obtained from the signal envelope described above.

The output amplifier stage uses a 6AK6 vacuum tube. A grid potentiometer provides a control of the bias current and thus controls the amount of noise reduction being applied to the light valve. The output is transformer-coupled to a full-wave copper-oxide rectifier which is filtered to provide a modulated direct current varying inversely with the envelope of the signal.

A volume-indicator meter and range switch similar to that provided

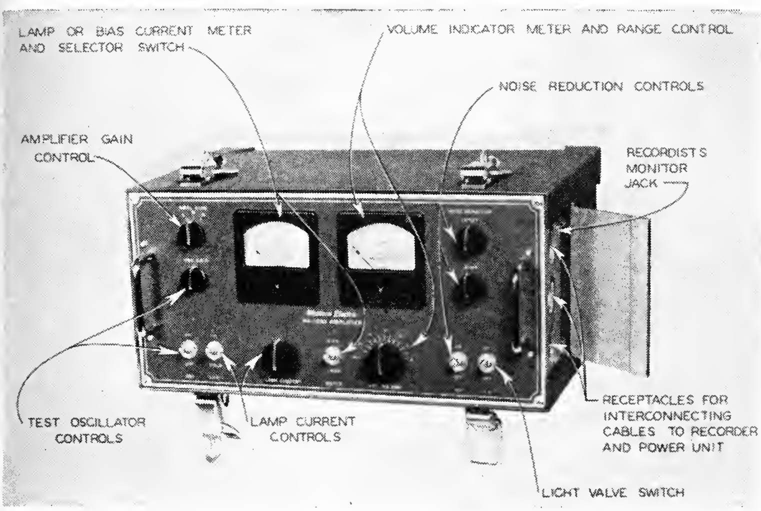

Fig. 6—RA-1282 amplifier—front view.

in the mixer and a lamp-current control circuit are also included in this unit. The lamp-current meter may alternatively be switched to read the value of noise-reduction bias current.

A front view of the amplifier is shown in Fig. 6. In the upper left are the amplifier-gain switch and oscillator-gain potentiometer. Below these are the oscillator OFF-ON switch and lamp operate-hold switch. The left-hand meter indicates lamp or noise-reduction-bias current as selected by the switch in the lower center. The lamp-current rheostat is located below the associated meter. The right-hand meter is the volume indicator with the volume-indicator range switch located immediately below. In the upper right are the noise-reduction input (or margin) and noise-reduction—bias-control pots. Below them are the noise-reduction and light-valve OFF-ON switches.

Three receptacles are provided on both the left and right ends for interconnection cables to the associated units, one of the recorder cables being required only when the optional phototube amplifier is installed in the recorder. A monitor jack for the recordist is also located on the right side. When the top cover is in place, the side flaps are held closed over the receptacles, thus protecting them from dirt and physical damage.

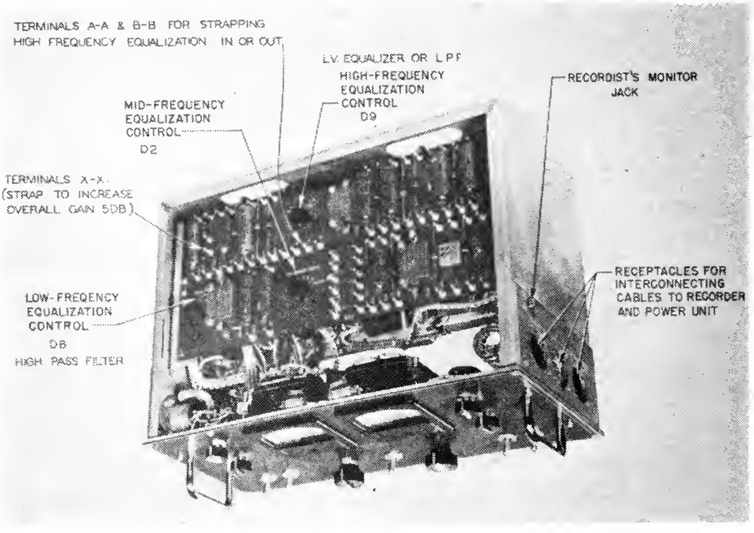

Fig. 7—RA-1282 amplifier—chassis top view.

By loosening two screws on each end of the unit, which are located on the interconnecting-cable receptacle panels, the chassis may be slipped from its case. A top view of the chassis with cover removed is shown in Fig. 7.

The high-pass filter (or low-frequency equalization) control switch is shown on the subpanel at the extreme left. In the center portion of the subpanel the mid-range and high-frequency equalization controls are located. By replacing strap *A-A* with strap *B-B* the high-frequency equalization may be removed completely from the circuit. The RA-1282 amplifier is $15^1/_2$ inches long by $11^3/_8$ inches high by 9 inches deep and weighs approximately 32 pounds.

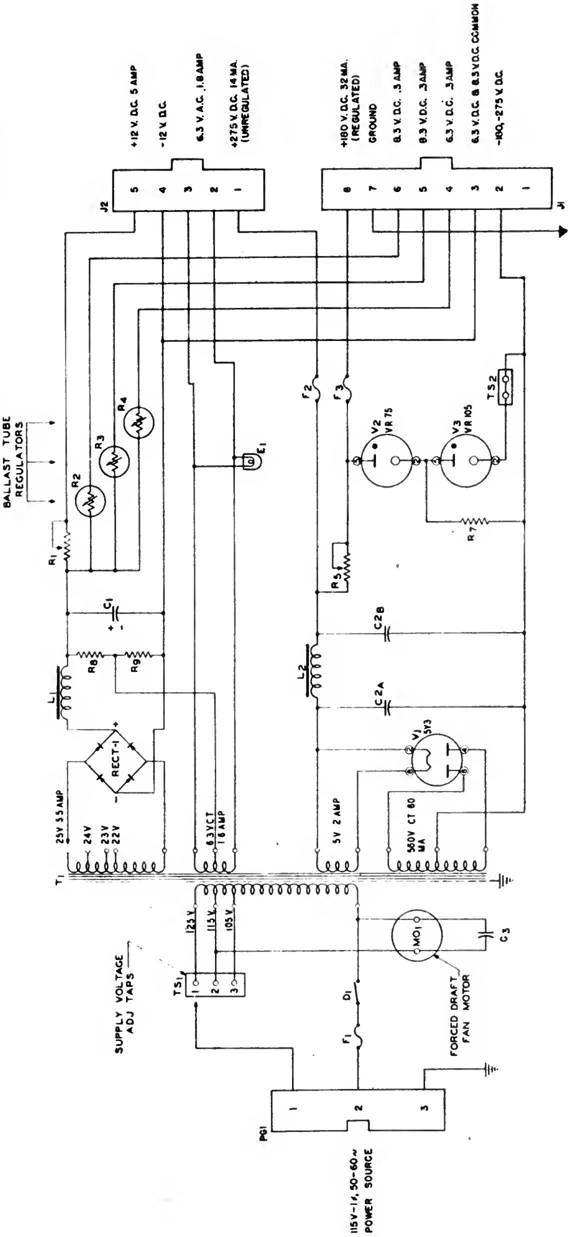

Fig. 8—RA-1284 power unit—schematic.

POWER UNIT

The RA-1284 power unit provides plate and heater voltages for all vacuum tubes and 12 volts direct current for the recorder exciter lamp. The power unit operates from a single-phase, 50 to 60-cycle power source of 100 to 130 volts. Taps on the input transformer provide for a power supply nominally 105, 115, or 125 volts.

A schematic of the unit is shown in Fig. 8. A power-supply switch controls power to the complete system. The 12-volt, direct-current portion of the unit utilizes a bridge-type selenium rectifier and inductance-capacitance filter. This circuit supplies 4.5 amperes to the

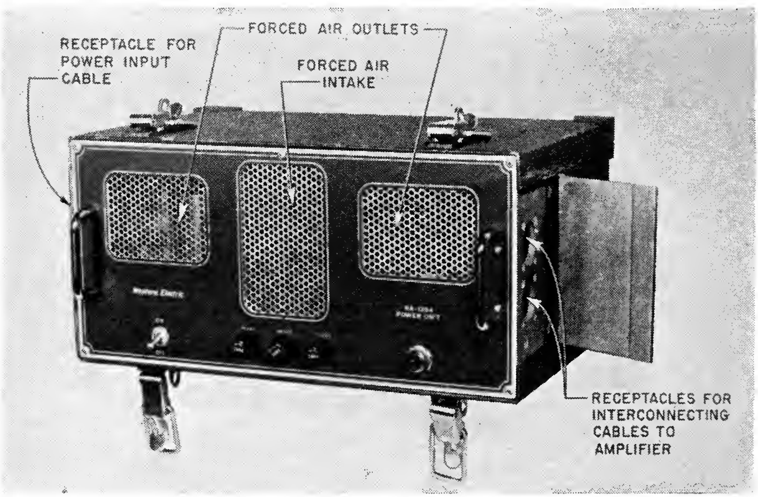

Fig. 9—RA-1284 power unit—front view.

recorder exciter lamp and 0.3 ampere each to the heaters of the two mixer preamplifiers and the first amplifier stage in the main amplifier. These three heaters are fed through separate ballast lamps which regulate the current to the required value independent of power-supply voltage, variations in lamp current, and length of connecting cables between the amplifier and the mixer. The remaining tubes in the RA-1282 amplifier receive heater supply from a 6.3-volt, alternating-current transformer in the power unit. The center-tap of the winding receives a 6-volt bias from resistances *R8* and *R9*, which reduces to a negligible value the introduction of hum components from the heaters.

The plate-supply circuit provides 30 milliamperes regulated at 180 volts for the main amplifier and 15 milliamperes unregulated at approximately 275 volts for the mixture preamplifiers and the optional phototube monitor unit. Regulation of the 180-volt circuit is provided by the two gas tubes *V2* and *V3*. The 275-volt supply is filtered further in the amplifier to provide 5 milliamperes at 220 volts direct current at the mixer terminals.

A small fan provides forced-draft cooling for the unit, drawing cool air in past the selenium-rectifier plates and forcing the air out past the other components. The use of the forced draft allows a considerable saving in weight and space for the rectifier and still allows a reasonable safety factor in the event of failure of the ventilating system.

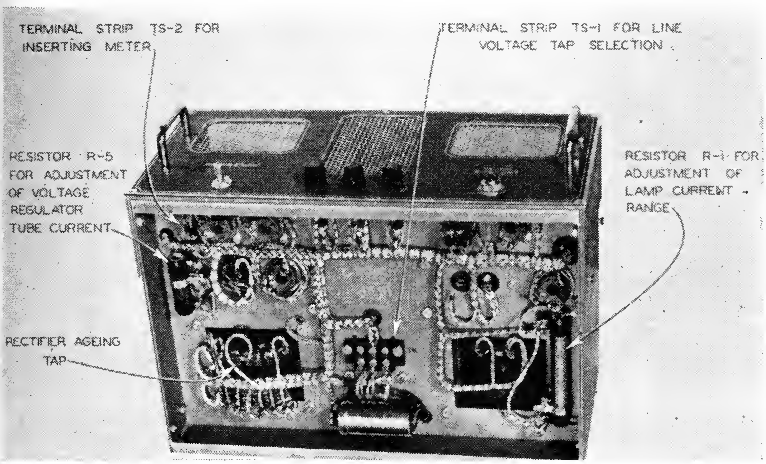

Fig. 10—RA-1284 power unit—chassis bottom view.

Fig. 9 shows a front view of the power unit with the top cover removed. The air intake for the cooling system is in the center, with the exhaust on the two sides. Also shown on the front panel are the power switch, power input and plate-supply fuses, and a power pilot lamp. Receptacles for the two interconnecting cables to the amplifier unit are shown on the right. A power-input receptacle is similarly located on the left side. Side flaps protect the receptacles when the cover is installed, as already described for the RA-1282 amplifier. A bottom view of the chassis with the cover removed is shown in Fig. 10. This shows an adjustable resistor on the right for setting the lamp current within the desired range, an adjustable resistor on the left for setting the regulating range of the gas tubes (depending on whether or not the optional phototube monitor assembly is used), and in the center, the adjustable taps for 105, 115, or 125 volts supply voltage. The power unit is mounted in a case the same size and of the same appearance as already described for the RA-1282 amplifier. The weight is 38 pounds.

In order that the system may be operated entirely from 96-volt batteries, an auxiliary inverter unit has been developed. It supplies 60-cycle power at a nominal 115 volts to the RA-1284 power unit, the total battery drain under full load being approximately 2.3 amperes. This unit contains a vibrator and associated tapped autotransformer

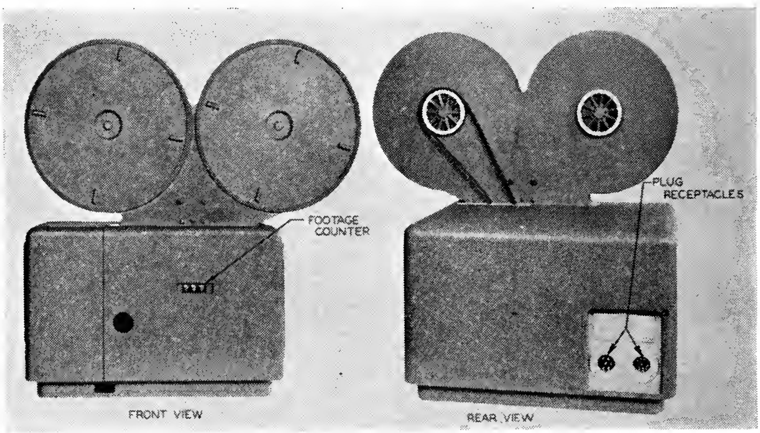

Fig. 11—RA-1231 Type recorder.

which permits adjustment of output voltages to 115 volts ±5 per cent for battery-supply voltages in the range of 85 to 105 volts. The unit is compactly constructed for portable operation, its dimensions being approximately 8 × 9 1/2 × 15 1/2 inches and its weight 40 pounds.

RECORDER

The recording machine, previously described in the JOURNAL,[1] may be either the RA-1231 or RA-1231-A Type, depending on whether 35-mm or 16-mm film is being used. The 35-mm model is shown in Figs. 11 and 12. A conversion-part set allows the recording machine to be modified at the studio or in the field so that it may be used interchangeably with the two widths of film. This recorder includes a sealed light valve and simplified modulator with prefocused lamp, producing a standard 100-mil variable-density track for 35-mm recording or standard 80-mil variable-density track for 16-mm recording.

A new fluid damped drive mechanism, also described in the JOURNAL,[2] is utilized. With this drive the 96-cycle flutter is essentially negligible and the total flutter for all frequency bands from two to 200 cycles per second is approximately 0.05 per cent. The total weight of the recorder, less film magazine, is 76 pounds. Standard Mitchell 35-mm and 16-mm magazines have been adapted for use with this recorder. A transformer, matching the 600-ohm output of the amplifier to the light valve, and a noise-reduction Simplex circuit are provided in the recorder.

The optional RA-1278 phototube monitor assembly, when provided, is also mounted in the recording machine. The amplifier por-

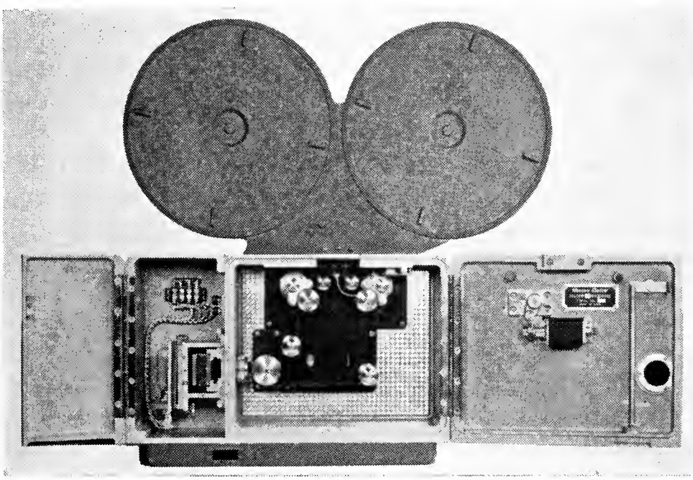

Fig. 12—RA-1231 Type recorder—front interior view.

tion of this assembly is shown schematically in Fig. 13. It is a two-stage unit with feedback around the first stage. One 1620 and one 6J5 vacuum tube are used. The output impedance of the amplifier is 50 ohms to match the mixer monitor circuit. It provides an output level of -10 to $+8$ dbm, depending on the type of light valve and lamp current used. For conditions of extremely low input-signal level the gain may be increased 10 decibels by means of a strap on the terminal strip which reduces the feedback. The total harmonic distortion at maximum operating level is not over 1 per cent. The signal-to-noise ratio with 100 per cent light-valve modulation is over 45 decibels. A continuously variable output attenuator is provided for balancing the output against the direct monitor level. A 600-ohm test input is

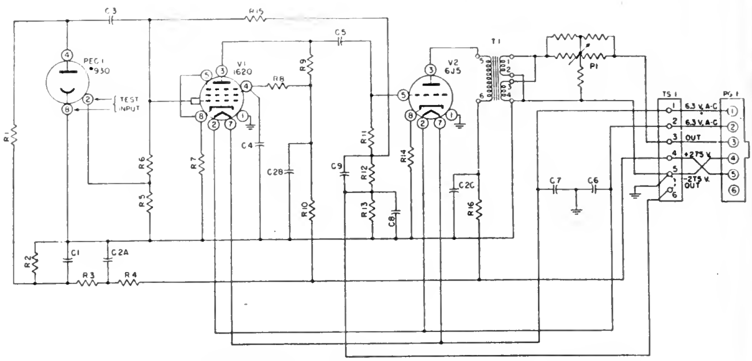

Fig. 13—RA-1278 phototube monitor unit—schematic.

provided on the phototube socket for making electrical transmission tests. The amplifier chassis is flexibly mounted to prevent microphonic noise when the recorder is operating.

As shown in Fig. 14 the phototube monitor assembly includes a deflector subassembly and a relay lens in addition to the amplifier chassis. The deflector transmits approximately 10 per cent of the incident modulated light through an aperture and the relay lens to a phototube mounted on the amplifier chassis. This chassis is located in the rear compartment of the recorder.

Several types of driving motors are available. These, with their associated chain and sprocket kits permit alternative operation synchronously from a 50- or 60-cycle, 3-phase supply, in interlock from a

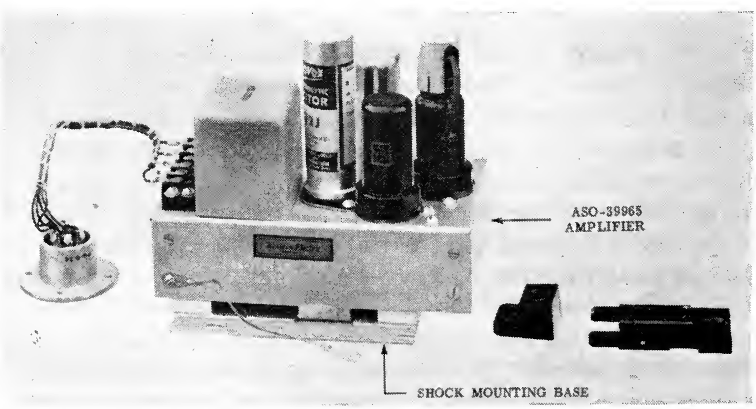

Fig. 14—RA-1278 phototube monitor unit—assembly.

3-phase distributor system, or in a multiduty motor system energized from a 3-phase, 220-volt alternating-current line or 96-volt batteries. For multiduty motor operation an optional RA-1444 control unit has been developed. This unit provides means for controlling one recorder motor and two camera motors when operating from either an alternating- or direct-current power source. When working from a 3-phase alternating-current supply all motors operate synchronously. When operating from batteries they may be operated individually or in interlock at film speeds of 21 to 25 frames per second for both 16-mm and 35-mm film.

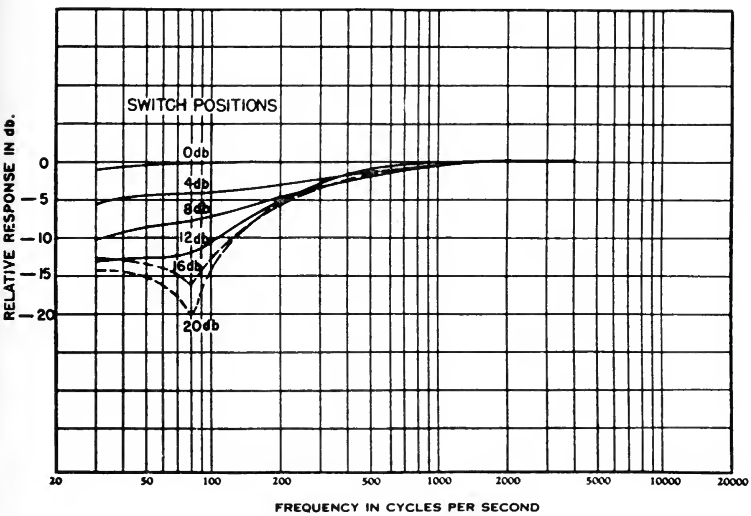

Fig. 15—RA-1283 mixer—dialog-equalizer characteristics.

An RA-1289-A photographic slater and RA-1290-A film punch are available as accessory items. These mount within the recorder and are energized from the RA-1284 power unit.

RESPONSE CHARACTERISTICS

The over-all frequency-response characteristic of the system without equalization is essentially flat from 50 to 10,000 cycles per second with the amplifier on each of its gain settings. However, in actual practice the characteristic is always modified to achieve particular over-all effects as discussed below.

Fig. 15 shows the frequency-response characteristic of the RA-1283 mixer, using the various steps of dialog equalization contained in each mixer preamplifier. The setting used in any particular instance will depend on the acoustic conditions on the set, the presence of wind or other low-frequency noises, and the quality of the particular voice being recorded.[3] These equalizers are adjustable in 5 steps of 4 decibels each at 80 cycles per second with an OFF position. The shape of the family of curves agrees closely with those in general use in Hollywood studios. The average setting is 4 or 8 decibels for 35-mm recording and 12 or 16 decibels for 16-mm recording. For music recording the dialog equalizer is normally in the OFF position.

Fig. 16 shows the frequency-response characteristic for the high-

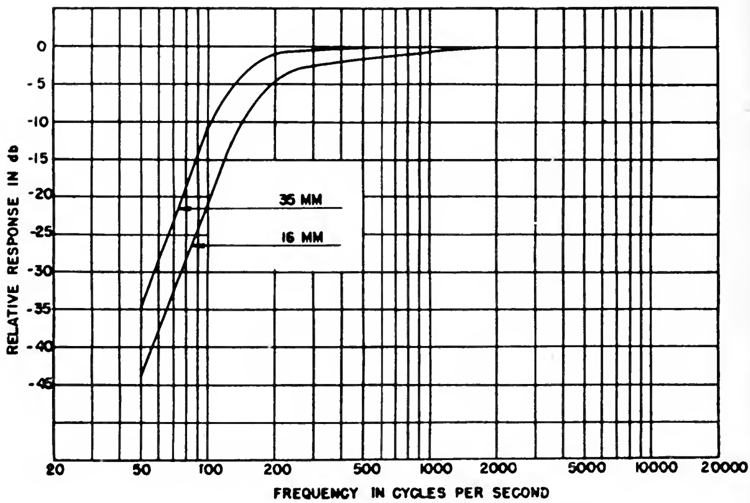

Fig. 16—High-pass filter characteristics.

pass filter which is located at the input of the RA-1282 amplifier. The high-pass filter is used particularly to eliminate components below the fundamental dialog frequency such as are produced by resonance effects on the set or other extraneous noise sources. These unwanted components, which may be subaudible, are thereby prevented from operating the noise-reduction circuit or intermodulating the audible signals. The filter cuts off rather sharply, with the 6-decibel loss point at approximately 120 cycles per second for 35-mm recording, and 180 cycles per second for 16-mm recording. A switch located on the upper side of the amplifier chassis transfers between these two positions or removes the filter from the circuit.

It will be observed that the dialog equalizer and high-pass filter combine to produce the desired over-all response at the low-frequency end, and that the low-frequency loss from each of these networks is greater for 16-mm than for 35-mm recording. This is because the high-frequency cutoff point is at a lower frequency in the 16-mm application because of the reduced film speed and it is necessary to reduce correspondingly the low-frequency response to obtain the most pleasing over-all balance.

Fig. 17 shows the adjustable mid-frequency equalization characteristics. The mid-frequency equalization requirements are based on experimental listening tests which have shown that the "presence" in dialog recording is made more realistic by accentuating the response

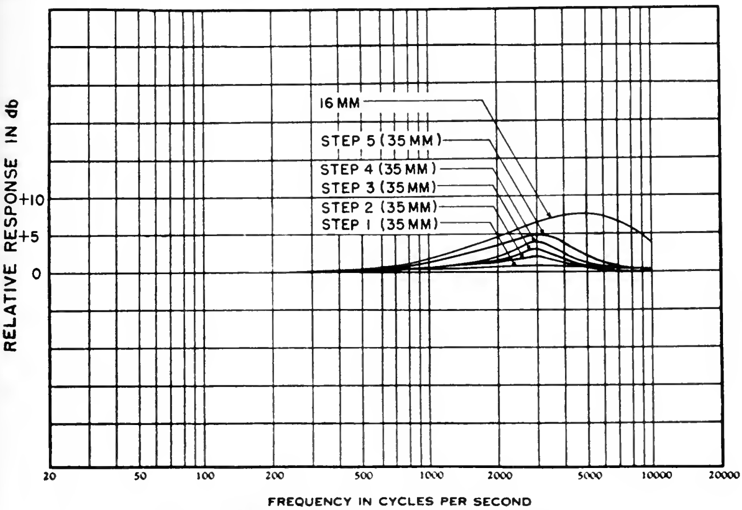

Fig. 17—Mid-range-equalizer characteristics.

in this range. The amount of this equalization varies somewhat in different studios and also depends on the type of microphone used, some of which have at least one resonant peak in this portion of the spectrum. With the Western Electric RA-1142 microphone a 3-decibel boost at 3000 cycles is an average equalization value for 35-mm recording. For 16-mm recording, additional pre-emphasis peaking at approximately 5000 cycles is added to the "presence" equalization in view of the inherent cutoff at 4500 to 5000 cycles on the reproduced film. Five steps of equalization of 1 decibel each plus an OFF position are available for 35-mm recording and one position for 16-mm recording. This control is also located on the upper side of the amplifier chassis.

Fig. 18 shows the frequency-response characteristic for the high-frequency equalization. For 35-mm recording this consists of an equalizer having response complementary to the resonance characteristic of the light valve, thereby making the light-valve modulation correspond to that of the signal over the entire useful frequency range. This characteristic introduces a loss of 9 decibels at the light-valve resonant frequency of 9000 cycles. For 16-mm recording this equalizer is switched to provide a low-pass filter cutting out slightly above 5000

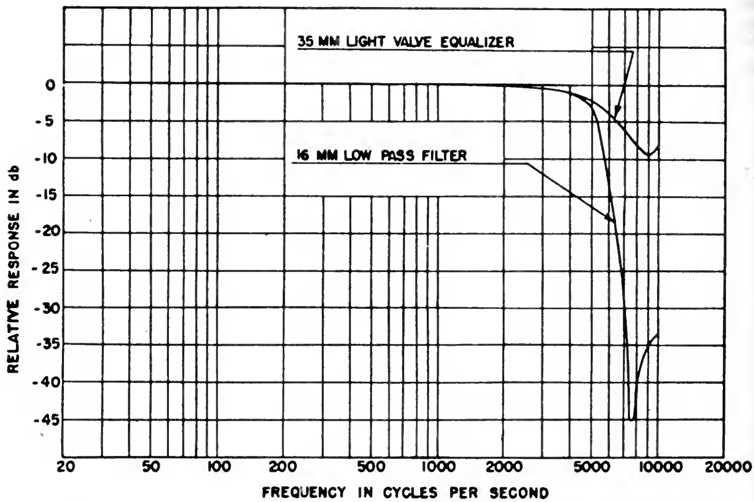

Fig. 18—Light-valve equalizer and low-pass filter characteristics.

cycles in order to suppress those frequency components beyond the 16-mm useful range.

OVER-ALL SYSTEM CHARACTERISTICS

Typical over-all-electrical-response characteristics for recording on 35-mm film are shown in Fig. 19. For dialog recording the low frequencies are attenuated and the mid-range boosted to obain the most realistic dialog quality. The light-valve equalizer is used to complement the effect of light-valve resonance. For music the low-frequency and mid-frequency equalization are removed. The light-valve equalizer is left in the circuit to provide an over-all system response (up to the film) which is flat over the useful frequency range, thereby obtaining the maximum fidelity for the recorded music.

In Fig. 20 a typical over-all electrical response for 16-mm recording is shown. As previously described, for dialog recording the low frequencies are attenuated to a greater extent than for 35-mm recording to obtain the proper balance with the high frequencies which are cut off at 5000 cycles. The mid-range boost and pre-emphasis are also shown. For music recording the low frequencies are attenuated to a lesser extent than for dialog. However, the extreme low frequencies are eliminated and the mid-frequency emphasis is retained to give the most desirable over-all response. Fig. 21 shows a transmission schematic and level diagram of the complete system for normal conditions of operation. Vertical lines on the chart represent fixed gains or losses. Sloping lines represent variable gains or losses.

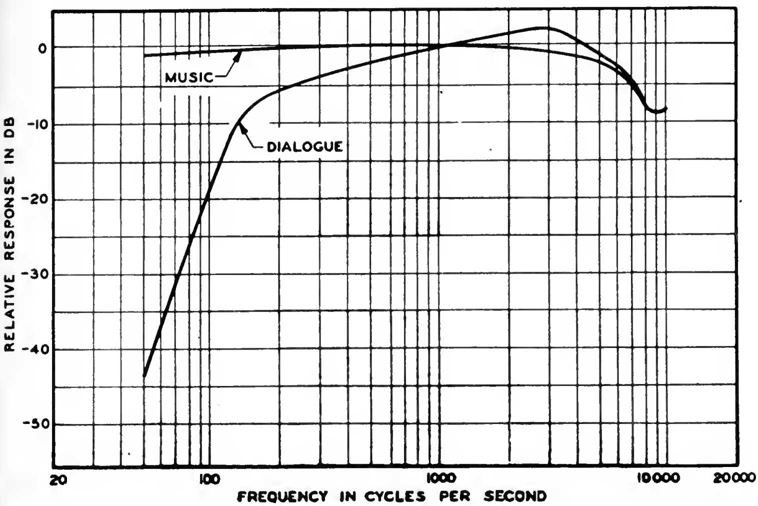

Fig. 19—35-mm recording—over-all-electrical-response characteristics.

Starting at the microphone, at the left end of the chart, an input level of -70 dbm is assumed. This corresponds approximately to that obtained from a Western Electric RA-1142 microphone located 3 feet from an average dialog source.

The signal level at the preamplifier outputs under these conditions is 37 decibels below their overload point, thus allowing an adequate margin for extremely high-level signals.

For this input signal level of -70 dbm the normal mixer output level of -55 dbm is obtained with 12 decibels attenuation remaining in the mixer pots. The signal-to-noise ratio at the mixer output under these conditions is 56 decibels.

For the normal mixer output level of -55 dbm, a $+15$ dbm level is obtained at the output of the final amplifier stage on medium amplifier gain step. This level corresponds to 100 per cent modulation of an average RA-1241 Type light valve. The amplifier signal-to-noise ratio of 65 decibels is well above that of the mixer unit. The signal-to-noise ratio of the system for this average recording condition is 55 decibels at the output of the electrical circuits. An effective signal-to-noise ratio of approximately 48 decibels can be realized from 35-mm film, and approximately 46 decibels from 16-mm film, with the application of noise reduction as provided in the system.

The system in normal operation has a margin of 3 decibels between

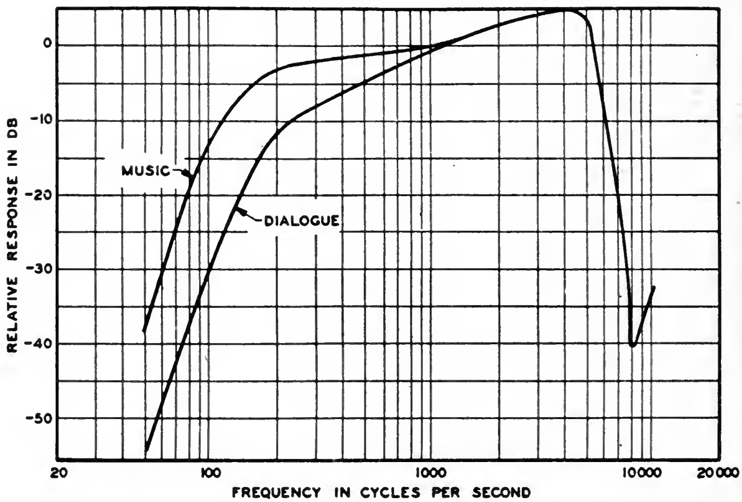

Fig. 20—16-mm recording—over-all-electrical-response characteristics.

the overload point of the light valve and the level at which the amplifier distortion reaches 1 per cent. Peak signals which are allowed to overload the valve for increased effective signal level can extend 7 decibels beyond the light-valve overload point with not over 5 per cent distortion. For peak signals 2 decibels below light-valve overload, and under optimum film-processing conditions, intermodulation can be held to 6 per cent, corresponding to approximately 1.5 per cent total harmonic distortion.

Fig. 22 shows typical frequency-response characteristics obtained from a 35-mm and 16-mm print for constant modulation of the light valve. The high-frequency losses include all film losses introduced in the recording and printing processes. They do not include

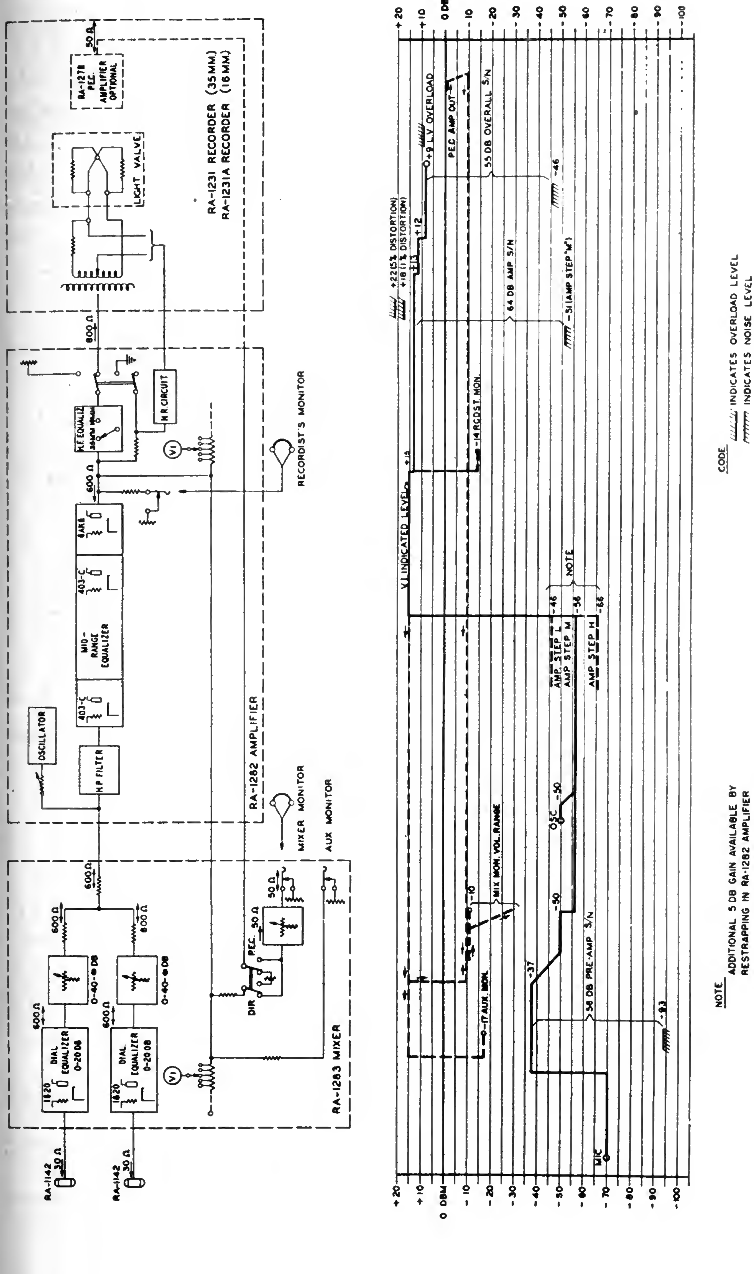

Fig. 21—300 Type recording system—transmission schematic and level diagram.

reproducing scanning losses since the data were obtained by scanning the print with a microdensitometer.

Conclusion

It is felt that the compactness, sturdy construction, and portability features of this equipment amply meet the requirements of the industry for a sound-recording system for general location work. Its versatility and flexibility of operation are of particular value to the small studio which from the standpoint of economy and convenience finds it extremely advantageous to have one type of system meet its

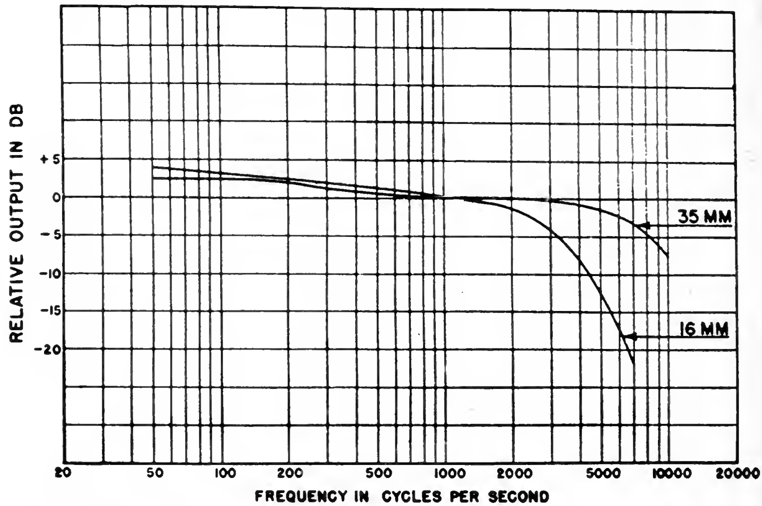

Fig. 22—Response characteristics from film print with constant light-valve modulation.

needs for dialog and music recording on 16-mm or 35-mm film, in the studio or on location. As indicated from the performance characteristics described in this paper, the mechanical and electrical design of the equipment make possible a high-quality sound product, the specifications for frequency range, signal-to-noise ratio, harmonic distortion, and flutter content being consistent with current requirements of major Hollywood studios.

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Demineralization of Photographic Wash Water by Ion Exchange*

By HARRY P. GREGOR and N. N. SHERMAN

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Summary—**An ion exchange system has been developed to purify photographic wash water and allow its re-use. The effluent from a print-washing machine is cycled through a cation and then an anion exchange resin bed, and returned to the machine. The purity of the water obtained approaches that of distilled water.**

This unit was developed for the United States Signal Corps, to be used in mobile photographic units, and is designed to reduce the amount of water required for print-washing. This process is applicable not only to circumstances where water is scarce, but also to processes where wash-water purity and temperature control are important, as in color photography.

The Ion Exchange Process

Cation exchange resins are insoluble, high molecular weight polyacids. They are prepared either by treatment of formed resins to produce acidic groups in the structure, or by having one of the substances used in the resin synthesis already contain the acidic group. An example of a cation exchange resin is shown in Fig. 1, where the resin has been prepared using phenol and formaldehyde (the normal constituents of Bakelite-type resins) and phenolsulfonic acid.

Cation exchange resins contain either phenolic, carboxyl, or sulfonic acid groups. Phenolic groups dissociate only in strongly alkaline solutions. Carboxyl groups dissociate at *p*H values above 7 to 8, while sulfonic acid groups are completely dissociated at virtually all *p*H values. The identification and chemical reactivity of these types of exchange resins are described by Gregor and Bregman.[1]

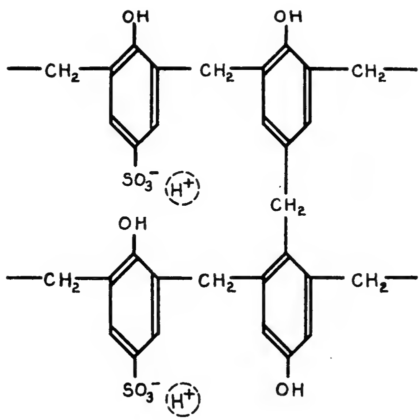
In a dissociated acidic group, the hydrogen ion is held in the immediate vicinity of the fixed anionic group by electrical forces, for the system must be electrically neutral. The hydrogen ion can, however, be displaced from the resin if another cation diffuses into the structure to take its place. Thus, if a solution of sodium chloride is placed in

* Presented October 28, 1948, at the SMPE Convention in Washington.

contact with the resin, the sodium ions replace the hydrogen ions and the solution is converted into one of hydrochloric acid. The sodium ion, in turn, can be displaced by other cations, including hydrogen. The reaction may be written, where the subscript R refers to the resin phases:

$$(R\text{—}SO_3^-\cdot H^+)_R + Na^+ \rightarrow (R\text{—}SO_3^-\cdot Na^+)_R + H^+.$$

The extent of exchange is governed by a modified mass-action effect. Anions present in the solution take part in this reaction only to the extent to which they determine the *p*H. For example, sodium ions

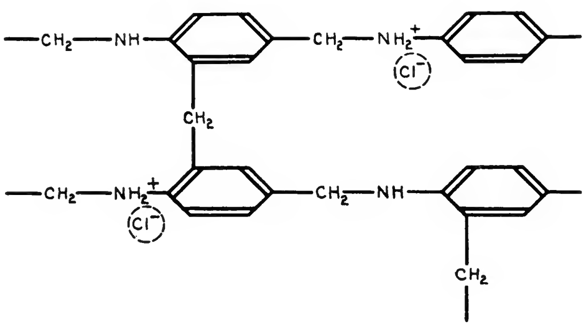


CATION EXCHANGE RESIN
PHENOLSULFONIC-PHENOL-FORMALDEHYDE
Fig. 1

can be taken up by phenolic groups only from a strong base solution, such as sodium hydroxide. Here the action of the resin is technically that of base absorption rather than cation exchange. This is also true for carboxyl resins, at lower *p*H values. If a solution of sodium chloride is passed through a bed of carboxyl resin exchanger, a small amount of sodium ions are exchanged, and then the hydrochloric acid formed represses the ionization of carboxyl groups and inhibits further exchange processes. The nature of the anion has no effect where sulfonic acid resins are used.

Anion exchange resins are insoluble, high molecular weight polybases, usually of the nitrogen-base type. Their active groups are either of the amine type, which is weakly basic, or may be of the guanidine or quaternary type, which are strongly basic. A weak-base resin prepared from aniline and formaldehyde is shown in Fig. 2.

The action of an anion exchange resin depends upon its base strength in exactly the same manner as that of a cation exchange resin is controlled by its acid strength. A weak-base resin can act only in acid solutions, where it absorbs acids through the formation of a salt. This is demonstrated also in Fig. 2. Thus, if a solution of sodium chloride is passed through the resin, practically no reaction occurs. However, if that solution were first passed through a cation bed in the hydrogen state and converted to hydrochloric acid, the acid could be absorbed and thus all of the salt removed, a process known as demineralization.



ANION EXCHANGE RESIN
ANILINE FORMALDEHYDE
Fig. 2

Weak-base anion exchange resins usually will absorb only those acids having an ionization constant of 10^{-7} or larger. Thus, boric acid ($Ka = 6 \times 10^{-10}$) is not absorbed from solution. Strong-base anion exchange resins are completely ionized at virtually all values of *p*H and thus, if originally in the hydroxide state, can convert a sodium chloride solution into sodium hydroxide. Very weak acids, which are not absorbed by weak-base exchangers, can be absorbed by the strong-base resins. Some typical reactions are:

$$(R{-}NH_2)_R + Na^+ + Cl^- \rightarrow \text{No Reaction}$$

$$(R_4N^+OH^-)_R + Na^+ + Cl^- \rightarrow (R_4N^+ \cdot Cl^-)_R + Na^+ + OH$$

$$(R{-}NH_2)_R + H^+ + Cl^- \rightarrow (R{-}NH_3^+{-}Cl^-)_R$$

The exchange capacities of commercially available ion exchange resins vary from 2 to 10 milliequivalents per gram of dry resin; most resins have capacities in the range 3 to 6 milliequivalents per gram. Ion exchange resins are manufactured in mesh sizes ranging from −16 to +50 United States Sieve, and are usually hard granules having negligible solubility.

EXPERIMENTAL PROCEDURES

Laboratory ion exchange beds were prepared to a depth of 6 inches in 1-inch plastic tubes. The details of the construction and opera-

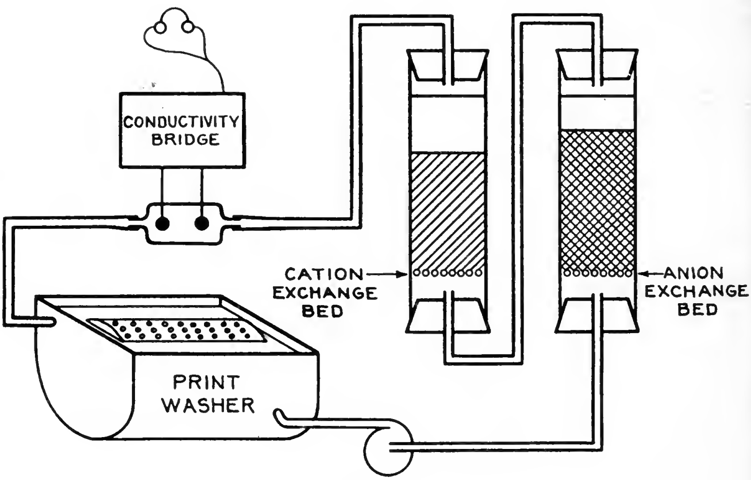


Fig. 3

tion of such tubes are described in handbooks published by the various ion exchange resin manufacturers. Because of the small size of these beds, slow flow rates of the order of 5 to 10 milliliters per minute were used. Cation exchange resins were put in the hydrogen state with hydrochloric acid, anion exchange resins in the base state with sodium hydroxide.

Two kinds of experiments were carried out, one with single beds and slow rates of flow, another with a cation and an anion exchange bed connected in series (for demineralization), operating at a high rate of flow with recirculation. A diagram of this latter apparatus is shown in Fig. 3. The purity of wash water was measured by electrical conductance. Provision was made for other measurements, including pH, rate of flow, pressure loss across beds, and chemical analysis from specific parts of the system.

Original experiments were performed using a natural used fix solution (Kodak F-5), which contained 1.55 milligrams of silver per milliliter. A synthetic used fix was prepared by allowing 2.5 gram $AgNO_3$, 1.8 gram KBr, and 0.1 gram KI to react in solution, filtering off the precipitate, and dissolving it in one liter of fresh fix solution (Kodak F-5). Four milliliters of developer (Kodak-76) were added to simulate natural conditions. This synthetic used fix solution contained 1.36 milligrams of silver per milliliter and was found to be stable for some weeks.

To simulate actual conditions which exist in print-washing, the synthetic used fix solution was diluted 1:100 before being passed through the beds for the slow runs. The actual performance of the resins and their capacities were quite independent of the dilution ratio, within wide limits. With the fast runs involving recirculation, the synthetic used fix was added directly to the washing tank, so that the volume of water in the system was constant.

Standard analytical procedures as described in SMPE publications, particularly that of Atkinson and Shaner,[2] were used.

EXPERIMENTAL RESULTS

The chemistry of the ion exchange process for the demineralization of photographic wash water depends in part upon the rate of flow in the system. At slow rates of flow, the sodium salts are converted to the corresponding acids by passage through the cation exchange bed. The principal constituent of the fixing bath, sodium thiosulfate, is converted to thiosulfuric acid. Since this acid is unstable, it decomposes to form colloidal sulfur and sulfite. This process occurs both in the cation bed and in the effluent.

The silver complex breaks down due to the destruction of thiosulfate, and the silver ions react to form silver sulfide. No silver is taken up by the cation exchange bed under these circumstances. Other cations as potassium and aluminum are exchanged in the bed. The reactions are:

$$2(R{-}SO_3^- \cdot H^+)_R + Na_2S_2O_3 \rightarrow 2(R{-}SO_3^- \cdot Na^+) + H_2SO_3 + S$$

$$2Ag(S_2O_3)_2^{---} \rightarrow 2Ag^+ + 4(S_2O_3)^{--} \rightarrow Ag_2S_2O_3 + 3S_2O_3^{--}$$

$$Ag_2S_2O_3 + H_2O \rightarrow Ag_2S + H_2SO_4.$$

Silver sulfide appears as a black precipitate. It settles out with the colloidal sulfur, or if the cation effluent is passed directly into an anion exchange bed, a layer of silver sulfide and sulfur is deposited on top of the latter bed. While the silver ions liberated by the decomposition of the complex might be taken up directly by the cation resin, the successive passage of more thiosulfate solution through the bed will reform the complex. In no cases was silver found in the cation bed.

The anion exchange bed was found to have absorbed thiosulfuric, sulfuric, and sulfurous acids. The ratio of thiosulfate to sulfite was usually rather small, and depended upon the rate of decomposition of the former into the latter. Acetic acid was absorbed, although boric acid remained in solution except when a strong-base anion exchange resin was used.

When the synthetic used fix was added to runs where water was recirculated at a rapid rate through the demineralization system, decomposition of thiosulfate and the appearance of colloidal sulfur were not observed. This is because the decomposition takes place at a finite rate, and the thiosulfuric acid is absorbed in the salt state, i.e., neutralized, before it can decompose. It was found that even at high rates of flow, the resins used absorbed the synthetic used fix as fast as it entered the beds. The rate-determining step for the process was that determined by the volume of the tank and the rate of flow, i.e., the rate of dilution.

Several different resins were tested for this process. It was found that Dowex 50* was the most satisfactory cation exchanger, being able to convert 1.5 liters of synthetic used fix solution per liter of bed. Ionac A 300† was found to be the most efficient anion exchange resin for this process, absorbing the cation effluent from 800 milliliters of synthetic used fix per liter of resin bed. Since this resin has approximately 20 per cent of its capacity in the form of strong-base groups, it also absorbs boric acid.

When a demineralization run was carried out with the volumes in the two beds adjusted for equivalent capacity, an over-all capacity of 500 milliliters of synthetic used fix solution is absorbed per liter of total bed volume. The results of a typical run are shown in Fig. 4. Here the capacity of the cation bed has been made larger than that of the anion bed. The conductance of the cation effluent is larger than that of the influent because of the exchange of sodium ions for faster moving hydrogen ions. The anion effluent has a specific conductance

* Dow Chemical Co., Midland, Michigan.

† American Cyanamid Co., New York, New York.

of 1.2×10^{-5} mho, has a pH of 6 to 7, and approaches distilled water in purity. In Fig. 4, the acid-absorbent capacity of the anion bed is exhausted first, as shown by a rise in conductance until the cation-bed effluent passes unchanged through it. The subsequent exhaustion of the cation bed is indicated by a drop in conductance to that of the influent.

After various runs, the beds were separated into vertical sections and treated with regenerant solutions to study the nature of the process. The Dowex 50 bed was regenerated with acid, and was found to be almost entirely in the sodium state, with small additional amounts of aluminum and potassium. No silver could be detected.

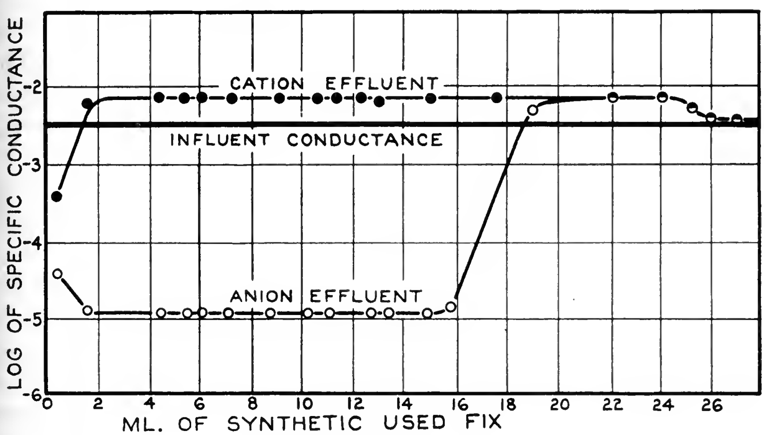


Fig. 4

The Ionac A 300 bed at the conclusion of a run was coated with a black precipitate, probably silver sulfide. When this bed was sectioned and regenerated, all of the silver added to the system was recovered from the upper third of the bed. However, the black discoloration did not seem to be affected. Thus, the silver was absorbed for the most part as the silver-thiosulfate complex, and is readily available for recovery. Most of the added thiosulfate was recovered in that form, indicating that it was absorbed before decomposition.

The demineralization unit is regenerable, and repeated cycles showed no significant changes in capacity.

The amount of fix solution which is imparted to wash water by photographic prints was determined by developing and fixing a quantity of exposed paper, then removing the excess liquid with a roller squeegee, followed by washing all the fix out of the paper. It was found that to wash one thousand 8- × 10-inch prints, a unit having a bed volume of approximately 5 liters would be required. Prints washed in this demineralized water were compared with ones washed in distilled water; no differences were observed. The stability and clarity of the prints were unchanged, as shown by "Fadometer" tests.

Other demineralization processes were also tested. By the use of a strong-base anion exchange resin ahead of a cation resin, the normal cycle can be reversed. Thus, neutral salts in the influent are converted to their corresponding hydroxides by the anion bed, followed by base absorption in the cation bed. In this experiment the anion exchange resin Amberlite IRA-400,* which has most of its capacity in the form of strongly basic groups, was used. This bed was followed by one of Dowex 50. While this demineralization system produced a good grade of wash water, its capacity was considerably less than that of the one adopted.

The use of a weak-acid cation exchange resin was also investigated. When a carboxyl resin is used in conjunction with an anion exchange bed, demineralization can occur. The small amount of acid formed upon the first pass is absorbed by the anion bed, and the neutral effluent upon recycling can have more of its cations converted to acid and be absorbed. This system was investigated, using Amberlite IRC-50* as the weak-acid cation exchange resin, and Ionac A-300 as the anion exchange resin. This system was able to demineralize wash water. However, the rate of the process was much too slow for print-washing. Also, the quality of water produced was poor.

The applicability of this method for color-process work was demonstrated by developing identical batches of Ansco color film simultaneously, one being washed in tap water and the other using the demineralization apparatus. The developing outfit was Type 2. No detectable difference in the quality of the two prints appeared. It has been observed that reticulation of film occurs in some instances where wash water of too high purity is used, due to the excessive swelling of the emulsion caused by osmotic pressure. This can be avoided for the demineralization process by adding a small amount of a nonelectrolyte, as urea, to the water, since compounds of this type are not affected by ion exchange.

* Rohm and Haas Co., Philadelphia, Pennsylvania.

Acknowledgment

The authors wish to express thanks to the United States Signal Corps for its support of this investigation, which was carried out under Contract No. 36-039 sc-36812 of the Signal Corps Engineering Laboratories, Fort Monmouth, New Jersey.

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Discussion

MR. JOHN I. CRABTREE: Does it not require a considerable amount of water to wash out the acid and alkali when regenerating the resins?

DR. HARRY P. GREGOR: It does require considerable amounts of water to rinse the beds after regeneration, two or three times the bed volume as a minimum. Since one quart of resin bed delivers the equivalent of 200 quarts of wash water, this will reduce the conservation factor from 1:200 to 1:66.

MR. CRABTREE: We have usually found that about six volumes of water are about the minimum to wash the bed, carry the regenerant, and accomplish the required rinsing of the bed after regeneration. What weight of resin is required per liter of fixing bath?

DR. GREGOR: Our data primarily are based on volume rather than weight. One quart of resin in water has a weight of approximately 1.2 kilograms. This will absorb about one-half quart of used fix solution.

MR. CRABTREE: Have you compared the efficiency of this method with the cascade system of rinsing in successive tanks, where you replace the first tank with the second tank, and so on?

DR. GREGOR: As I understand it, the United States Signal Corps specification of one quart of wash water required for each 8- × 10-inch print is based on the countercurrent system you describe.

MR. CRABTREE: Assuming that the new ion exchange agents described are actually as efficient as indicated and can be regenerated with so little water, there is still to be considered the weight of the apparatus, the weight of the regenerants, and the fact that materials such as hydrochloric acid and caustic soda, because of their hazardous nature, require somewhat more substantial containers than would the equivalent volume of water. We decided in our work some years ago that the matter simmered down to a question of whether the shipping space would be more efficiently used to carry extra wash water or the apparatus and chemicals required for deionization and decided that there was little if any choice between the two.

In the Army Medical Services they give the film a dip for a second or so in water and then squeegee the film between two sheets of transparent sheeting such as Kodapak. The film can then be handled like a dry film and can be washed at a later date after stripping away the sheeting. I do not see any object in trying to get a high-quality film or print right in the field when water is at a premium. It is probable also that the concentration of fixing bath in the wash water would be greater than 1 per cent. Have tests been made with more concentrated solutions?

DR. GREGOR: The units which we have developed for the Signal Corps are not designed to be regenerated under field conditions, but employ replaceable cartridge units which are used once and then sent back to a base area for regeneration. Since one quart of resin must be transported instead of 200 quarts of water, this constitutes a satisfactory solution to the logistical problem. We have been able to regenerate these units and recover the silver readily. However, this procedure applies best to commercial uses and to operations that can be carried out at a base area rather than to front-line conditions.

I do not know why the Signal Corps specifies washing of the prints rather than the process you describe. We have carried out our work within the frame of reference of the Service specifications.

In regard to the presence of fixing chemicals in the wash water, this was less than 0.001 per cent. The process was efficient to the extent that the purity of the wash water was greater than that of distilled water. As a consequence, the problem of delineating the upper limit of the amounts of fixing chemicals which can remain in the wash water, did not arise.

Meetings of Other Societies

August—

Institute of Radio Engineers West Coast Convention	August 30 through September 2 San Francisco, California

September—

Illuminating Engineering Society National Technical Conference	September 19 through September 23 French Lick, Indiana
National Electronics Conference	September 26 through September 28 Chicago, Illinois

October—

Photographic Society of America Convention	October 19 through October 22 St. Louis, Missouri
Optical Society of America Annual Meeting	October 27 through October 29 Buffalo, New York

October-November—

Radio Fall Meeting Joint IRE-RMA	October 31 through November 1 Syracuse, New York

March, 1950—

Institute of Radio Engineers National Convention	March 6 through March 9 New York, New York
Optical Society of America Winter Meeting	March 9 through March 11 New York, New York

Film Vaults: Construction and Use*

By JOHN G. BRADLEY

Motion Picture Consultant for the Library of Congress, Washington, D. C., on furlough status

Summary—The presently accepted type of film-storage vaults and the standards governing their use are reviewed. The discussion is made in terms of vent area per film load and the resulting pressures; horizontal versus vertical arrangement of film cans; open rack, shelf, and cabinet storage; units of risk for material of high subject-matter values; air conditioning; and related problems. Special mention is made of an insulating retractor belt for shelf storage.

Introduction

The recent advent of a new safety film base,[1] intended to replace some of the present film bases, merits preliminary comment in connection with this discussion. Substantial claims are made for its projection life as compared to the acetate safety film, for its safety characteristics as compared to the nitrate film, and for its chemical stability. It is hoped that before many years its superiority in all respects will have been demonstrated and that at least the use of the highly inflammable and chemically unstable nitrate film no longer will be necessary.

This long-range solution of the problem does not, however, account for the vast accumulations of nitrate film, much of which should be copied immediately, or for which added protection should be provided. Because a transfer of accumulated nitrate film to a safety base is expensive, beyond the current budgets of many film custodians, it appears that a nitrate-film-storage problem still exists and will continue to exist for many years to come. For the further reason that serious losses continue under present standards of vault construction and use, a review of the entire problem seems to be in order at this time. While this discussion emphasizes the hazards of nitrate film, it does not ignore the need for adequate protection of other types of record material of high value.

The General Problem Stated

Proper film storage (aside from the protection it should give the

* Presented October 25, 1948, at the SMPE Convention in Washington.

working staff) should reduce to a minimum the risk of loss from fire, water, and chemical deterioration. The average vault in current use does not meet these requirements. Fires continue at an uncomfortable rate, damage from water in an attempt to control such fires remains serious, and the application of known chemical preservation techniques is frequently difficult if not impossible. In this latter respect, the chemist and the custodian have gone ahead of both the underwriter and the architect. In fact, our national thinking in terms of vault construction and storage practices seems to have come to a halt many years ago.

For example, the Underwriters' Laboratories, the National Board of Fire Underwriters, municipalities, and others in a position to speak with authority on the subject, still approve the storing of 7 pounds of nitrate film for each square inch of vent area, still require heavy and expensive construction to prevent a rupture of the vault by reason of fire and internal pressure, still approve up to 10,000 pounds of film per vault unit regardless of the subject-matter value of such film, and still recommend the storing of cans on edges in both vaults and cabinets, which exposes the film to damage by water. On the subject of temperature and humidity control these same authorities are almost completely silent. These are the facts; what are the implications?

Neither experience nor experiment supports such practices, particularly when the protection of archival or other material of high value is involved. Certainly a cabinet in which each can of film is stored horizontally in a separate compartment that is vented to the exterior, as advocated by Crabtree and Ives[2] 19 years ago offers greater protection against both fire and water than a vault where the cans are stored on edge in open racks. Certainly the need for protection against high pressures and chemical deterioration has been amply demonstrated in recent years. Perhaps the apparent discrepancy between existing regulations and recently developed information is the fact that such regulations have not been thoroughly revised in several years, a discrepancy we hope will be corrected shortly.

Perhaps a better explanation is a matter of misplaced responsibility. For example, the architect is not supposed to be a chemist or a custodian. He builds for others and in the terms that others dictate. The underwriter's interest in fire control is based chiefly on a possible loss of property. He is a sort of scientific gambler; he takes a calculated risk and if he loses he pays the debt, but not by replacing a priceless record. He bets against lightning striking the storage building, someone winding a film too fast or dropping it on a concrete floor, excess humidity and overheating, short circuits, and other causes of film fires. He bets on the *average* and pays off on the *exception*. It is not his responsibility to worry about the exception even though it involves an irreplaceable item. Theoretically it is no concern of either the architect or the underwriter if the custodian wants to store films of both primary and secondary value in one vault as the unit of risk. But it is the custodian's fault if he fails to distinguish between such values and demand protection accordingly.

Fortunately such a distinction is being made now as never before and the need for greater protection appears more important by contrast. People are becoming more preservation-conscious. Sharper separations are being made among record materials of different values. The reissue value of some of the old classics is becoming increasingly obvious. Producers realize that the genius portrayed in a particular production may be impossible to recapture; while many of the factual pictures that record situations in time and place that cannot be reassembled, or that depict persons no longer living, have become priceless. The custodian is becoming an archivist.

It appears, therefore, that one of the basic prerequisites of appropriate vault construction and use is an appraisal of the material to be stored in terms of the protection required.

OPEN-RACK STORAGE—TERTIARY PROTECTION

In these terms, let us examine a typical film vault currently in use. It contains 750 cubic feet and has an authorized storage capacity of 10,000 pounds of nitrate film. In the 35-mm size, this amounts to some 2,000,000 feet, 2000 reels, or 200 ten-reel subjects. If all the material so stored represented camera negatives or archival items in any form, it is conceivable that one vault might house irreplaceable property costing 20 or 30 million dollars (or more) to produce, to say nothing of other costs such as human life, in the case of war pictures. This is a dangerous procedure, particularly when it is now a well-known fact that all the film so stored may be lost or seriously damaged in case of fire. It is obvious that in such a case such a risk is too great. Only when the film stored represents material of tertiary value such as worn and duplicate prints, could such a unit risk be justified.

Let us examine this vault further. It has a vent of one square inch for each 7 pounds of nitrate film or a total of 1400 square inches for the vault. Experiments conducted under high governmental and scientific auspices over the last few years have proved conclusively that such a limitation of vent to film load is dangerous, that it will produce pressures on the borderline of explosions, and that a rupture of the vault may and frequently does result. In case of such a rupture, neighboring vaults are involved in the losses, as actual incidents on record indicate.

A vent of 1 square inch for not more than 5 pounds of film is recommended; or to state the matter another way where vaults are already constructed, not more than 5 pounds of film for each square inch of vent should be allowed. With such a ratio, no serious pressure is likely.

Let us examine this typical vault still further but this time in terms of the arrangements of film cans, and the habits of (nitrate) film fires on which recent experiments have thrown much light. For example, the typical vault is designed for open-rack storage with the cans placed on edge. Upright partitions extending from floor to ceiling divide these racks into sections 36 inches wide each. This arrangement provides for the storing of some 20 or 25 cans (depending on their thickness) side by side on each rack in each section. There are no horizontal separations between racks so that an open space exists from the floor to the ceiling. Experiments have shown that if the film in one can ignites, the fire will spread sideways to the adjacent cans at intervals of less than five seconds. The fire will also spread vertically to floor and ceiling. In this case, the section is the unit of risk. But that is not all; the fire may jump across the aisle and involve the film on the other side of the vault and cross-fire back and forth until the entire contents of the vault are involved. If the water system should fail, the duration of the fire is generally less than three minutes. If the water system does not fail and the sprinkler heads operate properly, the spread of fire will be slower but may, and frequently does, involve the entire vault. If, by chance, some of the film escapes the fire, it is likely to be damaged by water.

In such a circumstance, the gamble is that there will be no fire; for it can be seen that if a fire occurs, the protection is negligible. Or, granting the possibility of a fire, the gamble is that the water sprinklers will operate, that the progress of the fire will be retarded, that the pressure will not rupture the vault, and that the loss will be limited to the original vault involved. Let it be repeated that only when the material stored represents tertiary values or items that can be easily and cheaply replaced, could such a risk be justified.

SHELF STORAGE—SECONDARY PROTECTION

If the custodian does not want to take the risks inherent in open-rack storage (just described), two solutions to his problem are suggested: (1) shelf storage for films of secondary values and (2) cabinet storage for films of primary values. Both shelf and cabinet storage, designed by the author several years ago, may be found in the National Archives Building, Washington, D. C., but are discussed here with certain improvements suggested.

In the case of shelf storage, the cans are stored flat to prevent damage from water. The upright partitions are increased in number

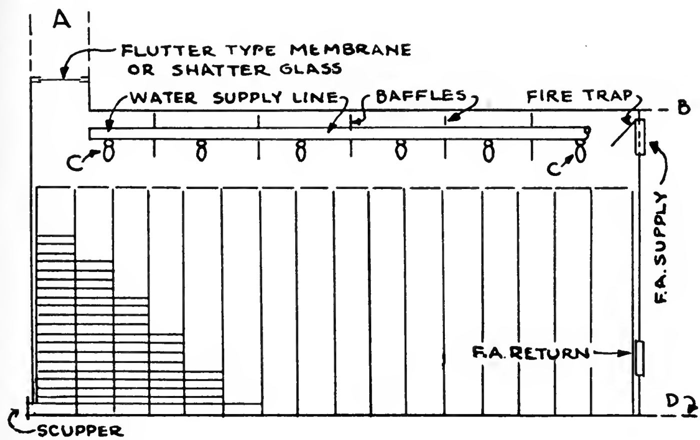

Fig. 1—Side-view elevation. *A*, flue to exterior; *B*, ceiling or roof line; *C*, sprinkler heads; *D*, floor.

from one every 36 inches (open-rack storage) to one approximately every 12 inches; that is, one for each tier of film cans. Such proximity of partitions limits the unit load involved in the horizontal spread of fire. (See Fig. 1.) The shelves are solid with a maximum of heat resistance and a minimum of heat conductivity and serve as insulators against a vertical spread of fire. (See Fig. 2.)

NOTE: In some instances where horizontal storage has been adopted, the cans rest on short flanges that are anchored to the sides of the upright partitions. In such a case it is argued that the use of such flanges, instead of solid shelves, allows the water from the sprinkler heads to reach each can in full volume. It should be pointed out, however, that water by itself may not prevent a spread of a nitrate-film fire; a vertical spread in this case. With such an arrangement the unit risk would be the entire tier of films.

To compensate for this loss in volume of water when insulating shelves are used, directional spray-type sprinkler heads are recommended. It is also recommended that these heads be so positioned

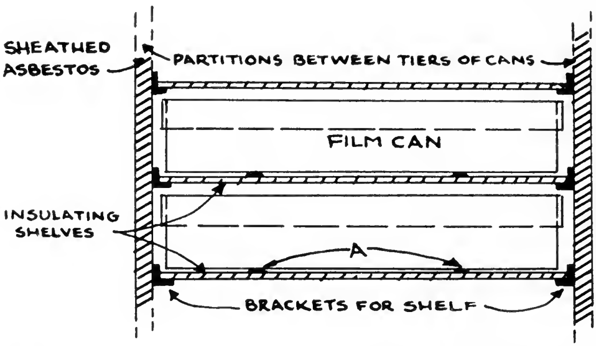

Fig. 2—Front-view elevation. *A*, "blisters" to support cans and create air and water space.

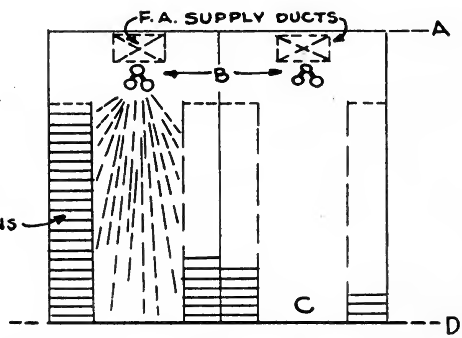

Fig. 3—End-view elevation. *A*, roof line; *B*, water sprinklers; *C*, vault aisle; *D*, floor line.

that the spray is thrown at an angle against the outer or exposed edges of the cans into the compartments. This is illustrated in Fig. 3.

*Insulating Retractor Belt:** Two additional dangers exist with respect to shelf storage that merit comment; heat conduction and cross fire. NOTE: The directional spray, mentioned above, will reduce the danger of cross fire but it may not eliminate it. In connection

* Patent pending.

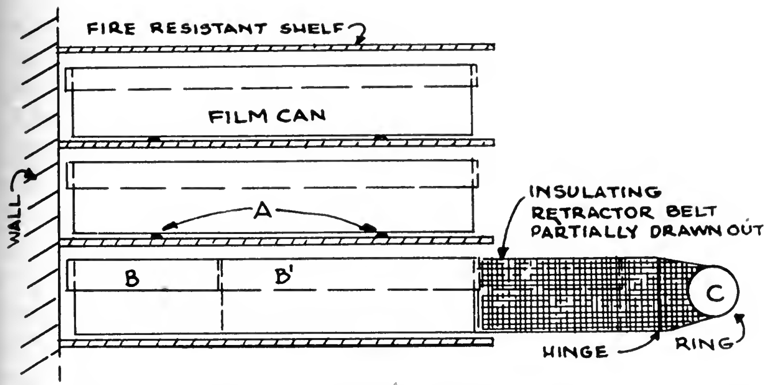

Fig. 4—Side-view elevation. *A*, "blisters" to support cans; *B*, can in place; *B'*, can partially withdrawn.

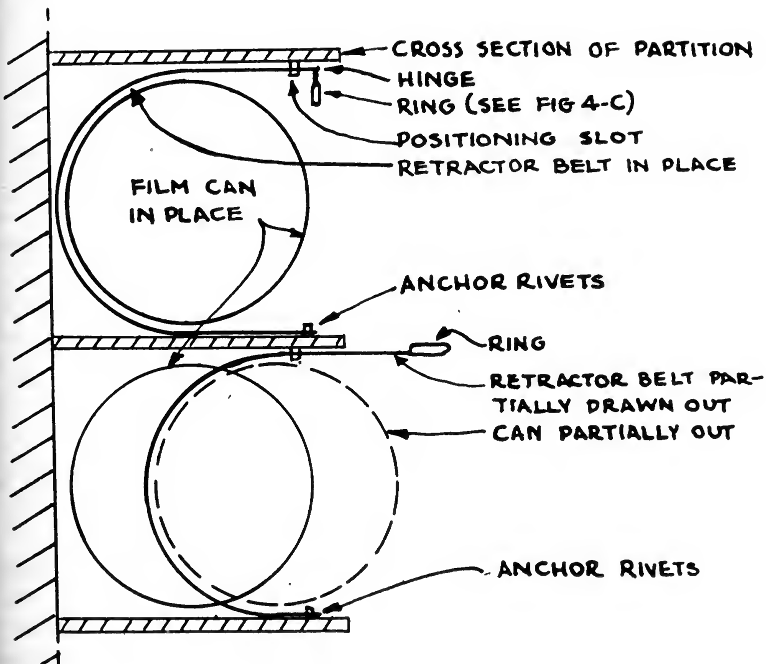

Fig. 5—Plan showing operation of retractor belt.

with both these dangers, attention is called to the above-mentioned belt, the principal functions of which are listed below.

(1) As a retractor device to pull the can from the compartment until it can be gripped by the fingers as illustrated in Figs. 4 and 5. With this device the compartment can be made smaller so that the total space saved in the vault is considerable. As a retractor device, the belt is applicable to both nitrate and safety film.

(2) As an insulating device to separate the metal partitions from the metal cans and thus minimize the danger of heat conduction from the one to the other as illustrated in Fig. 5.

(3) Again, as an insulating device to protect the front edges of the

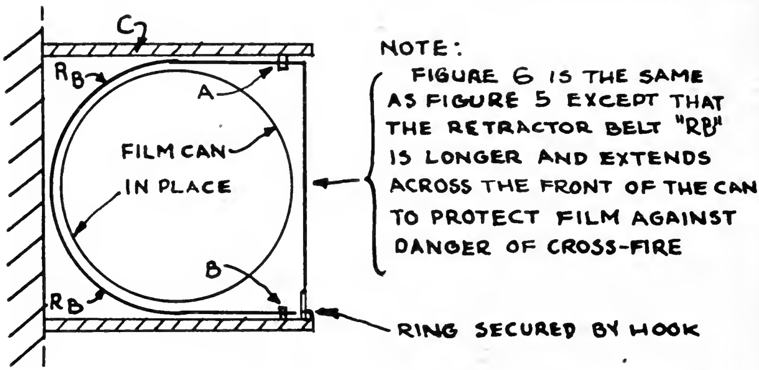

Fig. 6—Plan. *A*, positioning slot; *B*, anchor rivets; *C*, cross section of partition.

cans from the heat on the opposite side of the vault and thus lessen the danger of cross fire. (See Fig. 6.)

The insulating retractor belt can be made of any fire-resistant material such as asbestos or spun glass, woven to give it tensile strength. Its width should be approximately the same as the height of the can. It is anchored to one of the upright partitions, encircles the sides and back of the can, and runs through a positioning slot or guide on the opposite upright partition. If other means have been provided for protecting the front edges of the can (as will be suggested later in this discussion) or if safety film only is involved, the belt terminates just in front of the positioning slot with a hinged ring in its tapered end for easy handling. If, however, it is to be used as a protection against cross fire, it is extended across the face of the can to the original anchor point where its end ring is secured by a hook as illustrated in Fig. 6. When so used, the belt does not prevent water from entering the compartment in sufficient quantity for cooling purposes nor will it cause flooding of the film; there is ample space under its front part for drainage.

Fire and Water Baffles: Another means of protecting the front edges of the cans from cross fire consists of two hinged baffles, anchored at the front of the compartment as illustrated in Fig. 7. The lower baffle extends upward to a vertical height of approximately 1/4 inch and outward (into the vault aisle) at an angle of about 40 degrees. The two triangular spaces at the ends of this baffle are enclosed and the baffle is held in place by a spring. This spring permits it to swing downward when the can is being removed from or inserted into the compartment. The upper baffle hangs in a vertical position of its own weight. The two baffles, when in normal position, slightly

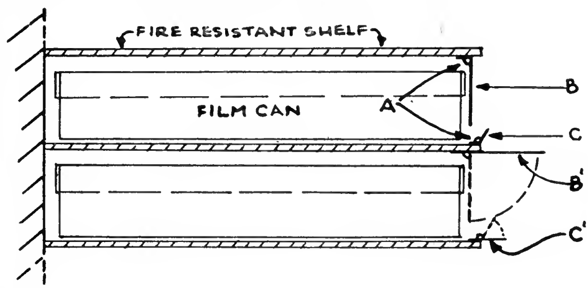

Fig. 7—Side-view elevation. *A*, hinges; *B* and *C*, baffles in place; *B'* and *C'* baffles open.

overlap, and thus protect the can from cross fire. The lower baffle serves the additional purpose of diverting water from the sprinkler heads into the compartment for cooling purposes; its limited height prevents flooding of the film.

The baffles may be opened, for inserting or removing the can, either by a simple bell-crank mechanism or by the use of the retractor belt. In the latter case, the shorter version of the belt is used as shown in Figs. 4 and 5. Its ring and about 1/4 inch of its tapered end are drawn through a slot in the lower part and one end of the upper baffle. About 6 inches of the front end of the belt is stiffened so that when it is pulled outward, it lifts the upper baffle and forces the lower baffle down. (See Fig. 8.) Both baffles remain open until the can is replaced and the belt pushed back into position.

Still another protection against the danger of cross fire is the use of half vaults; that is, films stored only on one side of the vault. In such a case, the cross fire from an affected compartment would strike the opposite wall where its force and heat would be reduced. This would be particularly true after the water sprinklers operated and the wall was kept wet with a sheet of flowing water.

NOTE: The suggestions covering the use of the insulating retractor belt, fire and water baffles, and half-vault storage are offered largely on the basis of theory, without the benefit of extended experiment. The theory is derived, however, from experiments with comparable situations and is believed to be sound.

As a further precaution against heat conduction, particularly in a vertical direction, it is recommended that air space be provided between the can and the shelf on which it rests. This can be done easily by ridges or "blisters" about $^1/_8$ inch in height either on the upper surface of the shelf or on the bottom of the can. (See Figs. 2 and 4.)

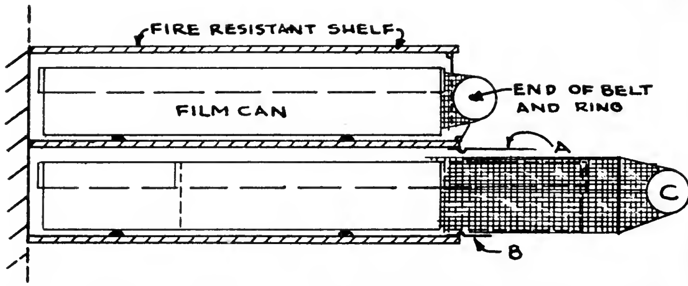

Fig. 8—Side-view elevation. *A*, upper baffle in open position; *B*, lower baffle open; *C*, ring and retractor belt partially withdrawn.

The cost of shelf storage herein described is not excessive in terms of the protection it provides. Perhaps the greatest objection is the loss in storage load per vault. This is not serious, however, because a vault of normal size will house nearly 1000 reels of 35-mm film with the tiers extending only 6 feet high. Such a load is not too far below that actually carried in general practice.

While there may be some risk of initial loss in shelf storage, before the sprinkler heads operate, such a risk is negligible when compared to the risk in open-rack storage.

CABINET STORAGE—PRIMARY PROTECTION

If the custodian wants maximum protection for material of maximum value as well as maximum safety for personnel, cabinet storage is recommended.

Both insulated and uninsulated cabinets have been described previously[3-6] and will not be discussed here except briefly, and in terms of construction and installation problems. The uninsulated or water-seal cascade cabinet, which is the more economical to install, will be cited as a typical solution to the problem posed.

The basic principle of the water-seal cabinet, stated briefly for the convenience of the reader, is a diversion of heat from the storage area of the cabinet into a common flue, and the introduction of water into the cabinet where it flows over, under, and around each film can. The source of the water is an automatic directional spray-type sprinkler head. Each film is stored horizontally in a metal can, and in a separate compartment that is vented to the common flue. The cabinet can be designed for either 1000- or 2000-foot reels of film and for as many of each as needed in either the 35-mm or 16-mm size.

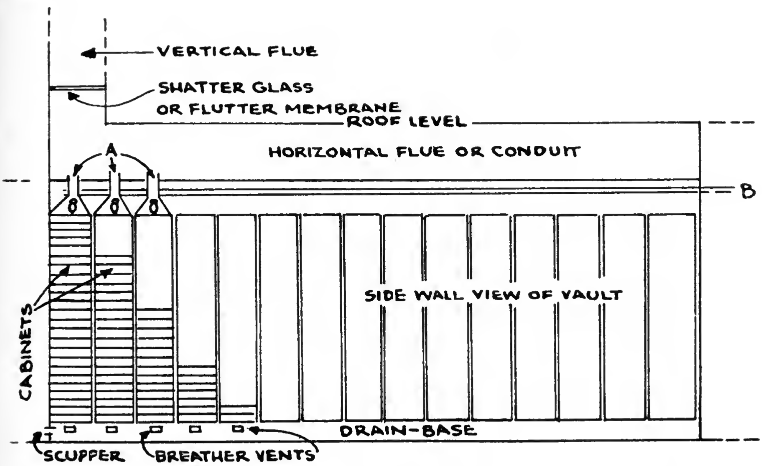

Fig. 9—Side-view elevation. *A*, cabinet flues; *B*, water-supply line.

For the sake of illustrating the construction problem under consideration, however, a cabinet that will hold 24 1000-foot, 35-mm reels is cited. It consists of a 4-inch drain base, a 72-inch storage section, and an 8-inch hood containing the water sprinkler. The overall height is, therefore, 84 inches. The topmost can is 76 inches from the floor, or within easy reaching distance without the use of a footstool or ladder. The installation of this cabinet requires either a hung ceiling, or a conduit over each row of cabinets, into which the upper part of the flue is inserted. Fig. 9 shows a side view and Fig. 10 shows an end view of such an installation. Fig. 11 shows a ceiling plan with the use of conduits. Fig. 12 shows an enlargement of a hood near the juncture of the ceiling or conduit.

The unit of risk is one reel or 5 pounds of film. Extended experiments indicate that an incipient fire *inside the cabinet* will not spread, nor will an external fire penetrate the cabinet. All fumes are filtered and siphoned off to the outer air. By reason of its airtight construction and the water-seal drain base, combustion seldom takes the form of a flame; hence the total heat is kept to a minimum for this type of fire. In the remote event that the water supply failed, the spread of fire (if any) would be very slow, and fire fighters could enter the vault and manually put the fire under control; that is, stop its spread by cooling the unaffected cabinets until the original or incipient fire burned out. This would not be practicable or advisable in the case of open-rack or shelf storage.

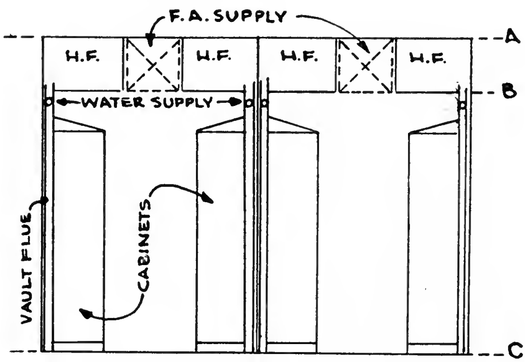

Fig. 10—End-view elevation. *A*, roof line; *B*, conduit or hung ceiling line; *C*, floor; *HF*, horizontal flues or conduits.

The custodian may, if he wishes, provide a reserve water-storage tank as insurance against a possible failure of the municipal water supply. It should be noted that the aperture of the sprinkler head recommended is only $^3/_8$ inch and delivers approximately 15 gallons of water a minute. It should also be noted that seldom will more than one sprinkler head be involved at any one time. In these terms, it can be seen that a reserve tank holding only 500 gallons would last some 25 minutes, or long enough for the incipient fire to burn out.

Another feature of the water-seal cabinet, recently developed and not previously reported in the JOURNAL, is a heat-conducting element. (See Fig. 12.) The purpose of this element is to accelerate the operation of the sprinkler head in case of an external fire; that is, a fire simulating a burning-building condition. NOTE: The average time required for the sprinkler head to operate during an *internal* fire is about 20 seconds after ignition. Preliminary tests with *external* fires indicate that the sprinkler head will operate within about the same time after the fire has contacted the heat-conducting element.

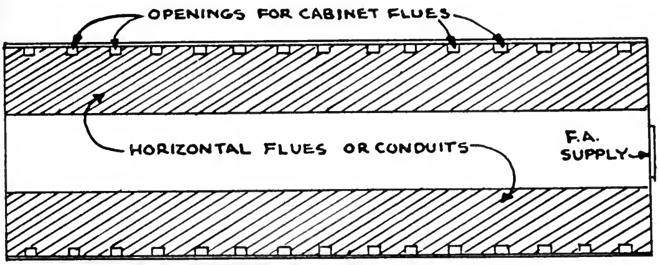

Fig. 11—Ceiling or conduit plan.

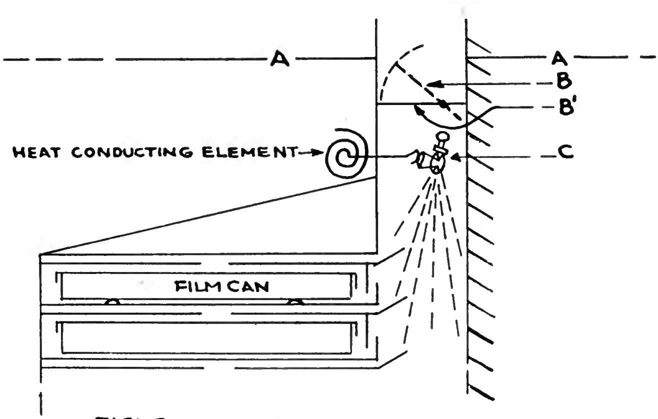

Fig. 12—Side-view elevation. *A*, ceiling or conduit line; *B*, fire trap open; *B′*, fire trap closed; *C*, spray-type water sprinkler.

MISCELLANEOUS CONSIDERATIONS

A suitable air-conditioning system, properly trapped against backfire, is recommended for all storage where material of high value is involved and where long-range preservation is a part of the problem. Figs. 1 and 3 show such an installation. If no air-conditioning system has been provided for existing vaults, dehumidifying units are recommended; these represent no serious installation problem.

Not only should drains of ample capacity be included in all sprinklered vaults, but means should be provided for keeping such drains open to full capacity; otherwise, a collapse of the floor from the weight of the water may result. For wall scuppers, a picket guard is suggested to prevent coarse material from entering and clogging the openings.

Prevailing regulations stipulate a limit for both the load of nitrate film stored (10,000 pounds) and the size of the vault (750 cubic feet). In terms of cubic footage, this means (among other possible dimensions) a vault 16 feet long, $5^1/_2$ feet wide, and $8^1/_2$ feet high. For cabinet storage of the type described, the load limit within these dimensions is about 700 reels of 35-mm film. A vault 16 feet long also represents a convenient limit in terms of water-supply lines and sprinkler heads if bulkiness in the supply lines is to be avoided.

In many instances, however, smaller vaults will be an advantage for the reason (among others) that cheaper construction may be employed. For example, the National Board of Fire Underwriters[7] approves vaults or work-storage rooms with metal-lath and plaster walls only $2^1/_2$ inches thick (among other thicknesses prescribed), providing cabinets are used. Up to 200 standard rolls may be so stored. See subsection 112 (a) of the NBFU Regulations. Among the places where such construction and cabinet storage is presently approved are work rooms, projection booths, rewinding rooms, shipping rooms, and studios.

In the design of new vault buildings where a row of vaults for each side of a common corridor is planned, it is recommended that the vault doors be staggered so that they do not face each other. It is also recommended that long narrow vaults be avoided; ample aisle space is not an extravagance.

References

(1) Charles R. Fordyce, "Improved safety motion picture film support," *J. Soc. Mot. Pict. Eng.*, vol. 51, pp. 331–351; October, 1948.

(2) J. I. Crabtree and C. E. Ives, "The storage of valuable motion picture film," *J. Soc. Mot. Pict. Eng.*, vol. 15, pp. 289–306; September, 1930.

(3) John G. Bradley, "Motion pictures as government archives," *J. Soc. Mot. Pict. Eng.*, vol. 26, pp. 653–661; June, 1936.

(4) Report of the Committee on Film Preservation, *J. Soc. Mot. Pict. Eng.*, vol. 27, pp. 147–155; August, 1936.

(5) John G. Bradley, "Changing aspects of the film-storage problem," *J. Soc. Mot. Pict. Eng.*, vol. 30, pp. 303–318; March, 1938.

(6) Report of the Committee on Preservation of Film, *J. Soc. Mot. Pict. Eng.*, vol. 35, pp. 584–607; December, 1940.

(7) Regulations of the National Board of Fire Underwriters for Nitrocellulose Motion Picture Film, New York, N. Y., 1939. Pamphlet No. 40.

66th Semiannual Convention
SOCIETY OF MOTION PICTURE ENGINEERS

Hollywood-Roosevelt Hotel • October 10–14, 1949 • Hollywood, California

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GENERAL INFORMATION

HOTEL RESERVATIONS AND RATES The Housing Committee, under Watson Jones, chairman, will make reservations for members and guests. Inform him at 1560 North Vine Street, Hollywood 28, California, of the accommodations you desire. He will book your reservations and confirm them.

TRAVEL Make your train or plane reservations early because West Coast travel in October normally is quite heavy.

PAPERS PROGRAM Authors who plan to prepare papers for presentation at the 66th Convention should write at once for Authors' Forms and important instructions to the Papers Committee member listed below who is nearest. Authors' Forms, titles, and abstracts must be in the hands of Mr. Grignon by August 15 to be included in the Tentative Program, which will be mailed to members thirty days before the Convention.

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CONVENTION GET-TOGETHER LUNCHEON The 66th Semiannual Convention Get - Together Luncheon for members, guests, and ladies attending the Convention will be held in the Blossom Room on Monday, October 10, at 12:30 p.m. There will be eminent speakers and entertainment.

Most important—Luncheon seating will only be guaranteed and assured if tickets have been procured prior to the Convention from W. C. Kunzmann, Convention Vice-President, or before 11:00 a.m. on October 10 at Registration Headquarters.

Checks or money orders issued for Registration fees, Luncheon, or Banquet tickets should be made payable to W. C. Kunzmann, Convention Vice-President, and *not to the Society*.

BANQUET AND COCKTAIL HOUR The Convention Cocktail Hour for holders of Banquet tickets will be held in the Redwood Room on the mezzanine floor, on Wednesday evening, October 12, between 7:15 p.m. and 8:15 p.m.

The Banquet (dress optional) will be held in the Blossom Room on Wednesday evening, October 12, promptly at 8:30 p.m.

There will be entertainment and dancing, and at this time the Annual Awards will be made.

Note: Tables for the Banquet can be reserved at registration headquarters prior to noon on October 12.

LADIES AND GUESTS Members are encouraged to invite their friends to attend the Convention. There will be eleven Technical Sessions open to all who wish to be on hand, and for the ladies who accompany their husbands, the Ladies' Committee is arranging a week of sight-seeing and special events. The Ladies' Registration Headquarters will be located in parlor suite 420–421 in the Hollywood-Roosevelt Hotel. The ladies attending the Convention should register and receive their badges, identification cards, and programs. Mrs. Peter Mole will serve as Hostess.

RECREATION The identification cards issued to members and guests who register for the Convention will permit them to attend Grauman's Chinese and Egyptian Theaters of the Fox West Coast Circuit, the Hollywood Paramount, the Pantages, and Warner Theaters, all of which are located on Hollywood Boulevard and near the hotel. Convention Headquarters will have a wealth of information on places to visit in or near the Los Angeles area.

TENTATIVE PROGRAM

Monday, October 10, 1949

9:30 A.M. Registration
Mezzanine Floor

Advance Sale of Luncheon and Banquet Tickets

12:30 P.M. Get-Together Luncheon
Blossom Room

3:00 P.M. Convening Session
Blossom Room

8:00 P.M. Technical Session
Blossom Room

Tuesday, October 11, 1949

10:00 A.M. Technical Session
Blossom Room

2:00 P.M. Technical Session
Blossom Room

8:00 P.M. Technical Session
Blossom Room

Wednesday, October 12, 1949

10:00 A.M. High-Speed Photography Session
Aviation Room

2:00 P.M. High-Speed Photography Session
Aviation Room

7:15–8:15 P.M. Cocktail Hour
Redwood Room

8:30 P.M. Banquet and Dance
Blossom Room

Thursday, October 13, 1949

Open Morning

2:00 P.M. Technical Session
To be announced

8:00 P.M. Technical Session
To be announced

Friday, October 14, 1949

Open Morning

2:00 P.M. Technical Session
Blossom Room

8:00 P.M. Technical Session
Blossom Room

Adjournment

JOHN H. KURLANDER

JOHN H. KURLANDER, head of the projection, photographic, and miniature-lamp section in the Westinghouse Lamp Division's Commercial engineering department, died June 24, 1949, in Nutley, New Jersey.

During World War II he developed a gunsight lamp which erased the blind spots American airmen encountered in firing at enemy planes diving out of the sun to attack.

His peacetime developments included the device that produces either a spot of light or flood of light from an ordinary hand flashlight; a blue-bulb photoflash lamp emitting invisible, unobtrusive light; "black-light" illumination for airplane instrument dials, and colored filter glass for automotive turn signals preventing "ghost" signals caused by the reflections of sunlight.

Mr. Kurlander's early work with photoflash lamps also resulted in the design of such a lamp to function dependably with mechanical camera-shutter synchronizers.

From 1930 to 1937, Mr. Kurlander was Secretary of the Society of Motion Picture Engineers. He joined the Society as an Active member in 1926, and later was elevated to the Fellow grade. He also was a member of the Illuminating Engineering Society, the American Optical Society, and the Society of Automotive Engineers.

Mr. Kurlander was graduated from Drexel Institute, Philadelphia, with a Bachelor of Science degree in Electrical Engineering.

In 1920 he joined the Edison Lamp Works in Harrison as lighting engineer. Six years later he became chief engineer of the Brenkert Light Projection Company, Detroit, and in 1929 joined the Westinghouse Lamp Division in nearby Bloomfield.

Standards Recommendation

Proposed Standard for 35-Mm Sprocket Holes

The April, 1948, JOURNAL published a proposed American Standard for Cutting and Perforating Dimensions of 35-Mm Motion Picture Combination Negative and Positive Raw Stock for a 90-day period of trial and criticism. A complete history of the development of this Standard over the past thirty years was also published. At the June 21, 1949, meeting of the Standards Committee the comments which had been received were reviewed.

The principal objections to the adoption of the Standard at this time came from representatives of Ansco. They wished additional time before recommending adoption of this Standard for the following reasons:

1. Ansco has a counterproposal which they believe will give better results in so far as steadiness in cameras is concerned and from the standpoint of wear during projection. Their proposal is a modification of the present Bell and Howell negative perforation except that the sharp corners have been rounded with a radius of approximately 0.01 inch.

2. It is their belief that if any combined positive-negative perforation is adopted as an American Standard now, existing perforating Standards for negative and positive stock should be withdrawn.

Therefore, because of the objections the Standards Committee decided again to return this proposed Standard to the Film Dimensions Committee under the chairmanship of Dr. E. K. Carver. It was recommended that additional tests be conducted to determine whether or not the Ansco proposal is superior to the presently proposed Standard.

Section Meeting

Central

The first paper presented at the May 12, 1949, meeting of the Central Section, was delivered by Samuel R. Todd, acting chairman, Chicago Board of Examiners of Motion Picture Machine Operators, Chicago Bureau of Electrical Inspection. His subject was "Potential Trends for Projection-Room Specifications Due to Advent of Acetate Film." The result of his investigation only pointed to the fact that no present safety rules could be relaxed. The booth which usually houses generator equipment and wiring carrying heavy loads will still have to be separated from the audience. Rewind machines still will have to be built of metal and enclose the film. Metal storage cabinets must house the film and keep it in order for the projectionist to show properly.

The next paper was entitled, "Adjustment, Care, and Repair of Soundhead Optical Systems," by P. V. Smith, of the RCA Service Company. This paper outlined the three different types of sound optical systems in present use. The breathing action of the lens system or air-pressure changes draws in oil which not only destroys the image obtainable, but also attacks the cement between elements. The need for laboratory services in restoring these lens systems to usefulness is stressed. A laboratory test table with optical bench was described. A test film with a tone on either side of the track for centering the image is used in the field.

New Products

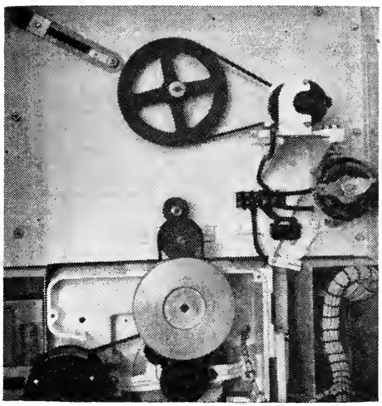
Further information concerning the material described below can be obtained by writing direct to the manufacturers. As in the case of technical papers, publication of these news items does not constitute endorsement of the manufacturer's statements nor of his products.

New Westrex Equipment

Automatic Rewind

Westrex Corporation, 111 Eighth Avenue, New York 11, N. Y., recently has made available its automatic rewind for the Westrex RR3S and RR3SP re-recorders.

The AR3 automatic rewind is an optional accessory for the Westrex RR3S and RR3SP re-recorders, providing



Automatic Rewind

facilities for rewinding a full reel in less than one minute. The automatic rewind includes a 110-volt, $^1/_6$-horsepower series-wound motor, a motor speed control which may be preset to the desired rewind speed, and a film-roller-operated microswitch which automatically disconnects the motor when the film end passes under the roller. The same microswitch is used to turn the device on and off, and no other operational controls or adjustments are required. For rewinding, the rewind motor drives the feed reel of the re-recorder through a pulley. During the running of film through the reproducer, the rewind motor idles, being driven from the feed spindle. Thus, no clutch change-over device is required. The automatic rewind has been designed to include standard parts which are simple and sturdy so that maintenance requirements may be kept at a minimum. The equipment may be easily installed, as existing holes are used for mounting the motor bracket.

Double-Film Attachment and Loop Adapter

The Westrex R2-3 double-film attachment was designed for use with Century projectors and Westrex R2, R3, or R4 reproducers, and may be adapted for installation on certain other types of projectors. A projector equipped with this attachment may be used for reviewing separate picture and sound print "rushes," or for re-recording from a separate sound print. In addition, the normal operation of the projector is retained.

The R2-3 double-film attachment consists of a large lower magazine, installed in place of the Century take-up magazine, and two film chutes which provide a path for guiding the film around the projector. The sound feed and take-up reels are located at the left

New Products

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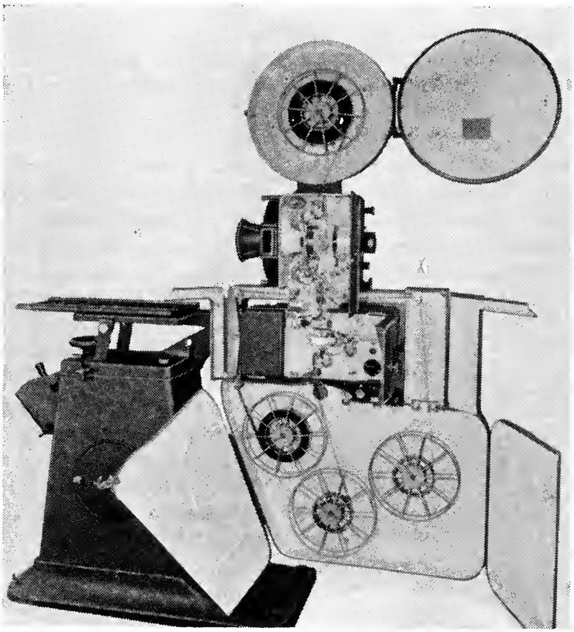

Double Film Attachment and Loop Adapter

in the lower magazine, and the picture take-up reel is at the right as viewed from the operator's side of the projector. The reels are arranged to simplify all threading operations.

The RL2-3 loop adapter consists of a large aluminum film container which fits into the lower magazine of the R2-3 double-film attachment. This optional equipment provides for the running of picture and, or, sound loops for scoring, dubbing, or re-recording purposes. Film loops of between 9 and 150 feet are accommodated.

The loop adapter may be rapidly installed or removed, being held in position with three knurled screws. Threading operations for either reels or loops have been greatly simplified as no external film-guide rollers are required.

Push-Pull Conversion Parts

The Westrex Series of P-200 push-pull conversion parts for Westrex re-recorders consists of a complete optical system and a phototube coupler which provide for the selective reproduction of 100-mil standard, 100-mil push-pull, or 200-mil, push-pull 35-mm area or density film in the Westrex RR3S re-

New Products

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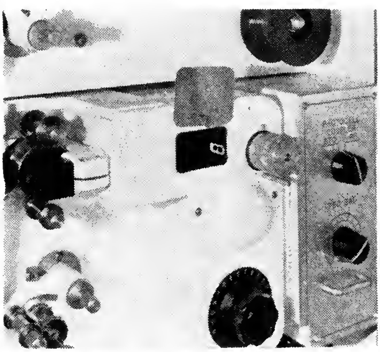
recorder or the Westrex R2, R3, or R4 reproducers. The push-pull conversion parts for the re-recorder and all of the reproducers are essentially the same, differing only in the mounting brackets for some optical parts and the physical arrangement of the phototube coupler. The basic optical parts include a scanning-lens assembly, a collector-lens assembly, a relay-lens assembly, and a mask assembly. The scanning beam of light on the film is 230 mils long to cover adequately all types of sound tracks now in use. The collector and relay lenses transfer the modulated light to the mask assembly where one of three mask openings is placed in the light path, depending on the type of sound track being reproduced. The masks are selected by means of an external three-position control knob. The light is then passed through separator lenses and reflected from a front-surfaced mirror onto a dual-cathode phototube.



Push-Pull Conversion Parts

The phototube coupler consists of a phototube mesh and a triode cathode follower which provides a 600-ohm output. An external switch control is included for connecting the dual-cathode of the phototube in parallel, for operation with 100-mil standard sound track, or in push-pull, for operation with 100-mil or 200-mil push-pull sound track.

In operation, the mask assembly control is preset in the 100-mil standard, 100-mil push-pull, or 200-mil push-pull position and the phototube coupler control is preset in the standard or push-pull position. No other operational adjustment is required.

The series P-200 push-pull conversion parts can be readily installed as they are designed to fit existing mounting details.

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Magnetic Recording in Motion Picture Techniques*

By JOHN G. FRAYNE and HALLEY WOLFE

Western Electric Company, Hollywood 38, California

Summary—**Development of magnetic recording at the Bell Telephone Laboratories is described with the application of such facilities to Western Electric recording and reproducing systems. A method of driving 35-mm magnetic film with a flutter content not greater than 0.1 per cent is described, as is a multigap erasing head.**

Introduction

Although the principles of magnetic recording on a steel wire were first demonstrated by Poulsen in 1898, this method of recording has had little if any application to practical recording techniques until the past few years. The reasons for the half-century delay between discovery of the method and its successful application to broadcasting and sound motion picture techniques may be attributed partly to a lack of understanding of the basic process, and partly to the fact that the quality of sound reproduced from the early devices left much to be desired.

During the late twenties research into the possibilities of obtaining high-quality sound from the magnetic medium was begun at the Bell Telephone Laboratories. This work led to the production of the Mirrophone magnetic recorder in 1941 which may be said to be the first high-quality magnetic recorder made available to the public. Although many of the principles employed in the Mirrophone have given way to later developments in the magnetic-recording art, they are still of interest in tracing the gradual improvements in this method of recording. The technique developed by Hickman at the Bell Telephone Laboratories and incorporated in the Mirrophone employed the perpendicular type of magnetization in which the elementary magnets are at right angles to the line of travel of the medium, which was a special steel-alloy tape known as Vicalloy.

Direct-Current Bias

In order to circumvent the inherent distortion in the magnetic-recording characteristic as exemplified in Fig. 1, showing relative

* Presented April 8, 1949, at the SMPE Convention in New York.

remanent induction and magnetizing force, Hickman[1] employed a direct-current saturation erase and a negative direct-current biasing field, as illustrated in Fig. 2. His explanation of the recording process is as follows. The tape, on passing between the direct-current erasing pole pieces, is magnetized to the saturation point *P* on curve *A*. On leaving the erase gap, the magnetic induction drops along the curve *B* to *R*. On passing between the recording pole pieces, a negative biasing flux brings the material to a point *N*. As the medium passes out from between the recording pole pieces, the residual induction will change from *N* to *O* which is a substantially neutral condition. If an alternating-current signal is applied between *A* and *B* on the hysteresis curve while the medium is passing through the gap

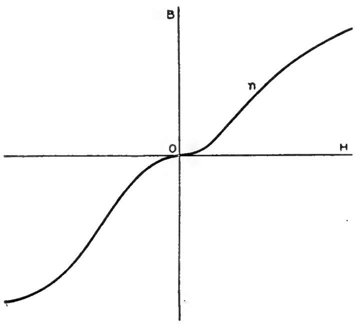

Fig. 1—Curve showing relationship between remanent induction and magnetizing force.

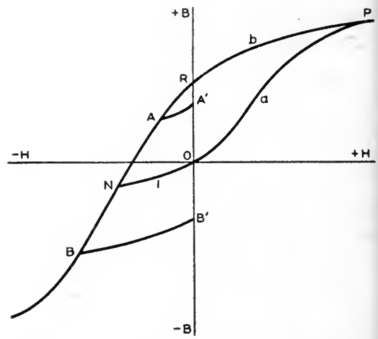

Fig. 2—Curves illustrating process of recording with direct-current bias.

the residual induction will vary between A' and B'. A more elaborate explanation of this recording process is given by Wooldridge.[2]

This method makes it possible to record over a large portion of the magnetization curve without appreciable distortion. At the same time the magnetic noise is kept at the minimum by virtue of working the tape about an essentially demagnetized condition.

With the Mirrophone recorder operating at a tape speed of 16 inches per second, the maximum signal-to-noise ratio of 38 decibels was obtained, with a substantially uniform equalized frequency response up to 8000 cycles. The quality and signal-to-noise ratio of these recordings were comparable to that of standard optical sound tracks, and at 8 inches per second the quality was considered satisfactory for dialog.

ALTERNATING-CURRENT BIAS

Although the direct-current-bias method was capable of giving fairly good quality, the quality was not sufficiently outstanding nor was the signal-to-noise ratio sufficiently great to capture the serious attention of the sound-recording industry. Consequently, research continued at the Bell Telephone Laboratories which culminated in the successful application of high-frequency bias and high-frequency-erasing methods instead of the direct-current methods generally employed up to that time. While a high-frequency-bias method was disclosed in U. S. Patent 1,640,881, issued in 1927 to

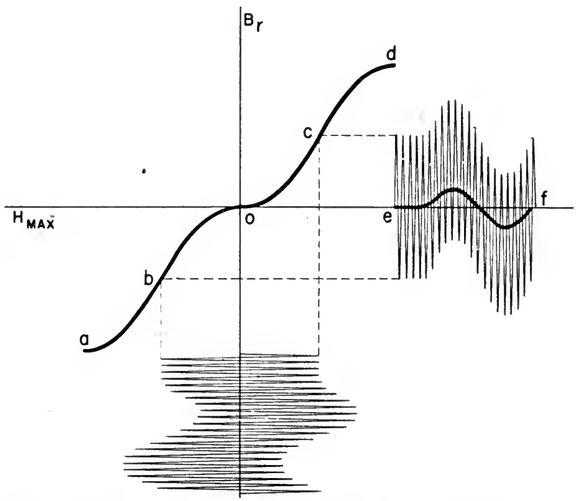

Fig. 3—Recording characteristics using alternating-current bias.

W. L. Carlson and G. W. Carpenter of the General Electric Company, its first known application to magnetic recording was at the demonstration of stereophonic-recording methods at the New York World's Fair in 1938 by the American Telephone and Telegraph Company. U. S. Patent 2,235,132 was issued in 1940 to D. E. Wooldridge of the Bell Telephone Laboratories covering new and improved techniques in applying the erasing and biasing high-frequency fields. The method disclosed by Wooldridge calling for the mounting of erasing and recording heads on the same recording unit with a high frequency applied to each unit is followed in most modern magnetic-recorder designs.

Although the complete theory of the high-frequency-bias method is complex,[3] a somewhat simplified explanation is given here. In endeavoring to picture the process, it is convenient to think of the recording material as passing through an intermediate stage just after leaving the recording field but before demagnetization sets in. In this stage the relation between residual magnetization and maximum magnetizing force in the gap is expressed by curve *abcd* in Fig. 3. A group of bias-frequency waves with superimposed audio-frequency wave is shown as an impressed magnetizing force around the origin *O*. Assuming that the curve *abcd* represents the recording characteristic, then the maximum values of B_r, the residual magnetization, may be traced as shown in the figure. After the medium leaves the recording gap almost complete demagnetization of the bias frequencies results, leaving a net induction which is the difference between the positive and negative halves of the bias waves. Thus the remaining magnetization is shown by the curve *ef* of Fig. 3. It will be noted that for a zero value of audio signal the medium is almost completely demagnetized with resulting low noise output from the tape. Further, since the audio signal is transferred to the linear position *b* and *c* of the characteristic curve, the distortion of the audio signal is low.

THE MAGNETOPHON

New impetus to more extended use of the magnetic recording medium was given by the discovery by the Allies in Germany at the close of World War II of the Magnetophon,[4] which had been widely adopted by the German broadcasting system. This machine utilized a plastic tape with either an impregnated or coated layer of magnetic iron-oxide powder with particle diameters less than 1 micron. With longitudinal-type magnetization and operating at a speed of 30 inches per second, a signal-to-noise ratio of about 60 decibels was obtained and an equalized flat response to 15,000 cycles was claimed. The sound quality from the Magnetophon was so superior to that of all previous magnetic recorders, that it immediately appeared inevitable that this improved medium would eventually be extended to all fields of sound recording.

The tapes employed in the Magnetophon and later in domestic magnetic recorders were $^1/_4$ inch wide and 2 to 3 mils thick. Without sprocket holes the tape speed could not be maintained in exact synchronism with a motion picture on perforated film unless some external form of speed control was employed. The development of a perforated film (35 mm or 16 mm) was therefore necessary before the new medium could be introduced to the motion picture field. As the result of considerable effort expended by certain companies such as the Minnesota Mining and Manufacturing Company and the du Pont Company, satisfactory magnetic iron-oxide emulsions on standard 35-mm film, mounted on either nitrate or safety base, have been produced.

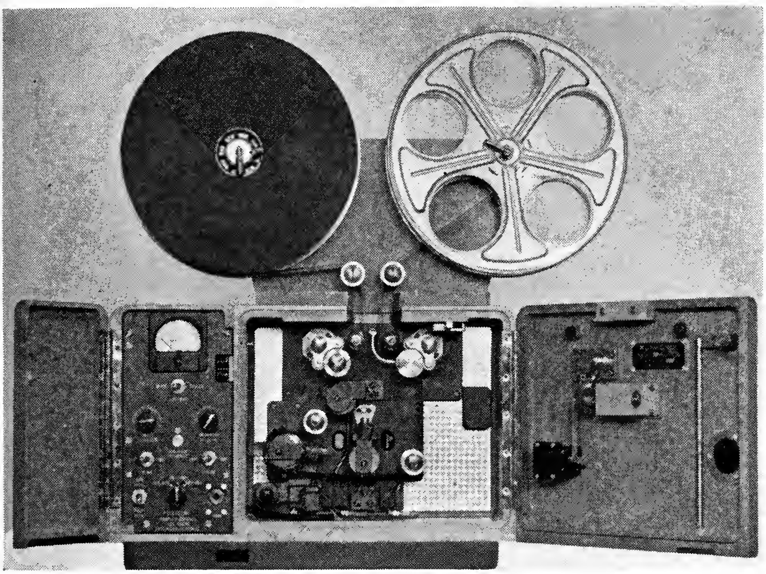

Fig. 4—Western Electric RA-1231 Type magnetic recorder, in which control panel has been substituted for optical components.

MOTION PICTURE ADAPTATION

To adapt magnetic recording for motion picture use it is essential that the quality obtained from the 35-mm magnetic film be at least equal in every respect to that obtained from optical sound tracks. This means that frequency response, signal-to-noise, and flutter performance must be at least comparable. The Magnetophon experience indicated that the first two of these conditions should easily be met even at the lower motion picture speed of 18 inches per second. The flutter problem presented in pulling a fairly stiff 35-mm film over a fixed recording head required careful consideration in order to match the almost flutter-free performance of modern sound recorders and reproducers. As discussed later in this paper this problem has been completely solved.

Before the studio can readily apply magnetic recording to production problems it is necessary to have magnetic-reproduction facilities throughout the studio comparable to those now afforded for optical sound tracks. Thus, provision must be made for reviewing the daily magnetic recordings in synchronism with the action. This means that review-room projectors must be equipped for magnetic reproduction

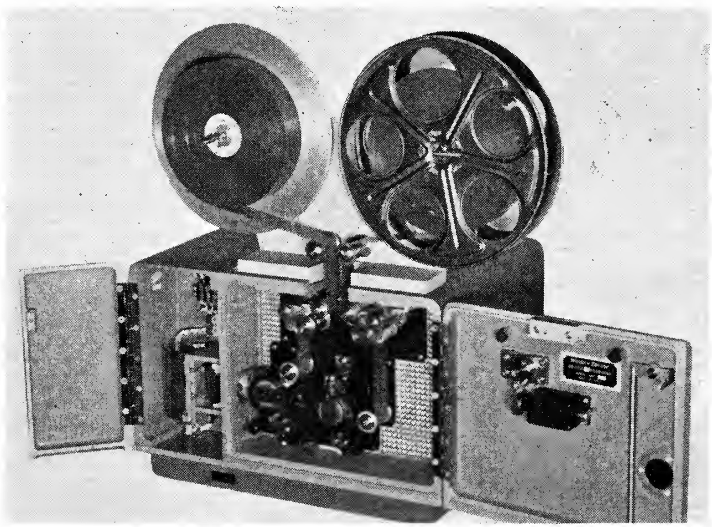

Fig. 5—Western Electric RA-1231 Type magnetic recorder, in which optical facilities are retained.

without impairing their ability to reproduce standard film sound tracks. Also, editing machines must be provided to aid in cutting and assembling the component magnetic tracks for re-recording to the release optical track. Finally, re-recording machines must be modified to reproduce the magnetic tracks with the same degree of excellence these machines afford for existing sound tracks.

As will be shown later in this paper, the Western Electric Company is making available magnetic modification parts for its RA-1231 series of film recording machines. It is also providing magnetic-reproducing facilities for its RA-1251 series of re-recording machines as well as for the RA-1435 theater-type of reproducers for review-room reproduction of magnetic recordings. It is also co-operating to provide facilities for editing and cutting magnetic sound tracks.

RECORDER

The magnetic recorder to be described utilizes the Western Electric RA-1231 photographic film recorder as a basis, with a number of added or substituted conversion parts. The standard speed of 18 inches per second has been retained.

Two versions of this recorder have been developed to date. In one, the optical components in the light-modulator compartment are

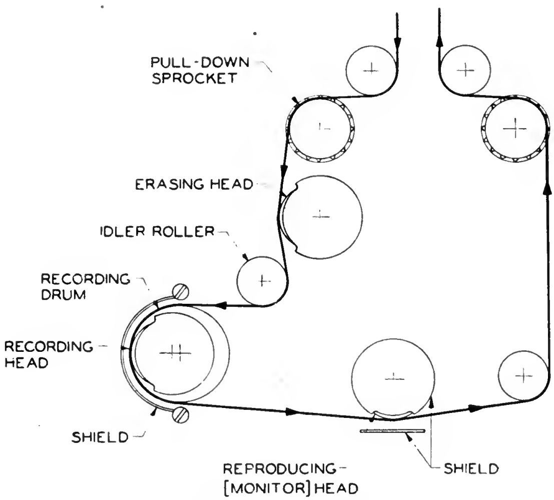

Fig. 6—Magnetic-recorder film path.

removed, and a control panel and a number of electrical items are substituted for them. This recorder is shown in Fig. 4. In the other version the optical facilities are retained, the control circuits being mounted external to the recorder (Fig. 5). In this latter version the recorder can be rapidly converted for use with either the magnetic or the photographic medium.

In both variations of the recorder, the general layout of heads and other components in the film path is the same and is shown in Fig. 6. When an erasing head is used it is mounted to contact the incoming magnet c film at the short loop between the pulldown sprocket and the first (upper) filter arm roller. The recording head is mounted on a damped supporting arm, and it contacts the magnetic coating at the recording drum. The reproducing or monitor head is mounted above the tight loop following the recording drum, between the drum and the second (lower) idler roller. Head adjustments are provided for setting track position, for properly positioning the gaps relative to the film loops passing over them, and for setting azimuth of the recording and reproducing heads.

The manner of mounting the recording head is indicated in Fig. 7. A recording drum somewhat narrower than that for optical recording is employed, the film thus overhanging about $^5/_8$ inch on the outboard side, as shown. The film is threaded so that the magnetic coating is on the inside of the loop in contact with the surface of the drum. The gap of the recording head contacts the inside of the overhanging loop near the edge of the drum. The recording head is flexibly mounted on an arm that is pivoted at a point directly below the recording gap. A spring attached to this arm supplies sufficient force to hold the recording gap against the film, the force of the spring being easily adjustable. Viscous damping applied to the mounting arm attenuates any vibratory motion imparted to it.

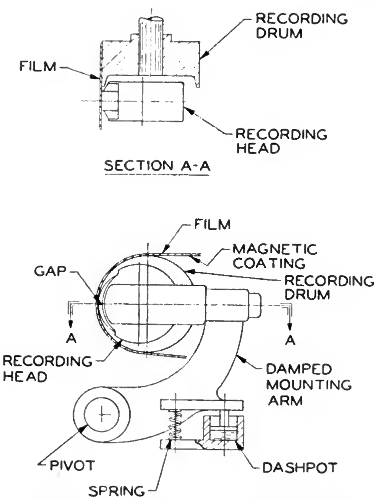

Fig. 7—Method of mounting magnetic-recording head.

This system of film propulsion over the recording head gives excellent performance with regard to freedom from flutter and amplitude modulation because it utilizes the same point of translation that has previously been determined as giving the optimum performance in optical recording.[5] When the force on the arm is properly adjusted the uniformity of film motion is comparable to that obtained in optical recording in the same recording machine. This is largely due to the fact that the film loop, being rigidly supported over most of its width, is not so subject to "polygoning" at the film perforations. Furthermore, the head automatically assumes the proper position when the film is threaded, any wear on the head being compensated by a slight motion of the arm. Measurements of flutter (summarized in a following section) confirm the superiority, particularly with regard to 96-cycle flutter, of this method over the usual method whereby the film is pulled over the head in an unsupported loop.

The undesirable 96-cycle amplitude and frequency modulation which are introduced in the region near the sprocket holes by the "polygoning" effect may be eliminated by moving the track position away from the sprocket holes. Since there seems to be no reason for maintaining optical track position on original magnetic records, a centerline position of 0.450 inch from the edge of the film has been tentatively established. The track width has been set at 0.250 inch leaving the inside edge of the track 0.136 inch from the inside edge of the sprocket holes. Adjustments are provided for moving the centerline when some other position is desired.

The monitoring or reproducing head picks up the signal about 0.4 second after it has been recorded. Because of the more unfavorable position of the reproducing head in the film path, the reproduced signal has more 96-cycle flutter than the recorded signal. However, the quality is entirely adequate for monitoring purposes, and flutter-free performance comparable to that at the recording position is obtained in the reproducer (described below) in which the same type of drum-controlled motion is employed. Also, if desired, the recorder itself can be employed as a reproducer, the recording head then acting as a reproducing head.

MAGNETIC-HEAD DESIGN

The magnetic pole pieces for the heads are constructed of circular laminations of Permalloy, tightly held in the halves of a divided, circular brass ring that, in turn, is positively aligned by an accurately made clamping fixture. An exploded view of such a head is shown in Fig. 8. Coils are wound on molded coil forms that slip over the pole pieces. Recording and reproducing gaps are each 0.0005 inch wide and 0.25 inch long, and are formed of shims of beryllium-copper alloy placed between the ground ends of the pole pieces.

The erasing head differs from the conventional type in that two gaps are used, so that an element of the recording medium is subjected to two successive erasing processes in passing over the head. These gaps are 4 mils wide and are spaced 6 mils apart. They are formed by inserting (between the pole pieces) a three-layer "sandwich" consisting of two shims of 6-mil nonconducting material separated by a Permalloy lamination. By thus applying an erasing field to the medium, allowing the latter to relax to the neutral state, then applying a second erasing field, very effective erasure is obtained with low-power dissipation in the head. Even with magnetic materials that are most difficult to erase, fully modulated signals have been completely removed. This has been accomplished with power values sufficiently low so that the head can be operated continuously without any significant temperature rise; stationary film can be kept in contact with the pole piece indefinitely without injury.

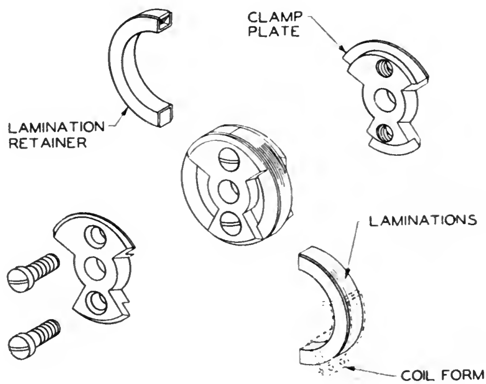

Fig. 8—Magnetic-recording head, exploded view of core details.

Each of the magnetic heads is enclosed by a Permalloy case for shielding, and in addition, external Permalloy shields in the form of plates are mounted adjacent to the recording and reproducing heads to provide further shielding of the exposed regions near the gaps.

RECORDING TRANSMISSION SYSTEM AND CONTROLS

The magnetic-recording channel includes all facilities required for recording and monitoring the signal output from an RA-1288 mixer, and for reproducing the signal after it is recorded. The channel can also be bridged across a normal bridging line. A block schematic of the complete system is shown in Fig. 9. The amplifiers, the bias oscillator, the power supplies, and various equalizers and other networks, are mounted on a single rack, whereas all the frequently operated controls are located on a single panel.

The main elements of the audio-frequency portion of the recording circuit are the two amplifiers, adjustable attenuator, pre-equalizers, and volume indicator. One oscillator supplies both bias current to the recording head and erasing current to the erasing head. This

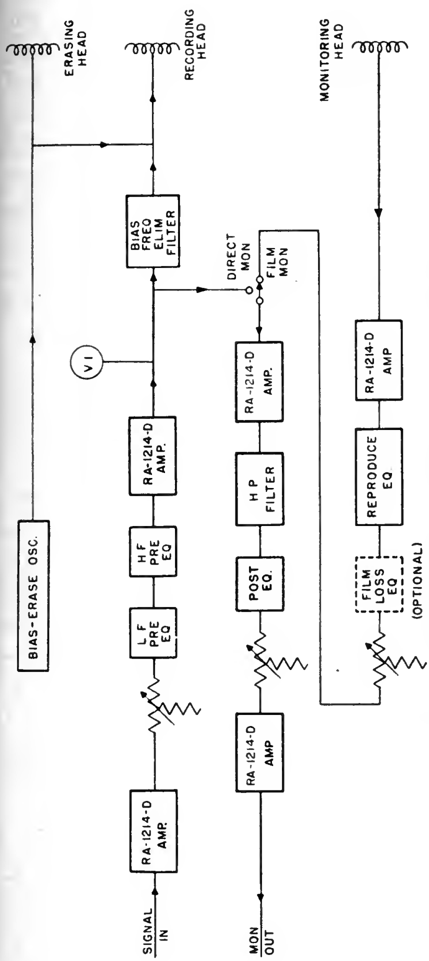

Fig. 9—Magnetic-recording-system block diagram.

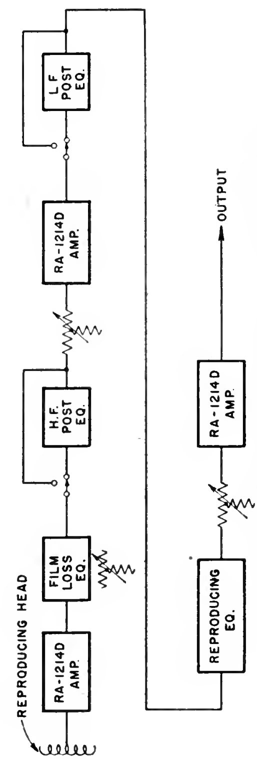

Fig. 13—Magnetic-re-recording-system block diagram.

oscillator is mounted in the rack with its separate power supply, its output being connected to the recorder circuits through a coaxial cable. The oscillator includes a resistance-capacitance-type circuit of high stability and an output amplifier with a push-pull circuit in order to reduce to a minimum the even harmonics of the bias frequency. A sharply tuned filter is located in the output to reduce further the harmonics and to prevent any audio-frequency noise in the oscillator from reaching the recording head. An oscillator frequency of 60 kilocycles is employed. This frequency is high enough so that any appreciable intermodulation products between the signal and the bias frequency are above the audio-frequency range.

The monitor system includes all amplifiers and networks required for delivering a properly equalized monitoring signal either from the recording head current (direct monitor) or from the recorded material on the film (film monitor). Equalizers in the film-monitor circuit include a 6-decibel-per-octave shelf equalizer to compensate for the low-frequency droop inherent in magnetic recording and a post-equalizer. A "film-loss" equalizer to compensate for the high-frequency film loss is optional. The monitor signal is delivered at headset level to a convenient jack and to a plug outlet for transmission to the mixer, or other remote location.

As previously indicated, the switches and other equipment for normal recording operations are mounted either on a small panel in the recorder, or externally in the version that retains the optical-recording facilities. A meter is provided for indicating bias and erasing current; normally this indicates bias current, but a nonlocking switch can be pressed to read erasing current. A bias-current adjustment is provided. Erasing current is controlled at the rack by means of an over-all oscillator output control. Additional controls are "on-off" switches for both bias and erasing current, a direct-monitor or film-monitor selector switch, a monitor volume control, and three-position selector switch that can be set for "signal-off," "record," or "reproduce." In the "reproduce" position the recording head is connected for reproducing, and oscillation of the bias oscillator is stopped in order to eliminate danger of erasing the record.

In locations where powerful permanent magnetic fields are present, as, for example, near magnetized structural steel, the introduction of appreciable second-harmonic distortion and noise in the record is possible, because of the resulting polarization of the recording head. To eliminate this difficulty, a source of direct current to the recording head has been provided in the oscillator. The current can be adjusted and its value can be read on a microammeter at the oscillator; a reversing switch is provided to reverse the polarity of the recording head. Thus, any polarization in the recording head can be canceled.

Under most circumstances it is not necessary to utilize this feature, but it is available if needed.

PRE- AND POSTEQUALIZATION

Pre- and postequalization are employed to increase the signal-to-noise ratio. Although the basic theory of operation of this method of noise reduction is identical whether it is applied to magnetic or to photographic recording, the magnetic medium requires somewhat different equalization for optimum results. Whereas with film recording the noise energy is predominantly in the high frequencies,

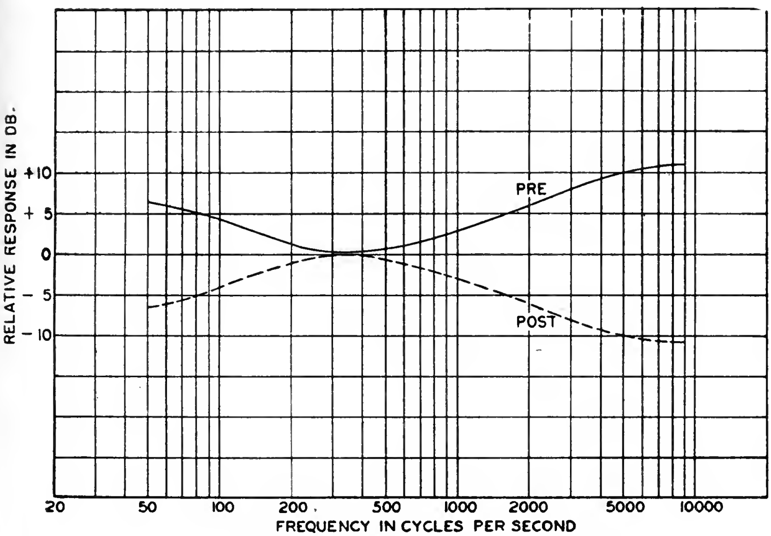

Fig. 10—Magnetic-recording pre-equalization curve.

with magnetic recording, mainly because of the 6-decibel-per-octave equalization, the low frequencies usually contain the greater portion of the noise energy. Therefore, in addition to the normal photographic-type high-frequency equalization, some equalization is applied to the frequencies below 250 cycles. The resulting over-all pre-equalization characteristic is shown in Fig. 10; the postequalization is, of course, complementary to this curve, as shown.

PERFORMANCE

Flutter measurements indicate that the method of film propulsion used in this recorder, in which the recording head is located at the recording drum, produces a record that is somewhat better than a print in the photographic process. The total flutter is about 0.1 per cent, mainly in the 80- to 130-cycle band. Since the flutter index is relatively low for this condition, the effects on sound quality are naudible.[6] At the monitoring or reproducing-head position, the well-known detrimental effects of free-loop and curved-gate scanning are evident, the total flutter being about three times that of the recording position. Here again the 80- to 130-cycle band predominates. At both positions the low-frequency flutter performance is excellent. No 96-cycle amplitude modulation can be seen on the envelope of a recorded signal viewed on an oscilloscope.

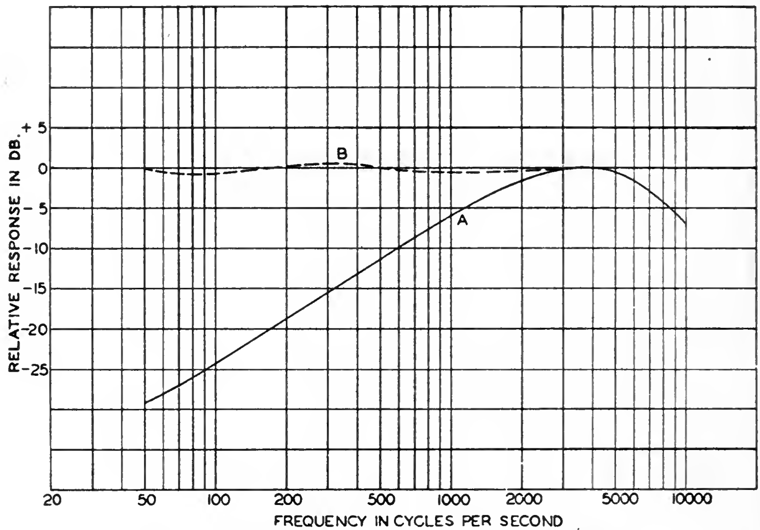

Fig. 11—Magnetic-system frequency characteristic.

The frequency response of the unequalized system is shown by curve *A* of Fig. 11. Equalization is added in reproduction to produce the characteristics indicated by curve *B*, and ordinarily a 40-cycle high-pass filter is also included. With music, excellent results have been obtained with this equalization only; however, the high signal-to-noise ratio will permit raising of the relative level of the frequencies beyond the peak response to produce an over-all response that is flat to about 10 kilocycles.

In determining the signal-to-noise ratio, the overload level was arbitrarily taken as that level at which the third-harmonic distortion is 2.5 per cent at 400 cycles. This frequency was chosen because it is near the region of maximum energy in the spectral-energy-distribution curve. The second harmonic is so low in level that it may be neglected. This figure for overload has some justification, since it has been found that excellent recordings of all types of material can be made with this as the peak recording level. On this basis, a signal-to-noise ratio of more than 55 decibels can be obtained when the frequency characteristic given by curve *B* (Fig. 11) is employed in addition to the usual 40-cycle high-pass filter. With pre- and post-equalization, the effective ratio lies between 58 and 62 decibels.

MAGNETIC RE-RECORDER

The magnetic re-recorder, like the recorder, is made by applying a number of conversion parts to a standard film machine. The Western Electric RA-1251-B re-recorder is the basic unit, to which are added mechanical and electrical items needed to reproduce the magnetic sound track. One method of scanning the track is accomplished at the scanner drum in a manner analogous to that utilized in the recorder. In the film path, the conversion involves removing the lens-and-prism assembly, replacing the scanner drum and installing the reproducing head and its movable, damped support and its shielding structure. The resulting film path is shown in Fig. 12.

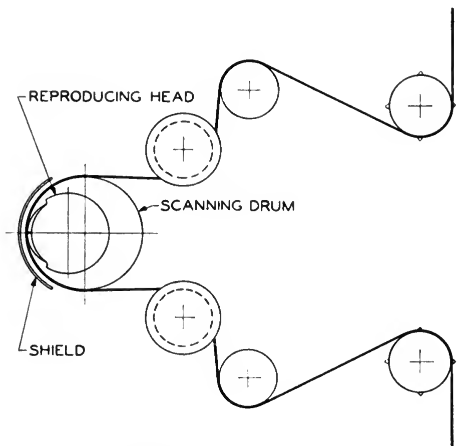

Fig. 12—Magnetic-re-recorder film path.

In another version of the re-recorder, the reproducing head replaces the roller in the film path just beyond the scanner drum. Thus, in this model optical facilities are retained, and the machine can be used to play either photographic or magnetic film.

Removing the circuit items not needed in magnetic reproducing, such as the phototube amplifier and the lamp-control equipment, leaves ample room for the magnetic-transmission system. This system, shown in block schematic in Fig. 13, includes RA-1214-D amplifiers, high- and low-frequency equalizers, and keys for switching them in or out of the circuit separately, the 6-decibel-per-octave reproducing equalizer, adjustable film-loss equalizer, gain control, and power supply. The output signal from the re-recorder has a nominal level of +10 dbm* when the gain is set at maximum.

Performance of this re-recorder is comparable in every way to that of the recording system as given above. When drum scanning is employed, the performance with regard to amplitude modulation and flutter is indentical to that of the recorder at the recording-drum position. In the other version, performance is comparable to that at the monitor position in the recorder. The figures of signal-to-noise ratio given for the recorder also apply to the re-recorder.

Review-Room Facilities

Since the studio review room must be capable of reproducing double film for dailies and composite film for release, it is necessary to provide facilities for magnetic reproduction as well as standard optical-track reproduction from composite prints. This has been done to date on the RA-1435 theater-type sound reproducer as illustrated[7] in Fig. 14. It will be noted that the standard optical-reproducing facilities are unchanged. In order to accommodate the magnetic-reproducing head, it has been necessary to move the lower idler roller about 1 inch to the right, the resulting film path being as shown in the figure. The flutter performance of this machine for magnetic reproduction shows a slightly h gher 96-cycle rate than for optical reproduction. However, because of the favorable flutter index at this high rate of flutter frequency, the quality of sound is not noticeably impaired.

Space requirements in the soundhead make it necessary to mount the magnetic-reproducing head outside the film loop rather than inside the loop as used on the RA-1231 recorder and RA-1251 re-recorder. This puts the emulsion in the same position as in the optically recorded films and is desirable in a machine which is used interchangeably for magnetic and optical recordings. The head is on a retractable mounting controlled by a rotatable knob at the lower left so that it is removed from contact with the film when photographic tracks are used.

Conclusion

A magnetic recorder has been described in which suitable recording, monitoring, and erasing facilities are provided. Magnetic sound tracks made in this machine at the standard speed of 18 inches per second are practically free from flutter and show an excellent

* Decibels with respect to 0.001 watt.

frequency response for sound-picture reproduction purposes. A standard film re-recording machine has been converted for reproducing magnetic sound tracks with a high degree of fidelity. In addition a standard theater-type sound reproducer has been modified to provide reproduction from either optical or magnetic sound tracks. Recordings of music and dialog made on this system show an excellence

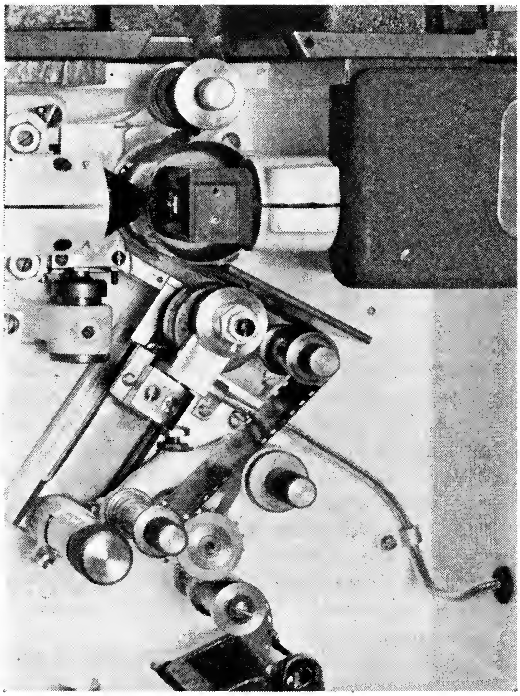

Fig. 14—Western Electric RA-1435 theater sound reproducer, showing facilities for reproducing magnetic track.

of quality unsurpassed in any previously known recording system. The complete absence of background noise lends an air of reality to the reproduced sound, making it indistinguishable from direct monitoring of the original pickup on the stage.

With the facilities described in this paper, the sound-recording engineer should be able to begin active adaptation of magnetic recording to his everyday production activities. Further, he should be able to carry on the magnetic program through all the various stages of editing and re-recording, up to the release negative which must for the present perforce be an optical sound track for theater reproduct on purposes.

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Discussion

MR. J. E. AIKEN: What are your decisions on the use of perforated material? We take it for granted, but at the same time we would like to know what the results are, particularly when the drive is synchronized for a nonperforated tape, and particularly if you can discuss the effects on synchronization of any heating effect that might take place at the moment of recording.

DR. JOHN G. FRAYNE: So far as the motion picture industry is concerned, it is accustomed to handling film with sprocket holes, using the standard well-known method of keeping exact synchronism with a synchronous or interlock drive system. The quarter-inch-tape machines have been used in some studios for various purposes with very good results, but mostly for playback purposes, rehearsals, and things of that nature. When one tries to record on tape without sprocket holes and to associate that with the picture, the slippage is too great for present standards of synchronization. That is not my conclusion; it is the conclusion of people in the industry.

With regard to stretching of the tape caused by heating, I have heard of that defect but I cannot vouch for it At this time sprocket holes, for either $17^1/_2$- or 35-mm, are definitely indicated for motion picture studios.

MR. LEON S. BECKER: Dr. Frayne, do you have any figures that are available on intermodulation?

DR. FRAYNE: No. The accepted method of measuring intermodulation is doubtful because of the equalization which we have to apply in reproduction. Take, for example, the 60- and 1000-cycle or 60- and 2000-cycle test which is made in ordinary intermodulation: the 60-cycle component is reproduced some 20 decibels higher on equalized setups than the 1000; so it completely throws the balance of 60 and 1000 out as far as analysis is concerned. The recording you heard here was made so the film showed a maximum third harmonic of $2^1/_2$ per cent and a second harmonic of less than $^1/_2$ of a per cent, which should be about 10 per cent intermodulation. The method of measuring distortion on magnetic is still, I would say, in the development stage. Undoubtedly, some peculiar form of distortion measurement will materialize. So far, the third harmonic seems to be a very good way of measuring distortion in magnetic recording.

MR. BECKER: Were the first two samples radio pickups?

DR. FRAYNE: Yes.

MR. BECKER: I felt that there was a considerable amount of distortion of some type, and in the last sample, which was a vocal, I wanted to hear an orchestra combination rather than a vocal and organ. I could not tell whether the distortion might have been caused by the radio transmission.

DR. FRAYNE: Some distortion undoubtedly was in the over-all system. This was reproduced over a system flat to somewhat above 9000 cycles. If this had been reproduced over the so-called Research Council characteristic, I think you would not have noticed any appreciable distortion.

MR. BECKER: Has Western Electric developed any special editing equipment?

DR. FRAYNE: We are co-operating with the Moviola Company at the present time, and I do not know just how far that has gone.

MR. BECKER: Does the contact of the recording head contribute to any appreciable degree to increased flutter content?

DR. FRAYNE: It does to a certain extent. In the old theater days, we had straight gates. Then we went to curved gates. Finally, we went to rotary gates. This is a compromise between rotary and curved gates. The motion of the film at the point of contact is dominated partially by the rotary motion of the drum and partially by the friction on the gate, but the flutter values I gave are comparable to that in film and better than a good print.

MR. BECKER: In other words, that figure 0.07 was the magnetic flutter?

DR. FRAYNE: Yes.

MR. GORDON CHAMBERS: I hope that the terminology Dr. Frayne used this morning will not catch on, and that the term "optical" will not come to be synonymous with photographic. He spoke this morning of an optical contact print, and I do hope that in Hollywood photographic recording will not be described as optical recording.

DR. FRAYNE: I am afraid it is too late to change the terminology now. It is already started.

MR. CHAMBERS: It is going to lead to considerable confusion for some time to come because we do have optical work as well as photographic.

MR. KENNETH C. GOODMAN: Has any thought been given to the tie-in of this equipment with 16-mm films that will be produced? In the Midwest, we shall have to produce many of our films for use on television. How can we synchronize it?

DR. FRAYNE: Is your television speed 7.2 inches in seconds? Is it a standard 16-mm speed?

MR. GOODMAN: Yes.

DR. FRAYNE: Then there is no problem any more than in 35-mm. This little recorder over here can be equipped for 16 as well as 35. You just have to change the plates mounting the drive mechanism in there. Of course you will have to change the head mountings.

MR. GOODMAN: Is the 16-mm machine available?

DR. FRAYNE: If anyone wants one we shall be more than happy to supply it.

Recording Equipment Throughout the World*

By R. E. Warn

Westrex Corporation, New York 11, New York

Summary—**The paper presents a survey of recording outside the United States of America, contrasting the problems of these studios with those of Hollywood. The equipment and service organizations developed to meet the needs of these studios are described.**

The film industry has long looked upon Hollywood and London as the focal points of recording activities, so much so, in fact, that it is often felt that these two centers embrace virtually all of the recording activities in the world. Actually, extensive film recording is today being carried on in practically every country of significance around the globe. All told there are approximately 200 studios producing 35-mm films outside of the United States. Most of these studios are small by Hollywood standards. However, the pride of local production is a very potent box-office reason for the existence of many of these units and, in addition, many governments have encouraged their establishment.

It will assist in understanding the problems of these studios to to consider typical cases. From the standpoint of size, facilities, geographic location, climatic and working conditions, they cover a wide range. For example, Fig. 1 shows the Azteca Studio at Mexico City which, until recently, had 23 stages and 7 recording channels. In June, 1948, fire destroyed six of the stages but even without them Azteca justifies the classification of a large studio.

An example of one of the smaller studio buildings is that of Commonwealth Films in Sydney, Australia. The activities of this studio are housed in one building approximately 150 feet long by 50 feet wide. In this building there are the offices, dressing rooms, recording rooms, sound stage, carpenter shop, and property-storage facilities.

The Sri Krung Studio at Bangkok, Siam, is an example of a studio catering to a very small market. Its pictures are produced in the Siamese language and distribution is effectively limited to the 100

* Presented October 26, 1948, at the SMPE Convention in Washington.

theaters in Siam. As a market this is approximately equivalent to the city of Washington, D. C.

The operating problems of these studios differ considerably from those of a Hollywood studio. The relatively small market to which they cater forces them to be highly versatile in policy, personnel, and equipment. In addition to features, many make commercials and documentaries, some produce newsreels, and some operate in both the 35-mm and 16-mm fields. Foreign pictures average a great deal higher percentage of location recording than Hollywood. In fact, in the smaller studios the greater portion of the picture is usually shot on location.

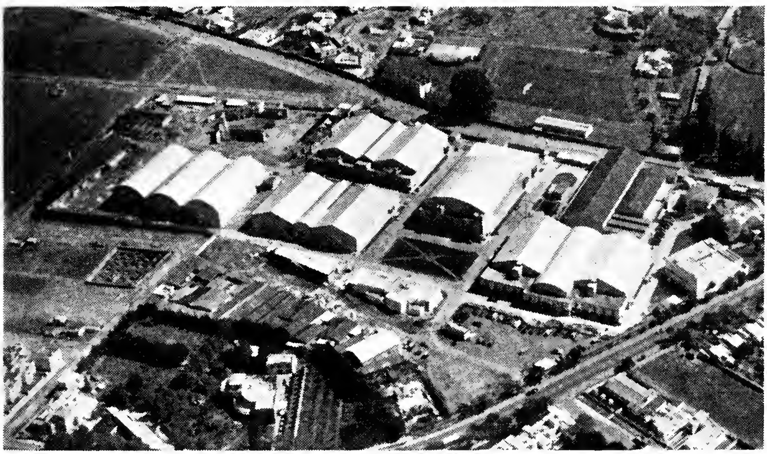

Fig. 1—Azteca Studio, Mexico City.

Dubbing is a highly important activity of many of these studios. For example, Fono Roma in Rome dubs an average of fifteen features per month, while Emelco in Buenos Aires dubbed one million feet of film on one recorder in the first seven months of its use. In some cases subtitles are used but this practice is diminishing. In many of the dubbing operations a print is provided by Hollywood which includes all sound except the dialog. In such cases it is particularly important that the quality of the sound provided by Hollywood be matched when the dialog is added.

Studio personnel have to be able to do a little of everything as there is not sufficient budget or volume of all types of activities to warrant specialists for every job. In many of the small studios there is only one recording channel and it must serve on location, in the studio, and for scoring and re-recording, sometimes for both 35-mm and 16-mm work. The equipment must be very portable and there must be no lost time because of technical difficulties due to mobility. These studios need quality comparable with Hollywood but the equipment must, in general, be more portable, more versatile, less expensive, and capable of producing good results with a minimum of attention.

The cost of local talent and technicians in these studios is a great deal less than in Hollywood. As an example of an extreme case, the star in one Malayan picture produced just before the war received the equivalent of $5.00 per day. This trend to lower costs is reversed in the case of equipment and any supplies imported from overseas for they cost appreciably more than they do in the United States, because of import duties and transportation charges. These differences in cost result in a change in emphasis in planning productions. In many cases the recording equipment is the controlling factor in scheduling, and production planning is centered around the availability of the recorder.

The Westrex Corporation serves only those studios located outside of this country. It is, therefore, essential that the equipment provided meet these conditions fully. To accomplish this, the Western Electric recording and re-recording equipment has been repackaged to increase portability and versatility, while at the same time holding cost to a minimum. This matter of cost is particularly important in many countries because of governmental restrictions placed on dollar expenditures. Incidentally, it is interesting to note that the current price of this recording equipment is appreciably less than that of equivalent prewar equipment, despite the numerous improvements which have been made.

There are four types of Westrex recording channels. The Series 700 system is a de luxe studio channel which can be used for 35-mm, density or area, 100-mil standard or 200-mil push-pull recording, or for 16-mm, standard area or density tracks. This system is very similar to the Western Electric Series 400 film recording system which has been described in detail elsewhere.[1] A two-channel mixer is supplied with this system in a floor mounting cabinet.

Fig. 2 shows the Series 600 system which is an all-purpose channel for recording 35-mm, 100-mil standard or push-pull track, density or area, or 16-mm standard density or area track. Essentially, it is the Series 700 system stripped of several of its operating features.

The automatic control, the built-in punch, and slater have been eliminated. The recorder and its quality of results are unchanged but elimination of these operating features has reduced the cost, weight, and size. As an example of its portability, Praesens Studio, Zurich, Switzerland, has one installed in a $1^1/_4$-ton Austin truck which has been used throughout Central Europe. Incidentally, any one or all of the features which have been eliminated can be added to the Series 600 system if and when required.

The series 500 system is the smallest of the double-film recording systems. It records 35-mm or 16-mm standard track sound and is

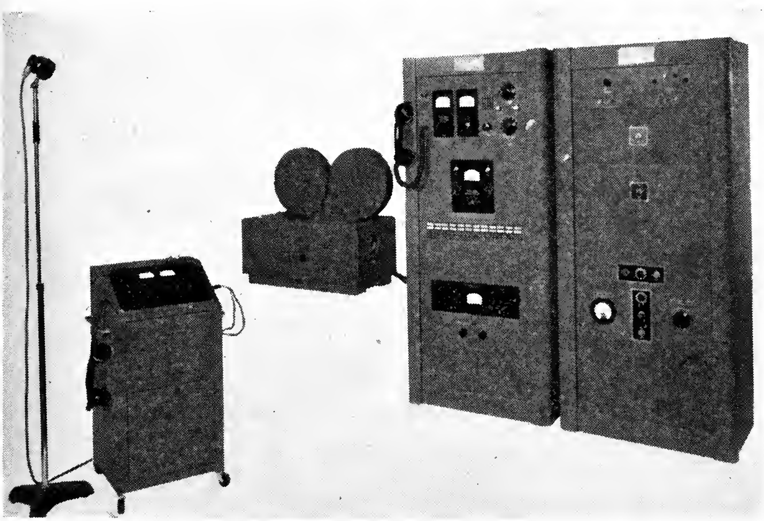

Fig. 2—Westrex Series 600 recording system.

the same as the Western Electric Series 300 system previously described.[2] In both weight and bulk it is less than half the physical size of the Series 600 system and is therefore particularly suitable for usage requiring a high degree of mobility.

The Series 200 system is a single-system, 35-mm, 100-mil standard track density channel which can be used with either Wall, Mitchell, or Akeley newsreel cameras. A detailed description of this system has been given previously by Hopper and Moody.[3]

In all these Westrex recording systems except the newsreel Series 200 the change from 35-mm to 16-mm recording, or vice versa, is accomplished by means of a set of conversion parts. The change can be made within half an hour by the normal operating personnel. The change from density to area, or vice versa, is also accomplished with a set of parts, in this case consisting chiefly of the modulator unit and light valve. Direct positive recording is also being made available by means of a conversion kit.

There are two types of Westrex re-recorders. One is for 100-mil standard density or area track and the other for 100-mil standard, 100-mil push-pull, and 200-mil push-pull tracks, density or area.

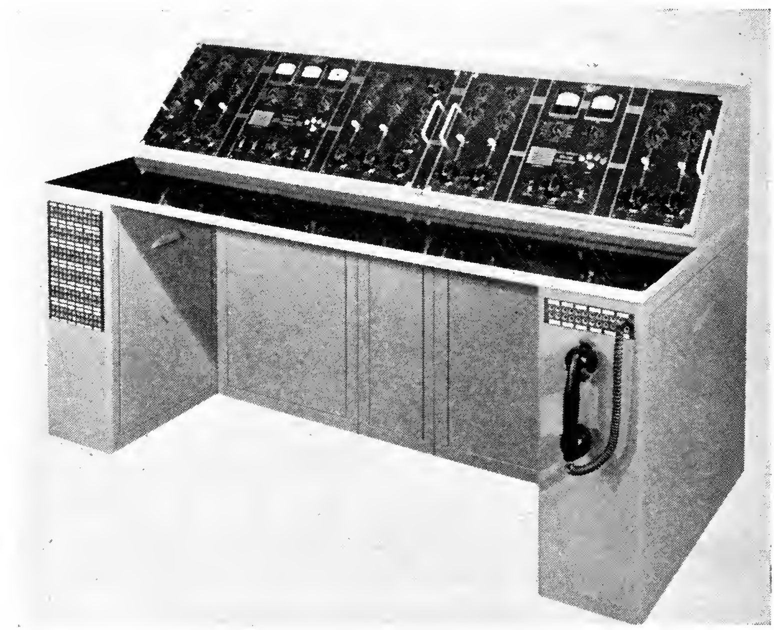

Fig. 3—Westrex M4AB re-recording mixer console.

On the push-pull re-recorder the change in tracks is achieved simply by turning an indicator knob and switching the phototube control from standard to push-pull. These re-recorders have a loop capacity of 25 feet. In addition, the base loop cabinet on which the re-recorder is mounted has a 30-foot capacity. There is a door at the top of the re-recorder for the extension of the loop upward and the base cabinet has removable side plates which make possible the use of adjacent cabinets for the running of very long loops. An automatic rewind with variable speed is available if required.

Disk reproducers are available which provide $33^1/_3$- and 78-revolution-per-minute speed operation, both with a flutter content of less than 0.1 per cent. One motor is used for both speeds, the change in speed be ng accomplished by reversing the direction of rotation of the motor and translating this reversal into a speed change by means of specially designed overriding clutches. Two types of reproducers are available. Either can be used for both vertical and lateral reproduction but one is slightly more suitable for vertical while the other favors lateral reproduction.

The Westrex re-recording mixer consoles are made on the building-block plan in self-contained sections of four positions each. The first section includes the monitoring and intercommunication facilities. Additional sections may be added to increase the number of input channels as required. The unit shown in Fig. 3 is a two-section console with a capacity of eight input channels.

More than 70 channels of these new equipments have already been installed in studios throughout the world. To achieve continuing good results it is essential that these studios keep up to date on progress in recording techniques and equipment developments. To assist in achieving the desired results Westrex has built up an organization of trained recording personnel located in London, Paris, Bombay, Shanghai, and Buenos Aires. This service program has already shown worth-while results in maintaining recording standards, and should assist the foreign studios to keep abreast of developments in Hollywood and to bring worth-while developments from abroad to the attention of Hollywood, to the benefit of the industry as a whole.

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The Picture Splice as a Problem of Video Recording*

By F. N. GILLETTE

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Summary—**Producing an invisible picture splice is one of the major problems of present-day video recording. The various quantities which must be controlled to produce an invisible splice are enumerated with special emphasis on the persistence characteristic of the cathode-ray-tube phosphor.**

Introduction

The term "video recording" might be defined as the process of making a photographic record of the picture portion of television-program material from the face of a cathode-ray tube. It involves a combination of the photographic and television arts. This union gives birth to a number of problems of technique which were not encountered in the practice of either of the parent arts.

This paper will consider just one of these problems, that of making the picture splice invisible. Most of the many factors involved here will be covered as briefly as possible in order that more time can be given to a consideration of the cathode-ray-tube phosphor and its influence on the splice.

To avoid certain ambiguities that would otherwise come up it is assumed at the outset that the film produced by video recording is to be used for theater projection and that it is produced by the direct-positive method. That is, that a positive film is obtained in a single photographic step by exposing the film to a negative video picture on the cathode-ray tube.

Since the motion picture and television industries are both very large and are firmly standardized on their present frame rates of 24 and 30 frames per second, video recording equipment is obliged to take 24-frame pictures of 30-frame events. The way in which this is accomplished is illustrated in Fig. 1. The upper figure represents the vertical scan of the television system. The scanning beam starts at the top of the picture, progresses at a constant rate to the bottom and returns rapidly to the top to start the next scan. A single sweep

* Presented April 5, 1949, at the SMPE Convention in New York.

down the picture is called a "field" and has a period, including the return time, of $^1/_{60}$ of a second.

The television system uses interlaced scanning in which only the alternate lines of the picture are scanned in one field, with the intervening lines scanned by the next field. Thus a television frame embraces two fields and has a period of $^1/_{30}$ of a second.

The lower figure shows the timing diagram of a motion picture camera, modified to fit video recording requirements. The time t_1 indicates the start of an exposure, this exposure continuing to t_2. A second exposure starts at t_3 and continues to t_4. The interval beteen t_3 and t_5 is $^1/_{24}$ of a second as required by the motion picture system. The duration of each exposure is $^1/_{30}$ of a second, allowing one full television frame to be recorded on each frame of film.

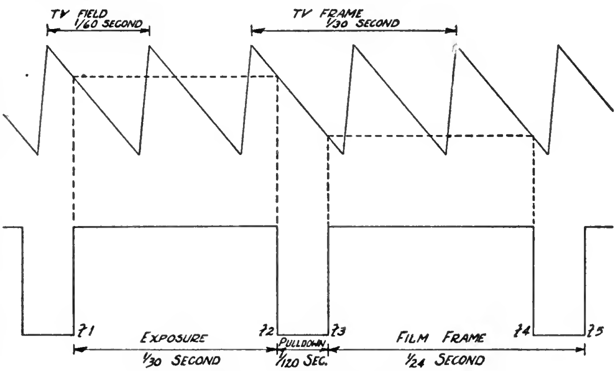

Fig. 1—Timing diagram.

The exposure timing mechanism constitutes the major difference in various video recording equipments now in service. In some cases an electronic timing circuit blanks the cathode-ray tube thus providing an electronic shutter. In others a mechanical shutter is used. Much of the following discussion will apply alike to both types of equipment. Where differences exist they will be pointed out.

It is indicated in the figure that the interval available for film pulldown, t_2 to t_3, is $^1/_{120}$ of a second, which is 72 degrees of the camera cycle. The shortness of this interval made necessary the design ot special cameras for video recording. At present there are several 16-mm movements which meet this requirement and at least one 35-mm movement.

Projecting certain points from the camera diagram to intercept the television diagram shows that the beginning and the end of an exposure coincide in vertical position on the cathode-ray tube, and that three television fields are involved in the exposure of each frame of film. Of the first and third of these fields only such segments are included as will add up to one field. The region on the film where these two picture segments join is called the "picture splice" in this paper.

The two exposures shown in the figure indicate that the picture splice will occur at two different positions. In following frames the splice will alternate between these two positions which differ in phase by one half of a television field. This is a significant point. It means that no matter how the camera is phased with respect to the television system at least one of the two splices will lie in the picture area.

It is for this reason that the quality of the picture splice is of such concern. Since the splice cannot be hidden by means of phasing the only alternative is to make it invisible. This requires that there be no change in picture brightness or structure above, below, or coincident with the splice. The factors which oppose this result are the subject of the present paper.

Structural Defects

Changes in picture structure have been mentioned as a source of visible splice defects. Some elaboration of this point is in order. The scanning mechanism of television breaks the picture down into a number of discrete horizontal lines, a total of 525 per frame, with some 500 of the lines in the useful picture area. Presenting these lines so that they are clearly resolved will add nothing to the clarity of the picture so that one normally would adjust the resolution of the photographic and projection equipment to conceal the line structure by merging each line with its neighbor. If overdone this action will lose detail in the picture so that one would attempt to hold the resolution of this part of the system somewhere between 400 and 500 lines, using here the television method of counting lines.

The success of this step depends upon the accuracy and stability with which each horizontal line is registered in its correct position on the film. If the lines of one field in a particular frame are displaced vertically with respect to the other field of that frame, the picture is no longer correctly interlaced, and if the displacement is an appreciable fraction of the space between lines, the lines become paired. In this case the picture contains but 250 lines, and with the system adjusted as suggested above, 250 lines will be resolved with ease.

There are many sources of line displacement, some of which are not at all connected with the splice or the video recording equipment, but even these often serve to betray the location of the splice. If one recalls that a frame bearing a splice in the middle of the picture is assembled from three television fields, the reason for this effect may be seen. The bottom section of the picture is a combination of fields 1 and 2 while the top section is a combination of fields 2 and 3. A vertical displacement which occurs only in field 1 will produce visible line structure only in the bottom half of the picture leaving the top half smooth. The transition from structure to no structure is a very effective eyecatcher.

An example of line displacement, which is characteristic of television in general and not specifically of video recording, is that which is caused by variation in the repetition frequency of the horizontal synchronizing pulses. The frequency is controlled at the transmitter by tracking the 60-cycle power-line voltage. Since the power line does not usually constitute a completely stable reference frequency, any frequency which is controlled by the power-line frequency will show a certain amount of random deviation. Such deviations are generally small, but the deviation required to produce a significant vertical displacement of the scanning lines is also small. Consequently, it is currently believed that frequency deviation of the horizontal pulses is a fundamental source of picture defect, which cannot be eliminated by any practical modification of the video recording equipment.

Other sources of structural defect are found in the video recording equipment. Of these several might be mentioned. Clearly any variation in picture size may make accurate superposition of two successive fields impossible. For this reason it is highly desirable to regulate all supply voltages which have any effect on deflection amplitude. This presents no difficulty except for the accelerating potential which is usually of the order of 30 kilovolts. Commercial regulators are available for this range, but they cannot cope with the type of current variation introduced by the gating action of electronic-shutter equipment. Consequently it is common practice to shunt the output of the supply with a large capacitor, a practice which makes operating personnel very respectful toward this part of the equipment.

Film motion may also create a structural defect. Since each line of the picture is registered on the film during a particular portion of the exposure interval, film motion during any part of the exposure will serve to displace certain lines with respect to the remainder. Incorrect camera phasing may allow the exposure interval to extend into the pulldown interval resulting in gross displacement of lines at the splice. Line pairing over a considerable area of the picture may be caused by a minute amount of film creep. With some movements such creep might be introduced by the action of a register pin which is in motion during the exposure. In any case, very careful design is required to avoid any trace of film motion.

BRIGHTNESS DEFECTS

Brightness defects can also serve to make the splice evident. An abrupt brightness discontinuity will be observable simply by comparison of adjacent areas. A more gradual transition will be noticed primarily as flicker. The fact that the picture splice occurs in a given location only on alternate frames means that any brightness defect associated with the splice will give rise to 12-cycle flicker. In either case the brightness defect need not be large to be annoying to a critical observer.

Screen brightness is, of course, related to the exposure received by the film, the exact relationship being determined by the intervening photographic processing. When the recording is a direct positive, the photographic step will have a gamma of about 2.5. This means that a small exposure difference will give rise to a screen-brightness difference which is two and a half times larger. Obviously very close control of the exposure is required.

If the exposure interval determined by the camera is not exactly equal to the period of a television frame an exposure defect will be introduced. With electronic-shutter equipment the effect is concentrated in the lines right at the splice, either as doubly exposed lines or as lines which receive no exposure. This would be a serious defect, but its prevention is not difficult. Since each television frame contains exactly 525 horizontal scanning lines it is possible to use pulse-counting circuits to insure that each exposure interval contains the correct number of lines.

Incidentally, counting pulses to determine the exposure provides a system which is quite tolerant to variation in frame rate of either television or camera. In fact, the two systems need not operate at the same frame rate; a point of possible advantage if signals originating at a distant point are to be recorded.

Mechanical-shutter equipment depends upon precise construction of the shutter and exact control of its rotation rate to achieve timing accuracy. Consequently, the camera must be locked in frequency to the television signal. Even with the two systems locked the inertia of the camera may prevent adequate accommodation to rapid change in television frame rate. To prevent such effects the two systems should be given the same time constant.

The effect of a timing error in mechanical-shutter equipment will be considered in a later section. Here it is only noted that it differs from that outlined above for the electronic shutter.

PHOSPHOR PERSISTENCE

Another source of exposure error may be found in the phosphor of the cathode-ray tube. Since this factor has not received much public attention to date, it will be given closer scrutiny than has been given the preceding points.

The films which are useful in video recording are all very slow films and are sensitive only in the blue region of the spectrum. Thus a satisfactory phosphor must have a considerable blue component in its light output. This fact plus certain features of operating convenience seems to have led all workers in the field to select the type P11 phosphor as being the most acceptable. Consequently, the following discussion will be confined exclusively to the P11 phosphor.

The light emitted by an element of area of a phosphor is not restricted to the very short interval during which the electrons of the scanning beam impinge upon that area, but instead continues for an appreciable time thereafter. The rate at which the intensity of emission falls off after scanning is characteristic of the particular phosphor. For the P11 phosphor the decay is of the type shown in Fig. 2.

The figure shows the instantaneous intensity of emission plotted as a function of time. According to the present standards of phosphor designation any P11 phosphor will follow this type of curve which is simply the reciprocal of some power of time. The exponent in the expression may have any value between 1 and 2. Experimental curves supplied by various manufacturers indicate exponents ranging from about 1.1 to about 1.4. Since a large exponent is desirable, at least for electronic-shutter equipment, a value of 1.5 has been used for this diagram, a value slightly higher than is justified by available data.

The amplitude factor has been adjusted to yield an intensity of 10 per cent of the initial intensity at 500 microseconds, a value which fits the data of several manufacturers. Clearly the simple inverse power law cannot apply in the neighborhood of zero time since infinite values of intensity would result. For this region, extending out to 250 microseconds, linear decay has been assumed.

The total light output of any element of the phosphor is proportional to the integral of this curve, that is, to the area under the curve. That portion of the total light which is effective in exposing the corresponding element of the film is determined by carrying out the

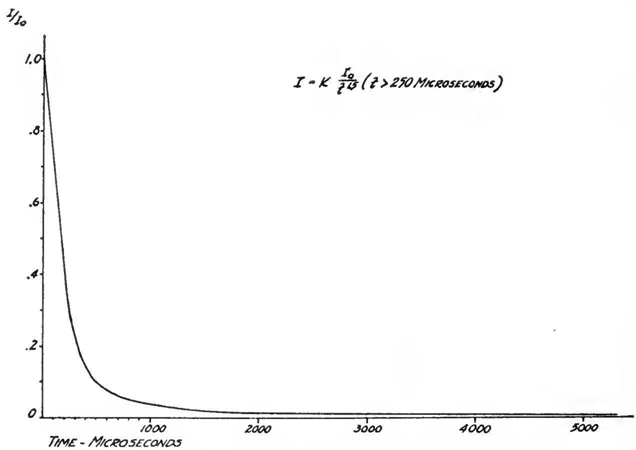

Fig. 2—Decay characteristic of P11 phosphor.

integration for just that interval of time, different for each line of the scan, during which light from the phosphor is permitted to reach the film.

The effective exposure of the element of film is assumed to be proportional to this integral. That assumption is not really justified in view of the well-known failure of the reciprocity law when applied to exposures of such short duration. However, no information is available on which to base a more accurate statement.

The mechanism that prevents light from reaching the film, thus limiting the period of integration, is obviously the closing of the shutter if the equipment contains a mechanical shutter. If the shutter is electronic there is actually no interruption of the passage of light from phosphor to film. Here the limiting action is the motion of the film during its transport period. While the film is in motion incident light does not contribute to the formation of a particular image point, but instead is spread over a large area of the film, thus contributing nothing but a general fog.

PERSISTENCE IN RELATION TO THE ELECTRONIC SHUTTER

In this respect electronic and mechanical shutters behave quite differently and require individual consideration. The case of the electronic shutter, illustrated in Fig. 3 will be considered first.

The top figure simply repeats the camera cycle which is shown in Fig. 1. The pulldown interval shown here is the maximum available for pulldown and is greater than the time actually required by the camera.

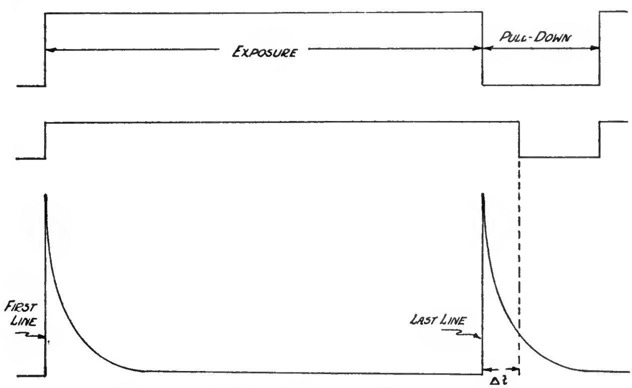

Fig. 3—Timing diagram—electronic shutter.

The central figure shows the actual pulldown interval of the camera. It will be noted that the end of actual pulldown has been made to coincide with the end of the available interval, this phasing being the most advantageous, as will be seen.

The bottom figure shows the light-output curves of the first and last of the 525 lines of the television frame. The 523 intervening lines are not shown because of the crowding that would result. The lines just outside the exposure interval are not shown because they do not exist on the cathode-ray tube, being blanked out electronically by the timing circuits.

The exposure for each line is calculated by integrating from the time of occurrence of that line to the time at which pulldown starts, indicated by the dotted line. The first line of the frame is thus integrated over a very long time and the exposure is essentially equal to the total light output from that line. The last line is integrated over a relatively short time, indicated as Δt, and if the persistence is long with respect to Δt a reduced exposure will result. Δt is equal to the difference between the time available for pulldown and the time actually used for pulldown and its value depends upon the particular intermittent used in the camera. Generally it will be something between 1 and 2.5 milliseconds.

The exposure integration has been carried out for a sufficient number of different intervals to establish the curve shown in Fig. 4. From this curve it is possible to determine the relative exposure

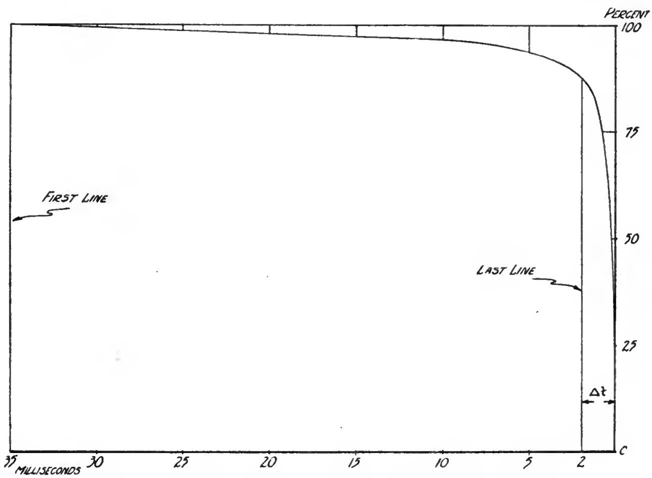

Fig. 4—Relative exposure versus line placement.

value for any line in the frame once the characteristics of the intermittent are known.

The curve is a plot of relative exposure against time of occurrence of the scanning line. The time scale is reversed, increasing to the left, and indicates the time by which each line precedes the beginning of pulldown. As an example of the use of the curve, the position of the last scanning line is indicated at t equals Δt. The value of the ordinate at this point is the relative exposure of the last scanning line. Each preceding line would be placed 63.5 microseconds farther to the left, this being the period of the horizontal lines. The position of the first scanning line is indicated at the extreme left.

Information extracted from this curve is shown in another form in Fig. 5. For this figure Δt is assumed to be 2 milliseconds. The vertical bars represent the horizontal scanning lines in the vicinity of the splice, the height of each bar indicating the relative exposure contributed by the line. The vertical scale is expanded to emphasize the differences that exist. The horizontal co-ordinate indicates the location of the line in the vertical dimension of the picture. It too is expanded so that individual lines may be shown.

The effective exposure for an extended area will be an average of the individual line exposures, this average being shown in the diagram by the two horizontal lines. They indicate the average exposure on the two sides of the picture splice to differ by some 6 per

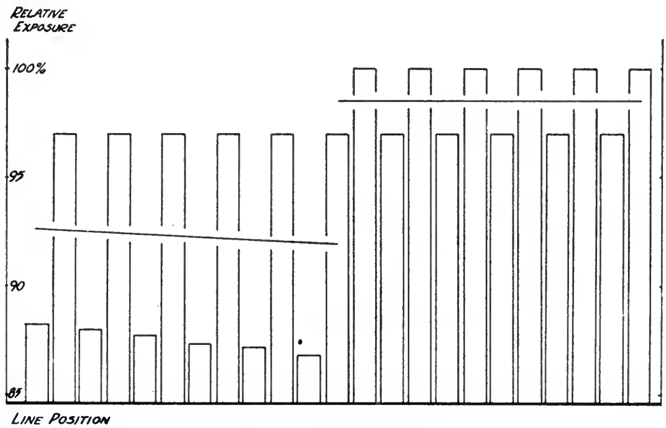

Fig. 5—Relative line exposure in picture-splice area.

cent. Multiplying this difference by the photographic gamma indicates a brightness difference at the projection screen of 15 per cent, a value which will certainly be visible.

The defect thus calculated is so large that one would tend to doubt the validity of the procedure except for the fact that P11 tubes have been encountered which do exhibit a persistence defect of this magnitude. Other P11 tubes seem to be completely satisfactory.

A similar calculation has been carried out, starting with an assumed screen-brightness difference which is acceptable and then working backward to determine a corresponding phosphor decay curve. For this curve the exponent in the inverse power law has a value which is very close to 2. The existence of satisfactory P11 tubes may mean that some tubes actually follow an inverse square law, although substantiating data have not been found. It may alternatively mean that the inverse power law is not a satisfactory approximation to the facts, particularly in the tail of the curve where the intensity values are very low and have not been checked experimentally.

PERSISTENCE IN RELATION TO THE MECHANICAL SHUTTER

In considering the action of a mechanical shutter, the situation will be found to be quite different. Electronic blanking is not used and all of the lines of the television scan are shown on the cathode-ray tube. Thus lines which have actually been scanned on the tube prior to the beginning of the exposure interval may contribute significantly to the exposure of the film by virtue of the phosphor's persistence.

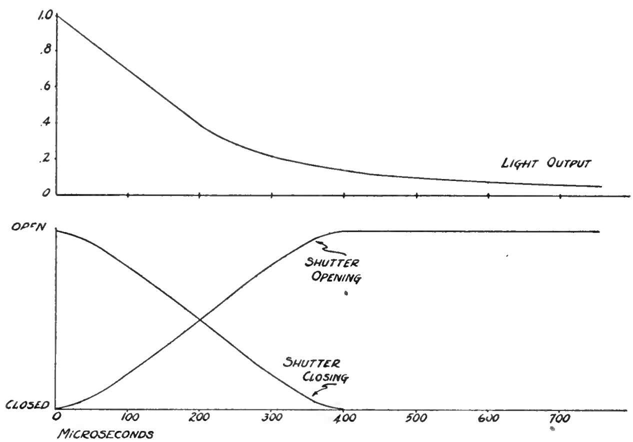

Fig. 6—Mechanical-shutter action.

The mechanical shutter is designed so that its closing edge crosses any point in the shutter plane exactly $^1/_{30}$ of a second after that same point was crossed by the opening edge. For a particular line which is scanned just before the shutter opens, the first part of its light output is blocked by the shutter, and only a segment of the tail of the output curve contributes to the exposure of the corresponding element of the film. However, since each line is scanned repeatedly at intervals of $^1/_{30}$ of a second, the same line is scanned again just before the shutter closes, and this time the initial portion of the light output reaches the film and only a segment of the tail of the curve is blocked by the shutter. If everything is working to perfection, the contributions from the two scannings of the line add up to give a total exposure exactly equal to that obtained from a single scanning of the line without the interruption of the shutter.

Thus it seems there is no first-order effect of persistence with mechanical-shutter equipment, so that it should be possible to use any P11 tube, or even phosphors of longer persistence.

However, there is a second-order effect which should be considered. If either the interval between scannings of a line or the open interval of the shutter should be incorrect, then the two scannings of the line would not be symmetrically located with respect to the opening and closing actions of the shutter and the sum of the two contributions

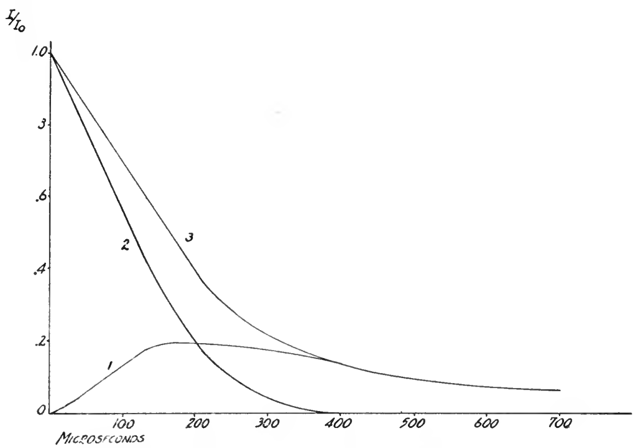

Fig. 7—Effective light output—correct timing.

would not equal the desired total. Calculating the exposure error that would result from a given error in timing will provide an evaluation of the tolerance of the system to timing errors.

The steps which are involved in such a calculation can be explained in connection with Fig. 6. The upper figure is again the persistence curve of the P11 phosphor. The lower curve shows what is thought to be the shutter action of the Eastman television recording camera. The conditions to which these curves apply involve a 2-inch lens, an aperture of $f/2.6$, and an object distance of 30 inches. The vertical co-ordinate for the shutter curves represents the relative transmission of the effective aperture of the system at any instant. The time scale is the same as that for the light-output curve.

To determine the relative exposure for each of the two scannings of a line located as shown with respect to the shutter cycle, each value of the light-output curve must be multiplied by the corresponding transmission values of the two shutter curves. This step is illustrated in Fig. 7.

Here curve 1 shows the effective light output for the first of the two scannings of the line. Curve 2 shows the same quantity for the second scanning. Curve 3 is the sum of curves 1 and 2 and represents the total light which is effective in exposing the corresponding area of the film. As expected, curve 3 is identical with the original light-output curve of the phosphor.

Fig. 8 shows the same group of curves, but they represent erroneous timing in that the closing of the shutter has been retarded 100 microseconds with respect to the second scanning of the line. This pro-

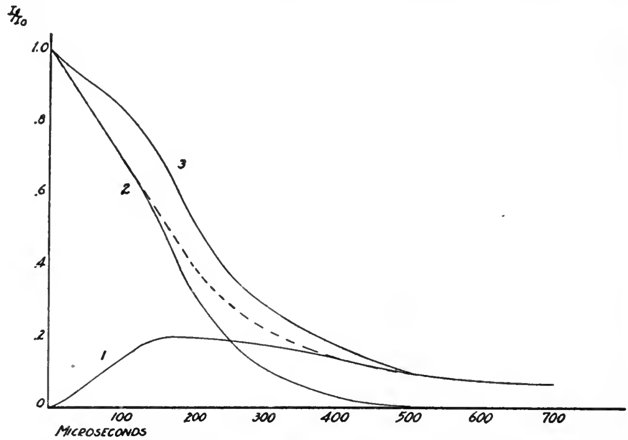

Fig. 8—Effective light output—retarded closing.

duces a defect in the total output curve which has been emphasized by showing with a dashed line the desired shape. The resulting exposure error is proportional to the area between curve 3 and the dashed line.

The same calculation was carried out for several values of shutter error and the various exposure errors were determined. The results are shown in Fig. 9. Here the horizontal co-ordinate is the shutter error in microseconds and the vertical is the exposure error which results. If again one averages the exposure over a small area and multiplies by the photographic gamma it is seen that a timing error of around 30 microseconds will produce a screen-brightness defect of about 6 per cent. Since this defect would be quite visible it follows that timing which is accurate to 0.1 per cent is not good enough.

It should be pointed out that this result applies only to lines which are scanned almost in coincidence with the opening and closing of the shutter, in other words, to some 6 to 12 lines at the splice. The effect diminishes rapidly for lines outside this group.

By selecting a phosphor with a faster decay, the area may be narrowed slightly but the magnitude of the error will be increased. Conversely, a slower decay curve will result in a smaller brightness error, but will spread it over a larger area.

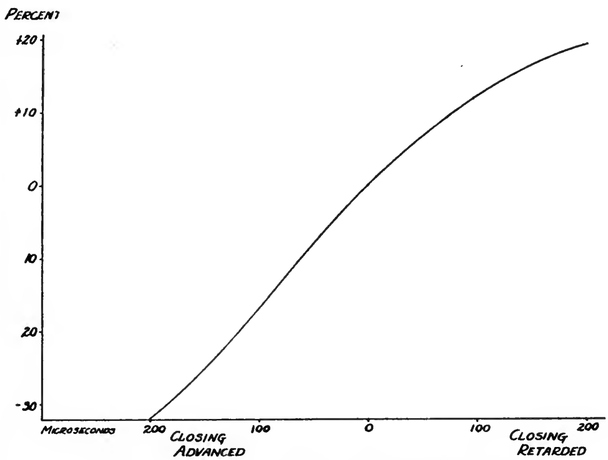

Fig. 9—Exposure error versus shutter error.

CONCLUSION

The comparatively detailed consideration of phosphor persistence is intended simply as an example of the type of quantitative study that must be given each of the many factors which affect the quality of the recorded picture. The goal in each case is to reduce the magnitude of any defect to a level below the threshold of detectability for that defect. At present the threshold values are largely established by the transmitted television picture which often contains defects of greater magnitude than those contributed by the recording process. As the transmitted picture is improved the threshold values will have more fundamental origins, usually some characteristic of the human eye. These latter values are the ones by which the equipment designer must be guided if the resulting equipment is to achieve acceptance for any extended period.

Navy Electronic Shutter Analyzer*

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Summary—A new electronic shutter analyzer employing a two-gun cathode-ray oscilloscope with two phototubes has been developed by the Navy. This device is designed to permit the rapid analysis and solution of numerous problems commonly encountered in photography including: (1) shutter operation and efficiency; (2) shutter-flash synchronization; (3) shutter-solenoid delay; (4) flash-gun-switch, solenoid-shutter delay; (5) internal-shutter-switch contact time; (6) switch or electrical contact efficiency; (7) diaphragm calibration; (8) duration and intensity of light as emitted by flashbulbs and some gaseous discharge tubes.

Introduction

The fundamental problem in everyday photography is to make sure that the correct amount of light is permitted to strike the unexposed negative in the camera. Since a film of infinite latitude has not as yet made its appearance, and narrow latitude color film has, it becomes increasingly necessary to measure accurately the effective exposure time.

The importance of "getting that picture," whether it be during a battle or in a research laboratory, warranted development of a testing device that would rapidly and graphically furnish the information necessary to calibrate the cameras properly. The problem was to develop an equipment which could be operated by a naval photographer and which would be useful in the solution of a majority of the photographic problems. The Research and Development Department of the United States Naval Photographic Center, under the general supervision of the Bureau of Aeronautics, conducted a survey of camera-shutter testing problems as encountered at various Naval research laboratories, test stations, and the like.

On the basis of this survey, it was decided to utilize the visual type of presentation on a cathode-ray oscilloscope as outlined in the American War Standard Specification Z52.63-1946. However, Specification Z52.63-1946 covering a "Method of Determining Performance Characteristics of Between-the-Lens Shutters used in Still-Picture Cameras" did not permit analysis of shutter-flash synchronism

* Presented April 8, 1949, at the SMPE Convention in New York.

or solenoid-shutter delays. It was considered that this limitation would be overcome by the simultaneous presentation of two curves on a cathode-ray oscilloscope which would represent two separate and distinct phenomena. Specifications were drawn up and a contract awarded the Triumph Manufacturing Company, Chicago, Illinois, for the development and construction of the Model 950 electronic shutter tester. Seven months later the equipment was delivered to the Navy for acceptance tests which disclosed that the manufacturer had exceeded the requirements of the specification. The credit for the design and construction of the shutter tester, or more appropriately, shutter analyzer, must be given to E. J. Doyle and William Sturm, chief engineer and assistant engineer, respectively, of the Triumph Manufacturing Company.

Before going into a more detailed description of the shutter analyzer, it is recognized that shutter-testing devices utilizing a cathode-ray oscilloscope and a phototube have been assembled and used in various laboratories. To the best of the author's knowledge, these early pioneer units have been assembled from odds and ends of laboratory electronic equipment while, on the other hand, the Triumph Model 950 tester is completely engineered and is in production (see Fig. 1).

DESCRIPTION

A DuMont type 5SP7 5-inch dual-gun, long-persistence, cathode-ray oscillograph with a dual set of controls is the main component of the electronic shutter tester. Two GL-929 photoelectric tubes with associated cables and a rectified 120-volt direct-current source of illumination comprise the balance of the equipment (see Fig. 1).

The shutter-tester, dual-gun, cathode-ray oscillograph has a dual set of conventional controls including horizontal and vertical beam positioning, focus, intensity, and vertical amplitude (Fig. 1). The horizontal amplitude of both curves, however, is simultaneously varied by a single control and may be linearly expanded approximately 500 per cent. Sweep speeds of 1 millisecond, 10 milliseconds, and 100 milliseconds corresponding to frequencies of 1000, 100, and 10 cycles per second are available by means of a selector switch. Both single sweep and repetitive sweep are furnished. Using the single-sweep position, each beam receives an intensifying pulse and the resulting curve will start at the left and then travel to the right. When using repetitive sweep, however, the resulting curve will never occur at the same location on the tube. The only exception to this rule occurs when the frequency of the phenomenon under study is either equal to or is an even multiple of the sweep speed of the tube. In this case, the resulting curve or curves will appear to be stationary. Triggering of the sweep may be initiated by:

(a) Information furnished to Channel I resulting from light energy as picked up by phototube 1.

Fig. 1—Electronic shutter analyzer (tester) including the light box and two phototubes.

(b) Information furnished to Channel II resulting from either light energy as picked up by phototube 2 or by the closure of an external electrical circuit through the receptacle located on the top surface of tube 2.

(c) Pressing the "trigger" button.

(d) A momentary contact across the "trigger external" terminals.

A timing oscillator furnishes alternate blanking and intensifying pulses of either 1-millisecond or $^{1}/_{10}$-millisecond duration. These timing pulses are superimposed upon both curves and provide a visual picture of the time relationship involved.

An off-on toggle switch, a red indicator lamp, a fuse, and a grounding terminal complete the list of controls as found on the front panel of the shutter tester proper. The simplified functional block diagram of the tester is given in Fig. 2.

OPERATION

The electronic shutter tester, or more appropriately, the electronic shutter analyzer, is ideally suited for testing between-the-lens shut-

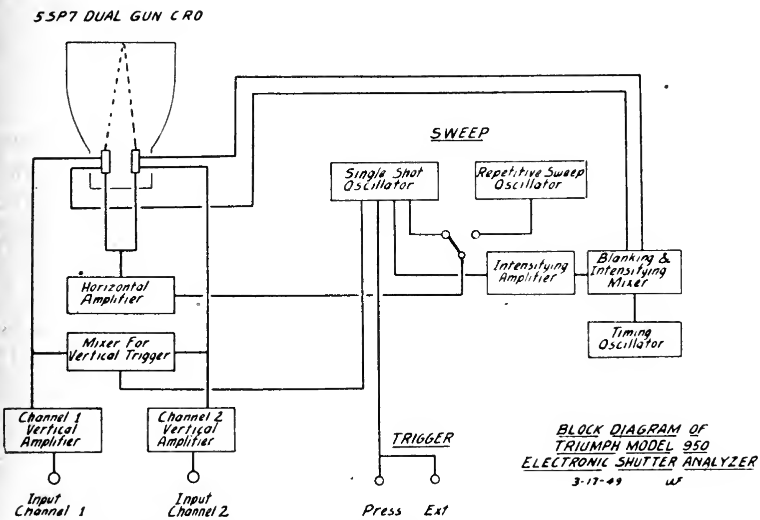

Fig. 2—Simplified block diagram of the shutter analyzer.

ters. However, a considerable amount of information concerning focal-plane shutters and rotating shutters, such as used in conventional motion picture cameras, may be determined through proper use of the tester.

A between-the-lens shutter may be tested conveniently when placed between a source of direct-current illumination and either of the two phototubes. When the shutter with its lens is mounted on a camera with a removable or open back, the open back of the camera is placed as close to the light source as possible. The phototube, however, must not be placed too close to the shutter as, in the case of large-diameter (4-inch) aerial camera shutters, the angle of acceptance

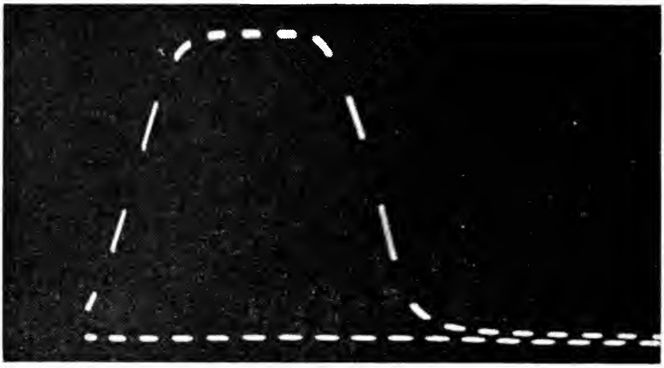

Fig. 3—Curve produced by a between-the-lens shutter operated at $^1/_{100}$ second with 1-millisecond timing markers.

of the phototube may be exceeded. For a given set of conditions, moving the phototube away from the lens or moving the light source away from the back of the camera will decrease the vertical amplitude of the curve on the oscilloscope as produced by the light passing through the shutter. The height of this curve may also be varied by the appropriate "vertical-amplitude" control of the analyzer. Fig. 3 illustrates the type of curve produced by a well-known shutter when set at $^1/_{100}$ of a second with a maximum diaphragm opening of $f/4.7$. The second gun of the cathode-ray oscilloscope in this case furnishes a convenient baseline. It can be seen that a negligible portion of the

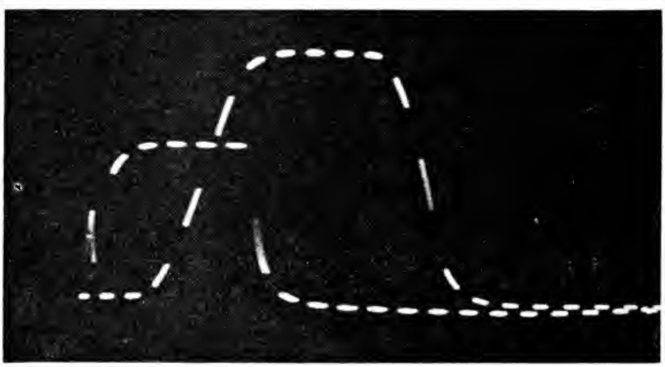

Fig. 4—The small curve was produced by wiping action of internal shutter contacts at the 5-millisecond delay setting. The large curve was produced by a $^1/_{100}$-second shutter.

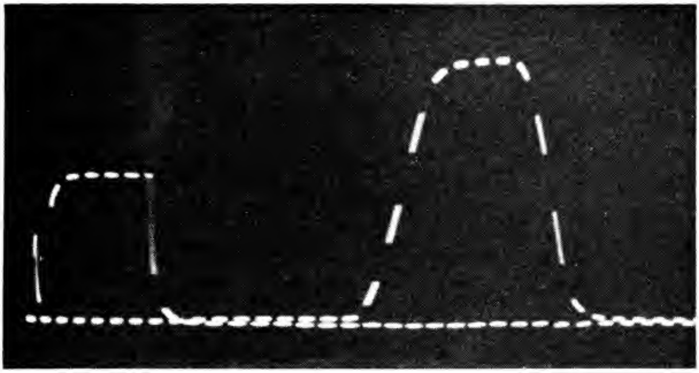

Fig. 5—Curves produced by the shutter of Fig. 5 but with a 20-millisecond delay setting.

curve at the extreme left has been lost because of the delay required for triggering the sweep. Even this small loss could have been eliminated by using an external method of triggering or by repetitive sweep if it had been desirable to analyze closely the opening portion of the shutter cycle. As a 1-millisecond timing pulse was used, each dot plus a blanking period is equal to 0.001 second. If a $^1/_{10}$-millisecond (0.0001-second) timing pulse had been used, the number of dots on the curve would have been increased by a factor of ten.

Fig. 4 illustrates the time relationship when the same shutter as above is manually actuated to check operation of the internal shutter

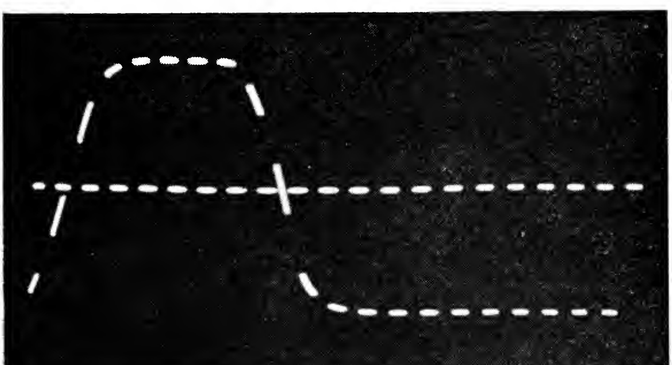

Fig. 6—Curve produced by the shutter of Fig. 3 with the baseline moved halfway up the curve.

contacts at the 5-millisecond delay setting. By counting the 1-millisecond timing dots, it is found by inspecting the small curve that the shutter contacts are making a good contact for approximately 5 milliseconds and that the shutter was wide open approximately 5 milliseconds after the initial closure of the shutter contacts. A 5-millisecond delay flashbulb, when used on this camera, would therefore, not be in perfect synchronism with the shutter and it would not be necessary to waste a flashbulb to verify this condition. Fig. 5 illustrates the time relationship at the 20-millisecond delay setting and it can be seen that a 20-millisecond delay flashbulb would be in synchronism with the shutter.

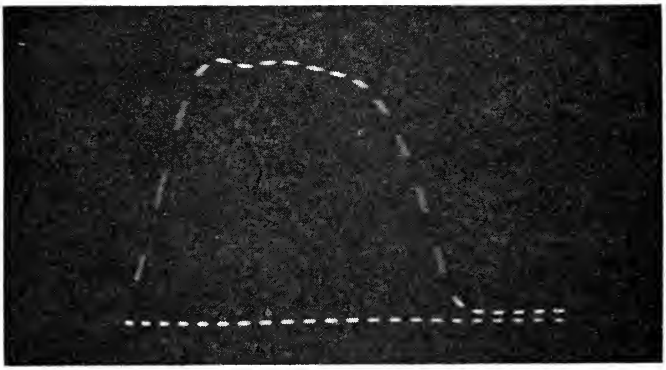

Fig. 7—Curve produced by the shutter of a 24-inch focal-length K-18 aerial camera at the maximum aperture of $f/6$.

It is well known that the effective exposure produced by a between-the-lens shutter can be determined by noting the length of time during which the shutter is passing more than 50 per cent of the maximum amplitude of light intensity as indicated on a curve of light transmission versus time. Referring to the curve of Fig. 3 as produced by a shutter set at $^{1}/_{100}$ second and drawing an imaginary line parallel to the baseline and midway between the baseline and peak amplitude, it will be noted that the portion of the curve thus cut off by this imaginary line has 7-millisecond timing markers. The effective exposure time is therefore $^{7}/_{1000}$ or $^{1}/_{140}$ second. Fig. 6 illustrates how the baseline may be moved halfway up the curve and then the number of timing marks may easily be counted to determine the effective exposure. The total "open time" or "action-stopping time" of the shutter is determined by counting all the timing markers on the curve of Fig. 3. The shutter efficiency is equal to the ratio of:

$$\frac{\text{effective exposure time}}{\text{total open time}} = \frac{7 \text{ milliseconds}}{11 \text{ milliseconds}} = 64 \text{ per cent.}$$

Fig. 7 was obtained by the action of the shutter of a K-18, 24-inch focal-length aerial camera with a maximum aperture diameter of 4 inches. It is quite apparent that a definite "shutter bounce" has occurred as the shutter reached its maximum aperture. This portion of the curve may be more closely analyzed by either expanding the curve horizontally or by switching from the 100-millisecond sweep to the 10-millisecond sweep.

FOCAL-PLANE SHUTTERS

Focal-plane shutters with constant slit widths present a more difficult problem of analysis than do between-the-lens shutters. Between-the-lens shutters whether wide open or barely open, are passing light which simultaneously strikes the entire area of the film during the "total time open" cycle of the shutter. Focal-plane shutters with constant-width slits scan the negative and the exposure depends upon slit width and slit velocity. The efficiency, however, is a constant depending upon the physical construction of the camera and the f stop and is given by the formula

$$\text{efficiency} = E = W \div \left(W + \frac{D}{f}\right),$$

where

W = slit width
D = distance between focal plane and curtain
f = stop of lens.

A curve on the cathode-ray oscilloscope resulting from the travel of the focal-plane shutter slit closely resembles the curve produced by the between-the-lens shutter of Fig. 3. If the slope of the opening part of the curve is the same as the slope of the closing part of the curve, it is reasonable to assume that the curtain velocity at the beginning of the exposure is equal to the curtain velocity at the end of the exposure. The curtain velocity or exposure during the "flat" portion of the curve, however, is not so easily determined. As the effective exposure time is that required for the slit to move a distance equal to the width of the slit itself, the effective exposure time for any point may be determined by appropriately masking off the ground glass as located at the focal plane. For example, when the curtain slit is $^1/_4$ inch wide, a parallel $^1/_4$-inch-wide slit on the ground glass would be left unmasked. The location of this slit could, for example, be placed at the geometric center of the ground glass. Fig. 8 shows a curve with 0.0001-second timing marks obtained by this test method utilizing collimated light. The time required to pass from zero to maximum amplitude may be designated as t_1, and t_2, the time to pass from maximum amplitude to zero. The slit velocity during the short time required for the slit to travel a distance equal to its own width may be assumed to be practically constant and then $t_1 = t_2$. In this case, t_1 is

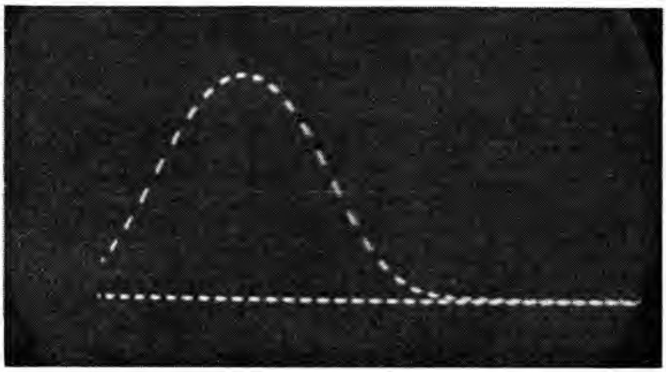

Fig. 8—Curve produced by a focal-plane shutter that has moved a distance equal to the shutter slit width. (0.0001-second timing markers.)

the time required for the slit to travel a distance equal to its own width. Then,

$$\text{velocity of slit } V_s = \frac{S}{t_1}$$

where S = slit width. Effective exposure time $T_e = S/V_s$.

Substituting,

$$T_e = S \div \frac{S}{t_1} = t_1.$$

From Fig. 8, it can be determined that the effective exposure time at the center of the 4- × 5-inch plate is approximately equal to 0.0012 second or $^1/_{830}$ second. A series of these slits may be placed on the ground glass and a corresponding number of similar curves will be produced. For example, a slit could be placed at the top, center, and bottom of the ground glass and the effective exposure corresponding to the three slit locations could be determined. Knowing the slit widths, slit spacings, and the time intervals, the curtain velocity may be computed at each of the three locations.

PHOTOGRAPHIC FLASHBULB AND FLASHTUBE ANALYSIS

The light emitted by flashbulbs may not only be analyzed from the standpoint of synchronization with the camera shutter but may be studied with respect to comparative intensity, duration of flash, and general shape of the light-output-versus-time curve. The shape of this curve may resemble that of Fig. 8 for 5- or 20-millisecond delay flashbulbs or the curve may be flat on top for a long-duration flash as required for use with focal-plane shutters.

The analyzer may be used for studying the light-emission curves resulting from the discharge of capacitors through gas-filled tubes as developed by H. E. Edgerton of the Massachusetts Institute of Technology. Fig. 9 illustrates the characteristic type of curve produced by most electronic flash equipment. Fig. 10 is a photograph of the curve produced from the light emitted by a well-known portable flash unit. Timing marks of 0.0001 second reveal that approximately $^{3}/_{10,000}$ second was required for the light to reach peak intensity while approximately $^{16}/_{10,000}$ second had elapsed during the flash-decay period. The shape of this curve is typical for all electronic flashtubes including the strobotac, strobolux, and microflash.

The sweep circuits of the analyzer were checked with signals furnished by a signal generator that had first been calibrated with the Bureau of Standards broadcast audio-frequency signals. The percentage of error at frequencies up to 40 kilocycles was found to be less than $^{1}/_{2}$ of 1 per cent.

The accuracy of the tester sweep circuits was profitably utilized in the analysis of focal-plane-shutter slit speeds and deformations of slit shapes at high linear velocities. A strobotac was first calibrated by means of the shutter analyzer at a speed of 6000 revolutions per minute (100 cycles per second). With the analyzer sweep set at 10 milliseconds or 100 cycles per second, the strobotac control was rotated until one stationary curve similar to Fig. 9 appeared on the screen. A strobolux, which has a much higher light output, was operated from the strobotac with phototube 2 placed in front of the strobolux while phototube 1 was in front of the strobotac. As the

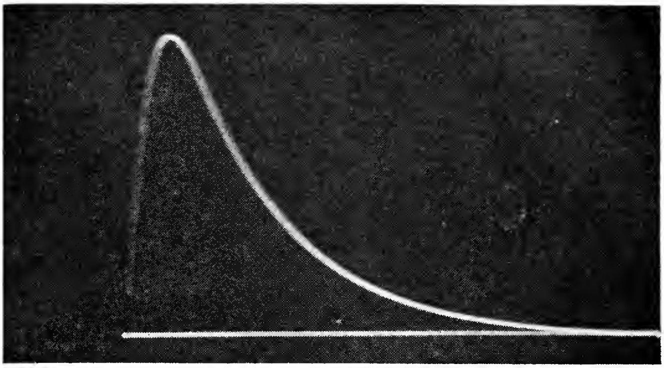

Fig. 9—Typical curve produced by an electronic flashlight source.

strobolux frequency is controlled by the strobotac, two stationary synchronous curves appeared on the screen which indicated that the calibrated frequency of the strobotac had remained undisturbed. Increasing the strobotac frequency until two pairs of curves appeared on the screen produced a calibrated 200-cycle-per-second pulse. The camera was loaded with film and the focal-plane shutter operated with the camera facing the strobolux.

The images recorded on the developed negative were in the form of horizontal bars which are proportional to the shape of the shutter slit. The distance between bars depends upon the curtain velocity and the strobolux frequency which during the test was $^1/_{100}$ and $^1/_{200}$ second.

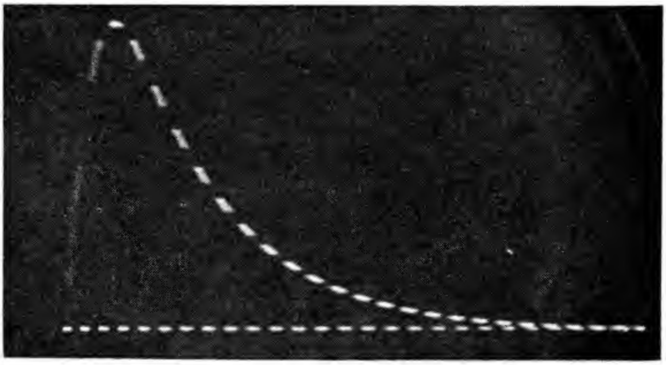

Fig. 10—Curve produced by a portable speed lamp with 0.0001-second timing markers.

Leica-type and other cameras that are not equipped with removable backs present a more difficult problem since the reflected light must be utilized. A strip of aluminum foil was placed in the focal plane of a Leica camera and a No. 2 floodlamp operated from a 110-volt direct-current supply was used as the light source. Operation of the small focal-plane shutter exposed the aluminum foil to the light which, when reflected, triggered the sweep through the No. 1 phototube and produced a curve that indicated the time required for the slit to traverse the film gate.

Motion Picture Shutter Testing

The rotating shutter of the conventional motion picture camera may also be analyzed to a certain extent by the shutter tester. A limited number of tests have been made using a 35-mm Mitchell motion picture camera operated at speeds varying from 10 to 100 frames per second. Using repetitive sweep, numerous interesting curves were obtained by directing a 110-volt, direct-current spotlight through the aperture and picking up the light beam from an appropriately placed mirror. The camera tachometer frame-per-second dial readings were easily checked and the effect of varying the shutter angle from zero to 170 degrees was noted. The curve produced at 170 degrees open-shutter angle had a flat top with symmetrically sloping sides and closely resembled the curves produced by between-the-lens (Fig. 3) and focal-plane shutters.

Conclusion

In conclusion, it may be stated that an instrument capable of furnishing the answer to such a wide variety of photographic problems will be a welcome addition not only to the Services, but to the photographic industry as well.

Simultaneous Determination of Elon and Hydroquinone in Photographic Developers*

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Summary—A sample of the developer solution is diluted with a *p*H 5 acetate buffer and its absorbancy† measured at two wavelengths in the ultraviolet region. The concentration of Elon‡ and hydroquinone in a fresh unused developer solution can be determined directly from these two absorbancies. Used or old developer solutions are analyzed by extracting the unoxidized Elon and hydroquinone with ethyl acetate. Absorbancy measurements made on the system before and after extraction serve to determine the amount of Elon and hydroquinone present.

Introduction

The present methods that have been available for determining the concentrations of Elon and hydroquinone in a developer solution have necessitated a preliminary extraction in order to remove the Elon and hydroquinone from interfering materials. Lehmann and Tausch[1] have published an analytical method for Elon in which the Elon was extracted for several hours in a continuous extractor and then determined by an iodometric titration. Evans and Hanson[2] developed colorimetric methods for both Elon and hydroquinone. The developer solution was extracted with ethyl acetate at a *p*H of approximately 8 and the Elon which was extracted in the ethyl acetate layer allowed to react with furyl acrolein. The color produced was measured on a filter photometer. The hydroquinone was determined by extracting it with ethyl acetate at about *p*H 3, adding potassium ferricyanide and sodium sulfite and measuring the color.

In the method recommended by Baumbach[3] and Atkinson and Shaner,[4] hydroquinone was separated from the Elon by extraction at

* Presented April 8, 1949, at the SMPE Convention in New York.

† Where the transmittance of a solution is measured relative to the solvent, the National Bureau of Standards has recommended use of the term transmittancy with symbol T_s and the term absorbancy, A_s, where $A_s = -\log_{10} T_s$.

‡ Elon is the trademark of the Eastman Kodak Company for a photographic developing agent that is mono-methyl-*p*-aminophenol sulfate.

pH 2 and was then titrated with iodine. By extraction of a separate sample at a pH of about 8, both Elon and hydroquinone were extracted and titrated with iodine. The Elon concentration was then determined by difference.

Evans, Hanson, and Glasoe[5] extracted hydroquinone at pH 2, then adjusted the pH to about 8 and extracted the Elon. Each extract was analyzed by means of a polarograph. Similar extractions were also employed by Stott who then determined the concentrations of Elon and hydroquinone in the separate ethyl acetate layers by titrating each potentiometrically with an acid solution of cerate such as ceric sulfate.[6]

Baumbach[7] extracted the developer solution at pH 8.0 to 8.5 with methyl acetate and Shaner and Sparks[8] used methyl ethyl ketone. The Elon in the solvent layer was titrated with hydrochloric acid and the hydroquinone plus Elon was then titrated with iodine. This method is subjected to large errors in the Elon analyses when less than one gram per liter of Elon is present.

Levenson[9] in an evaluation of the various methods states that the potentiometric method of Stott is prone to give large errors, especially for Elon. He[10] has developed a modification in which he states the errors are reduced to 1 per cent for hydroquinone and 2 per cent for Elon.

Although many of the existing methods give results of the required accuracy, the analyses are lengthy and considerable experience is required on the part of the analyst for maximum accuracy.

EXPERIMENTAL

Studies of the ultraviolet absorption of Elon and hydroquinone showed that each had characteristic absorption peaks in the ultraviolet region. The rather large absorbancies necessitated dilution of the developer solutions to secure a lower absorbancy which would be in the useful range of the Beckman Spectrophotometer. It was determined that a sufficiently stable solution could be obtained by diluting 1 milliliter of developer sample with* 100 milliliters of pH 5 acetate buffer. The dilution should, of course, be changed to secure maximum accuracy if the concentrations of Elon and/or hydroquinone are very large or very small. The absorbancies of the mix ingredients other than Elon and

* In order to speed the determination, 1.00 milliliter of sample was diluted *with* 100 milliliters of acetate buffer. The buffer was measured with an automatic pipet.

hydroquinone were small enough to be considered constant and compensated for in the determination of Elon and hydroquinone. The magnitude of the basic mix (i.e., a mix containing all other constituents except Elon and hydroquinone) absorbancies was small enough so that a change of 50 per cent in the concentration of any of the basic mix ingredients did not significantly change the absorbancy. This is illustrated by the developer used in this work which contributed a blank absorbancy of 0.010 at 270 millimicrons and 0.008 at 290 millimicrons.

The method has been applied successfully to all developers containing Elon and hydroquinone so far examined.

The Elon and hydroquinone were Eastman Kodak chemicals and the inorganic chemicals were of photographic quality.

The developer used in this work had the following composition:

Constituent	Concentration, Grams per Liter
Sodium sulfite	45.0
Elon	(Refer to text)
Hydroquinone	(Refer to text)
Sodium carbonate monohydrate	50.0
Potassium bromide	2.0

The chemicals were dissolved in the order given. Slight warming was occasionally applied to get the Elon into solution. It was important that the Elon was in solution before the hydroquinone was added to minimize the oxidation of the latter.

Typical absorption curves for Elon, hydroquinone, and the complete developer mix are shown in Fig. 1. From examination of the curves, it will be seen that at 290 millimicrons, where the maximum absorption of hydroquinone appears, there is also some absorption by the Elon. However, by measuring the absorption at 270 millimicrons in addition to the measurement at 290 millimicrons, it was possible simultaneously to determine the amount of Elon and hydroquinone present in a developer.

ANALYSIS OF FRESH DEVELOPERS

Reagents

*p*H 5 acetate buffer. Add 23 grams of anhydrous sodium acetate to 58 milliliters of 2 molar acetic acid and dilute to 1 liter with distilled water. Adjust the final pH of the solution to 5.00 ± 0.02 with glacial acetic acid or sodium hydroxide.

Cleaning solution. Mix one volume of denatured alcohol and one volume of 3 normal hydrochloric acid.

Apparatus

Beckman Spectrophotometer, Model DU, with ultraviolet accessories.

Fused silica absorption cells, 1 centimeter.

Procedure

Dilute 1.00 milliliter of sample with 100 milliliters of pH 5 acetate buffer. Determine the absorbancy of this solution at 270 and 290 millimicrons.

NOTE: Distilled water was used in the blank cell as a reference liquid. Care must be taken to see that the distilled water and the acetate buffer do not stand in contact with rubber or plastic tubing as material is leached from these substances that can cause serious errors in the analysis. In this laboratory, the reagents are allowed to flow in glass tubing with only very short connections of plastic or rubber tubing. The silica cells are cleaned before each analysis with acid-alcohol cleaning solution and rinsed with distilled water.

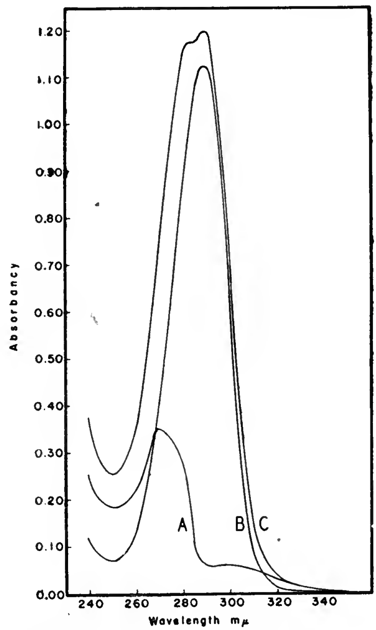

Fig. 1—Typical absorption curves.
A, Elon, concentration 5 grams per liter.
B, hydroquinone, concentration 5 grams per liter.
C, Elon and hydroquinone, concentration 5 grams per liter.

Determine the absorbancy of a "basic mix" at 270 and 290 millimicrons after diluting 1 milliliter with 100 milliliters of pH 5 acetate buffer. Subtract the absorbancies of the basic mix from the absorbancies of the sample. Determine the concentrations from a calibration grid as is shown in Fig. 2 or by calculation using equations such as (2) and (3).

DETERMINATION OF ABSORBANCY INDICES

Prepare mixes containing all the mix ingredients with the exception of hydroquinone, using concentrations of Elon covering the expected range. Dilute 1 milliliter of each of the mixes with 100 milliliters of *p*H 5 acetate buffer and determine the absorbancies at 270 and 290 millimicrons.

In the same manner, prepare mixes containing hydroquinone but no Elon and determine their absorbancies at 270 and 290 millimicrons after dilution with *p*H 5 acetate buffer.

Prepare a basic mix. Dilute with the acetate buffer and determine the absorbancies at 270 and 290 millimicrons. Subtract the absorbancies of the basic mix from the absorbancies of each of the standard mixes containing Elon or hydroquinone and determine the "absorbancy indices"[11] according to the equation

$$a_s = \frac{A_s}{bC}, \qquad (1)$$

where

$a_{s1}, a_{s2}, a_{s3}, a_{s4}$ = absorbancy indices
A_s = absorbancy of sample
b = length of solution path
C = concentration* of Elon or hydroquinone.

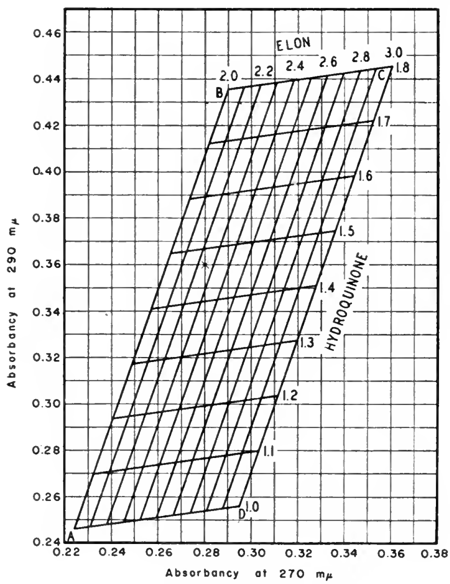

Fig. 2—Typical calibration grid.

* The absorbancy indices in this paper have, for convenience, been calculated expressing the concentrations as the concentrations of Elon and hydroquinone in the original developer solution. Since the cells used throughout this work had solution paths of 1.000 ± 0.005 centimeter, the length (b) in (1) has been assumed as unity and constant.

In Table I, a series of calibration mixes is shown. The absorbancies in the table represent the absorbancies after each was corrected for the absorbancy of the basic mix.

TABLE I

ABSORBANCY INDICES*

Elon, Grams per Liter	$A_{290\ m\mu}$	a_{s1}	$A_{270\ m\mu}$	a_{s3}
6.00	0.058	0.010	0.425	0.071
6.00	0.057	0.010	0.426	0.071
4.02	0.039	0.010	0.286	0.071
4.00	0.042	0.010	0.284	0.071
3.00	0.030	0.010	0.217	0.072
2.00	0.021	0.010	0.141	0.071
2.00	0.022	0.011	0.141	0.071
1.00	0.011	0.011	0.070	0.070
	Avg.	0.010	Avg.	0.071
Hydroquinone, Grams per Liter	$A_{290\ m\mu}$	a_{s2}	$A_{270\ m\mu}$	a_{s4}
6.00	1.361	0.227	0.494	0.082
6.00	1.355	0.226	0.492	0.082
5.00	1.129	0.226	0.410	0.082
5.00	1.129	0.226	0.410	0.082
4.00	0.910	0.227	0.333	0.083
2.11	0.479	0.227	0.175	0.083
	Avg.	0.226	Avg.	0.082

* The slit widths used for the analyses were 0.43 mm at 270 millimicrons and 0.36 mm at 290 millimicrons, corresponding to spectral bandwidths of 1.3 and 1.4 millimicrons, respectively. The absorbancy indices have been found valid for use in analyses on three different Beckman Spectrophotometers.

CALCULATION AND USE OF EQUATIONS

One method of calculating the concentration of Elon and hydroquinone is to use equations derived from the fundamental relationship given in (1).

$$A = a_{\text{Elon}}C_{\text{Elon}} + a_{\text{hydroquinone}}C_{\text{hydroquinone}}.$$

Introducing the absorbancy indices from Table I, the following equations are obtained for each wavelength:

$$A_{270} = 0.071C_{\text{Elon}} + 0.082C_{\text{hydroquinone}}$$

$$A_{290} = 0.010C_{\text{Elon}} + 0.226C_{\text{hydroquinone}}.$$

The transformation of these equations is straightforward and yields the following equations:

$$C_{\text{Elon}} = 14.84A_{270} - 5.39A_{290} \quad (2)$$

$$C_{\text{hydroquinone}} = 4.66A_{290} - 0.66A_{270}. \quad (3)$$

It must be remembered that (2) and (3) are general equations. Any absorbancy correction due to the blank must be subtracted before the concentrations of Elon and hydroquinone are calculated.

Preparation and Use of Calibration Grid

Choose the lowest combination of Elon and hydroquinone expected (such as point A in Fig. 2 where concentration of Elon is 2.00 grams per liter and concentration of hydroquinone is 1.00 gram per liter) and calculate the total absorbancy at each wavelength as follows using (1).

At 270 millimicrons:			
Absorbancy of Elon	$= a_{s3}C$	$= 0.071 \times 2.00$	$= 0.142$
Absorbancy of hydroquinone	$= a_{s4}C$	$= 0.082 \times 1.00$	$= 0.082$
Total absorbancy at 270 millimicrons			$= 0.224$
At 290 millimicrons:			
Absorbancy of Elon	$= a_{s1}C$	$= 0.010 \times 2.00$	$= 0.020$
Absorbancy of hydroquinone	$= a_{s2}C$	$= 0.226 \times 1.00$	$= 0.226$
Total absorbancy at 290 millimicrons			$= 0.246$

Plot the two total absorbancies (as point A in Fig. 2) which represent an Elon concentration of 2.00 grams per liter and a hydroquinone concentration of 1.00 gram per liter. Compute Points B, C, and D in a similar manner. Draw lines through these four points which represent the outer limits of the grid. To complete the grid, subdivide each side of the parallelogram into the number of parts represented by the range in concentration. Increments of 0.1 gram have been found practical.

It is thus possible to determine the concentration of both Elon and hydroquinone simultaneously when the absorbancy of a sample at each wavelength is known.

For example: Assume that the following absorbancies (each corrected by subtracting the absorbancy of the basic mix) were obtained during an analysis of a developer; the absorbancy at 270 millimicrons was 0.280, and at 290 millimicrons was 0.360.

These two absorbancies fix the point X on Fig. 2, which corresponds to an Elon concentration of 2.24 grams per liter and a hydroquinone concentration of 1.47 grams per liter.

ANALYSIS OF USED DEVELOPERS

Extraction of Elon and Hydroquinone with Ethyl Acetate

Preliminary investigations showed that Elon and hydroquinone could be completely extracted from a developer solution at pH 8.0 to 8.5 by the use of a solvent such as ethyl acetate. Ethyl acetate was chosen because of its low toxicity, small fire hazard, and its relatively low absorbancy in the region of 270 to 290 millimicrons.

Extraction of Oxidation Products

Hydroquinone monosulfonate, quinhydrone, quinone, and Elon monosulfonate were selected as compounds that exist or would be converted into compounds that might exist in a used developer solution.[12]

A mix was prepared containing 3.88 grams per liter of sodium hydroquinone monosulfonate and no Elon or hydroquinone. The absorption curves were determined before and after extraction as shown in Fig. 3, curves A and B. Curve B has been adjusted to compensate for the dilution brought about by the pH adjustment that was necessary to insure complete extraction. It is concluded from the curves A and B in Fig. 3 that the amount of hydroquinone monosulfonate extracted is negligible. The small difference between the curves may possibly be due to the presence of a small amount of hydroquinone in the sodium hydroquinone monosulfonate.

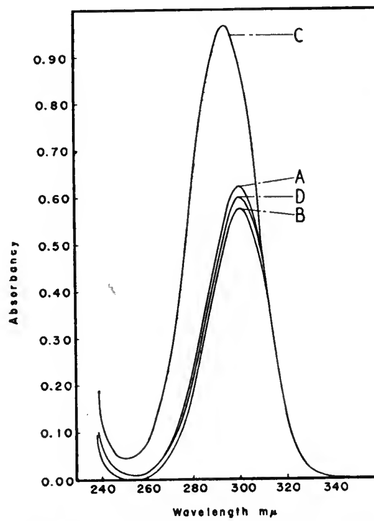

Fig. 3—Extraction study with hydroquinone monosulfonate and hydroquinone.
A, hydroquinone monosulfonate.
B, solution A after extraction.
C, solution A with hydroquinone added.
D, solution C after extraction.

In this study, this practice was followed for all curves obtained after extraction.

An addition of 2.00 grams per liter of hydroquinone was made to the original sodium hydroquinone monosulfonate solution and the absorption curve determined before and after extraction, as shown in curves *C* and *D* of Fig. 3. These curves show that hydroquinone was extracted quantitatively in the presence of sodium hydroquinone monosulfonate.

To study the effect of quinhydrone and compounds formed by interaction of quinhydrone with other compounds in a developer, a mix was prepared containing 2.00 grams per liter of quinhydrone and no Elon or hydroquinone. The absorption data are shown for the solution before and after extraction in curves *A* and *B* in Fig. 4. One gram per liter of hydroquinone was added to the water layer after the above extraction. The resulting spectrophotometric curve is curve *C* in Fig. 4 and is noted to be virtually the same as curve *A* (which was obtained from a sample containing 2.00 grams of the quinhydrone). The close similarity of curves *A* and *C* can be explained by the splitting of quinhydrone into hydroquinone and another product, which appears to be quinone, which is not extracted. Extraction of solution *C* (curve *C*) resulted in curve *D*, which is noted to be nearly identical with curve *B*, showing that the added hydroquinone was extracted.

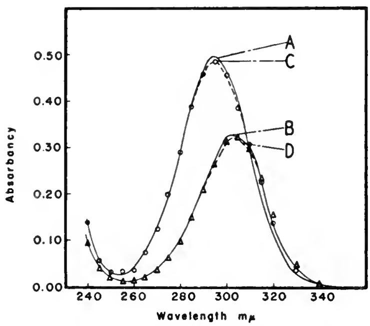

Fig. 4—Extraction study with quinhydrone and hydroquinone.
A, quinhydrone.
B, solution A after extraction.
C, solution B with hydroquinone added.
D, solution C after extraction.

To study the effects of quinone, a mix was prepared containing 2.00 grams per liter of quinone and no Elon or hydroquinone. The absorption curve of this mix before and after extraction with ethyl acetate is shown in curves *A* and *B*, Fig. 5. The change in absorbancy and curve shape is considered to be due to the presence of some quinhydrone as an impurity in the quinone. The addition of 2.00 grams per liter of hydroquinone and subsequent extraction is shown by curves *C* and *D*, Fig. 5. It is noted that the extraction of the hydroquinone was virtually complete.

To check on the extraction of Elon monosulfonate, a mix was prepared containing 1.18 grams per liter of Elon monosulfonic acid and no Elon or hydroquinone. The absorption curves of this mix before and after extraction are shown in curves *A* and *B*, Fig. 6. There is some change in curve shape but in view of the close agreement at 270 and 290 millimicrons, it is probable that only a very small error, if any, would be introduced into the analysis of Elon and hydroquinone by this difference. Elon (2.00 grams per liter) was then added. Curve *C*, Fig. 6, shows the resulting absorption curve. The sample was then extracted. Curve *D*, Fig. 6, shows that the Elon was extracted quantitatively in the presence of Elon monosulfonate.

From the above results obtained in the extraction studies of hydroquinone monosulfonate, quinone, and Elon monosulfonate, the extraction of a used tank sample with ethyl acetate would remove only Elon and hydroquinone. In the case of quinhydrone (i.e., semiquinone-type compounds), however, approximately half of the material present is probably extracted as hydroquinone.

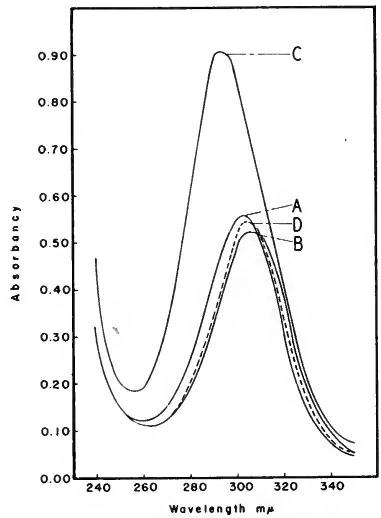

Fig. 5—Extraction study with quinone and hydroquinone.

A, quinone.
B, solution A after extraction.
C, solution A with hydroquinone added.
D, solution C after extraction.

Procedure

Pipet a 25-milliliter sample of the used developer into a 125-milliliter separatory funnel and add 3 drops of phenolphthalein. Add dropwise 7 normal sulfuric acid until the indicator turns colorless. (The resulting solution should have a *p*H of 8.0 to 8.5.) Record the volume of acid added.

Extract three times with 25-milliliter portions of water-saturated ethyl acetate (75 milliliters altogether), discarding the ethyl acetate layer each time. Dilute 1.00 milliliter of the extracted developer with 100 milliliters of *p*H 5 acetate buffer and determine the absorbancy at 290 and 270 millimicrons. Correct these absorbancies for the volume change by using the following formula:

$$\frac{(\text{absorbancy})\ (25 + \text{ml } 7\text{N } H_2SO_4)}{(25)} = \text{corrected absorbancy.}$$

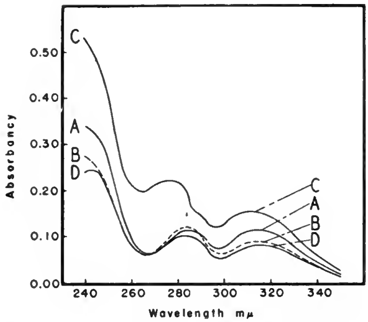

Fig. 6—Extraction study with Elon monosulfonate and Elon.
A, Elon monosulfonate.
B, solution A after extraction.
C, solution A with Elon added.
D, solution C after extraction.

Dilute 1.00 milliliter of the unextracted developer with 100 milliliters of acetate buffer and determine the absorbancies at 270 millimicrons and 290 millimicrons. Subtract the corrected absorbancies after extraction from the absorbancies before extraction and, using these differences, determine the concentration of Elon and hydroquinone from the grid or by calculation from the equations.

This extraction procedure should be checked on a basic mix in order to determine if the ethyl acetate is extracting any material in addition to Elon and hydroquinone. If this is the case, a blank value should be subtracted from the absorbancies before referring to the grid.

Separation of Elon and Hydroquinone from Oxidation Products

A mix was prepared containing 6.00 grams per liter of Elon and 3.00 grams per liter of hydroquinone. Exposed film was processed in this developer solution until the Elon concentration had dropped to 5.51 grams per liter and the hydroquinone to 2.48 grams per liter. The absorption curve of the extracted developer was determined and corrected for the dilution due to the sulfuric acid which had been added. The absorption curve of the developer solution before extraction was also determined. The difference between these two curves was obtained and the result is shown in Fig. 7. If the procedure extracts Elon and hydroquinone only, and in the amounts as shown by the

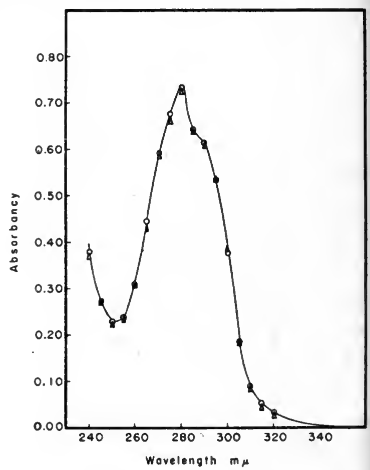

Fig. 7—Absorption curve of extracted material compared to the absorption curve of Elon and hydroquinone.
O, extracted material from used solution; Δ, hydroquinone plus Elon in fresh solution.

analysis of the used developer, then this curve should be identical with the curve of Elon and hydroquinone at these concentrations (i.e., 5.51 grams per liter of Elon and 2.48 grams per liter of hydroquinone).

Accordingly, a fresh developer was prepared with Elon concentration at 5.51 grams per liter and hydroquinone concentration at 2.48 grams per liter. The absorption curve of this mix is shown in Fig. 7. The close similarity of these two curves shows that the material extracted by the ethyl acetate was Elon and hydroquinone.

The results of this experiment show that the presence of the oxidation products of Elon and hydroquinone had no measurable effect upon the analysis. Other developer solutions which have contained larger and smaller amounts of oxidized Elon and hydroquinone have been analyzed, and it seems likely that large variations in the amount of oxidized material do not markedly affect the determination.

EFFECT OF BUFFER *p*H UPON THE ANALYTICAL RESULTS

The *p*H of the acetate buffer was varied by changing the ratio of sodium acetate and acetic acid, and the absorbancy indices of Elon and hydroquinone determined. The results are shown in Table II and

TABLE II

CHANGE IN ABSORBANCY INDICES WITH CHANGE IN *p*H OF BUFFER

	Elon		Hydroquinone	
*p*H	290 mμ	270 mμ	290 mμ	270 mμ
4.96	0.009	0.071	0.022	0.081
5.05	0.010	0.071	0.022	0.080
5.17	0.013	0.070	0.022	0.081
5.42	0.019	0.068	0.022	0.082

TABLE III

EFFECT OF *p*H OF BUFFER

*p*H of Buffer	Hydroquinone, Grams per Liter	Elon, Grams per Liter
4.90	2.89	6.12
4.99	2.93	5.97
5.08	2.98	5.95

it is evident that the buffer pH must be maintained at pH 5.00 ± 0.02 to insure reasonable constancy for the absorbancy index of Elon.

Actual trials in which the pH of the buffer was changed are given in Table III. Any change in absorbancy of Elon will, of course, affect both the Elon and hydroquinone results.

Effect of Temperature Upon the Analytical Results

The temperature of the diluted solution should be maintained within a few degrees of the temperature at which the absorbancy indices were determined. This is shown in Table IV in which the variation of Elon and hydroquinone is shown for change in temperature.

Table IV

Effect of Temperature upon Analytical Results

Temperature, °C.	Elon, Grams per Liter	Hydroquinone, Grams per Liter
15	6.28	2.95
23	6.15	3.02
33	6.10	3.06

Precision and Accuracy

Fresh Developers

A series of developer solutions was prepared, in which known amounts of Elon and hydroquinone were used in making the solutions. These solutions were analyzed using the procedure for the analysis of fresh developers and the results obtained are shown in Table V.

The data of these analyses were tested by the method proposed by Youden.[13] A plot was prepared in which the mixed values were plotted along the abscissa and the analysis values plotted along the ordinate. The best straight line was then calculated to fit these points. From this line, the slope and intercept were determined.

The results of the statistical study of the hydroquinone results in the range 2.00 to 6.00 grams per liter showed that the slope was 0.989, which was not significantly different from unity, and that the extrapolated intercept was 0.033, which was not significantly different from zero grams per liter. The standard deviation in terms of individual analyses was 0.041 gram of hydroquinone per liter.

TABLE V

ANALYSIS OF DEVELOPERS BY THE METHOD FOR FRESH DEVELOPERS

Mix No.	Mix Concentration, Grams per Liter Hydroquinone	Mix Concentration, Grams per Liter Elon	Analysis, Grams per Liter Hydroquinone	Analysis, Grams per Liter Elon	Deviation, Grams per Liter Hydroquinone	Deviation, Grams per Liter Elon
A	6.00	6.00	5.98	6.05	−0.02	+0.05
			5.90	6.02	−0.10	+0.02
B	6.00	6.00	5.95	6.00	−0.05	......
			5.94	6.05	−0.06	+0.05
C	4.00	4.00	4.10	3.98	+0.10	−0.02
			4.10	3.98	+0.10	−0.02
D	4.00	4.00	3.97	4.02	−0.03	+0.02
			3.97	4.02	−0.03	+0.02
E	4.00	4.00	3.92	3.95	−0.08	−0.05
			3.92	3.98	−0.08	−0.02
F	4.00	4.00	4.02	4.00	+0.02	......
			4.02	3.98	+0.02	−0.02
G	4.00	4.00	4.00	4.00	......	......
			3.99	4.02	−0.01	+0.02
H	4.00	4.00	4.00	3.86	......	−0.14
			4.00	3.95	......	−0.05
I	4.00	4.00	4.04	4.05	+0.04	+0.05
			4.05	4.15	+0.05	+0.15
J	3.00	6.00	3.03	5.98	+0.03	−0.02
			3.04	6.05	+0.04	+0.05
K	3.00	6.00	2.97	6.08	−0.03	+0.08
			2.97	6.08	−0.03	+0.08
L	3.00	6.00	2.98	6.04	−0.02	+0.04
			2.98	6.05	−0.02	+0.05
M	3.00	6.00	3.03	6.00	+0.03	......
			3.01	6.08	+0.01	+0.08
N	3.00	6.00	3.00	6.00	......	......
			2.98	6.05	−0.02	+0.05
O	3.00	6.00	3.02	6.02	+0.02	+0.02
			3.00	6.00	......	......
P	3.00	6.00	3.02	6.02	+0.02	+0.02
			3.03	6.05	+0.03	+0.05
Q	2.48	5.51	2.47	5.48	−0.01	−0.03
			2.47	5.45	−0.01	−0.06
R	2.19	5.75	2.19	5.90	......	+0.15
			2.19	5.90	......	+0.15
S	2.00	2.00	1.97	1.98	−0.03	−0.02
			1.97	1.98	−0.03	−0.02

An identical study of the Elon results in the range 2.00 to 6.00 grams per liter in Table V showed that the slope was 1.019 and the intercept was −0.075 gram per liter, and that these results were significantly different from unity for the slope and zero for the intercept. Cross-checks on absorbancy indices and rechecks of blank values indicate that these factors were not responsible for the deviation of the intercept from zero and the slope from unity. These differences may be caused by unknown factors related to the mixing procedure and the standing time before analysis. Future work in the range 0.00 to 2.00 grams per liter may shed light on this subject. The standard deviation in terms of individual analyses was 0.055 gram of Elon per liter.

It is apparent in the data in Table V that the deviation between duplicates is much less than the deviation between successive mixes. This deviation was studied and the data also show that almost all of the deviation of a single analysis as calculated by Youden's method is because of the variability between mixes. The standard deviation between duplicate analyses of the same mix was 0.003 gram per liter for hydroquinone and 0.007 gram per liter for Elon.

Used Developers

A series of developer solutions was prepared, in which known concentrations of Elon and hydroquinone were used in making the solution. These solutions were analyzed using the procedure for the analysis of used developer solutions and the results are shown in Table VI.

These data were tested using Youden's method in the same manner as was used for the fresh developers. The results of the study showed that the slope for the hydroquinone analysis was not significantly different from unity. However, the intercept was −0.050 gram per liter, which was significantly different from zero. In nearly all cases, the amount of hydroquinone which was extracted was less than the amount put into the mix. This indicates that a portion of the hydroquinone was oxidized during the mixing process or that the extraction was not complete. The amount of extractable hydroquinone decreases on standing, and it seems probable that the principal factor responsible is oxidation. This is in accordance with the oxidation mechanism described recently by Levenson.[9] The standard deviation in terms of individual analyses was 0.039 gram per liter of hydroquinone.

The results of the Elon study showed that both the slope and intercept were not significantly different from unity and zero, respectively.

TABLE VI

ANALYSIS OF DEVELOPERS BY THE METHOD FOR USED DEVELOPERS

Mix No.	Mix Concentration, Grams per Liter Hydroquinone	Mix Concentration, Grams per Liter Elon	Analysis, Grams per Liter Hydroquinone	Analysis, Grams per Liter Elon	Deviation, Grams per Liter Hydroquinone	Deviation, Grams per Liter Elon
A	6.00	6.00	5.96	5.70	−0.04	−0.30
	6.00	6.00	5.98	5.80	−0.02	−0.20
B	6.00	0.00	5.88	0.05	−0.12	+0.05
	6.00	0.00	5.93	0.05	−0.07	+0.05
C	4.00	4.00	4.03	3.85	+0.03	−0.15
	4.00	4.00	4.03	3.85	+0.03	−0.15
D	4.00	4.00	3.94	4.00	−0.06	......
	4.00	4.00	3.93	3.97	−0.07	−0.03
E	3.00	6.00	2.97	6.05	−0.03	+0.05
	3.00	6.00	2.95	6.08	−0.05	+0.08
F	3.00	6.00	2.94	5.98	−0.06	−0.02
	3.00	6.00	2.94	6.00	−0.06	......
G	3.00	6.00	2.95	6.00	−0.05	......
	3.00	6.00	2.95	6.02	−0.05	+0.02
H	3.00	6.00	2.93	6.15	−0.07	+0.15
	3.00	6.00	2.92	6.18	−0.08	+0.18
I	3.00	3.00	2.88	2.95	−0.12	−0.05
	3.00	3.00	2.89	2.97	−0.11	−0.03
J	2.48	5.51	2.45	5.50	−0.03	−0.01
	2.48	5.51	2.45	5.50	−0.03	−0.01
K	0.00	6.00	−0.05	6.08	−0.05	+0.08
	0.00	6.00	−0.05	6.08	−0.05	+0.08

The standard deviation in terms of individual analyses was 0.114 gram per liter of Elon.

The data in Table VI also showed that the deviation between mixes was the contributing factor to the size of the standard deviation of single analyses for both Elon and hydroquinone. The standard deviation between duplicate analyses of the same mix was 0.009 gram per liter of hydroquinone and 0.006 gram per liter of Elon.

ACKNOWLEDGMENTS

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Lubrication of 16-mm Films*

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Summary—This paper describes materials suitable for the lubrication of 16-mm films. Wax-carbon tetrachloride formulas are given, together with the precautions which must be observed in using them. Slower-evaporating wax-isopropyl alcohol mixtures are described for use where additional drying space is available. By the use of these formulas, 16-mm films can be adequately lubricated at a material cost of $0.01 per 400 feet of film.

New formulas using Freon, a rapid-drying, noninflammable solvent, of extremely low order of toxicity, are suggested. A suitable surface treatment for use with films to be run on repeater mechanisms is described.

I. INTRODUCTION

SEVERAL ARTICLES have appeared in this JOURNAL on the subject of the lubrication of motion picture film.[1,2] It has become an established practice in most film laboratories to lubricate either the edges or the entire emulsion surface of 35-mm prints prior to projection. This practice was adopted because of the difficulties encountered when freshly processed prints were being projected for the first time. The gelatin in the emulsion of freshly processed film is very adherent to a hot metal surface and the adhesion of the film to the hot gate causes particles of gelatin to be rubbed off the film. Some of these particles may adhere to form a crust on the metal parts of a gate, and this crust will greatly increase the frictional resistance of the film through the gate. The result of high friction or "sticking," as it is referred to by projectionists, is noisy and unsteady projection and often damage to the film.

The difficulties attending the projection of unlubricated 16-mm films are similar to those encountered in the projection of 35-mm prints. A freshly processed, unlubricated 16-mm film may project satisfactorily. This is sometimes the case if the moisture content of the film is low and if the projector is in perfect operating condition and is used frequently. At higher moisture contents of the film, either as the result of insufficient drying or of the high relative humidity of the

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atmosphere, and with projectors infrequently used and not in excellent repair, "sticking" in the gate is liable to occur. In certain cases, an unsteady picture and distorted sound will result. In addition, there may be abrasion marks through the center of the row of perforations and along one or both sides of the sound track. If the "sticking" is severe, loss of the lower loop usually will occur and, if projection is continued, the film may become damaged beyond repair. Thus, for good operation, 16-mm films require adequate lubrication just as do 35-mm prints.

There is some dissimilarity, however, between the methods of lubrication used on 35-mm film and those on 16-mm film. Edge-waxing is the method frequently used throughout the industry for the lubrication of 35-mm prints. In this method a band of low-melting paraffin is applied from a solvent to the centers of both rows of perforations on the emulsion side. The Eastman Kodak Company has employed a modification of this method for 16-mm "customers' originals," both black-and-white and color, since 1928. For 16-mm films, there is used a very dilute solution of pure mineral oil in carbon tetrachloride.

With the advent of 16-mm sound prints it was suggested that the application of mineral oil on the sound-track side of the film be omitted so as not to impair the sound quality. Sticking was frequently encountered as the result. A new method, therefore, was sought which would ensure adequate lubrication of the sound-track side as well as of the perforated side. Over-all lubrication of the emulsion surface appeared to be the solution of the problem.

II. Over-All Wax Lubrication of 16-Mm Films

Extremely thin coatings of certain waxes over the entire emulsion surface were found to be ideal. Each of these waxes forms a continuous transparent layer over the entire surface, providing excellent lubrication and some slight amount of scratch protection as well.

A. Waxes from Carbon Tetrachloride

Carbon tetrachloride has long been used as a solvent for waxes and oils. It is the main constituent of many film-treating and film-cleaning formulas. It evaporates rapidly, is noninflammable, and inexpensive. It has, however, one serious drawback, i.e., the toxicity of its vapors. It has been claimed that it is unhealthy to work in an atmosphere in which the odor of carbon tetrachloride can be detected by the aid of the unfatigued nose. Carbon tetrachloride can be used if precautions are taken to prevent its vapors from escaping into the workroom air—even in small amounts.

If there is room inside the drying cabinet, between the point of dryness of the film and the take-up reel, for the installation of the lubricating device, this section of the cabinet can be blocked off and the carbon tetrachloride vapors drawn off to the outside of the building with the aid of an auxiliary fan. Such a system is in operation in several laboratories. An apparatus for the continuous application of wax solutions to film is shown in Fig. 1.

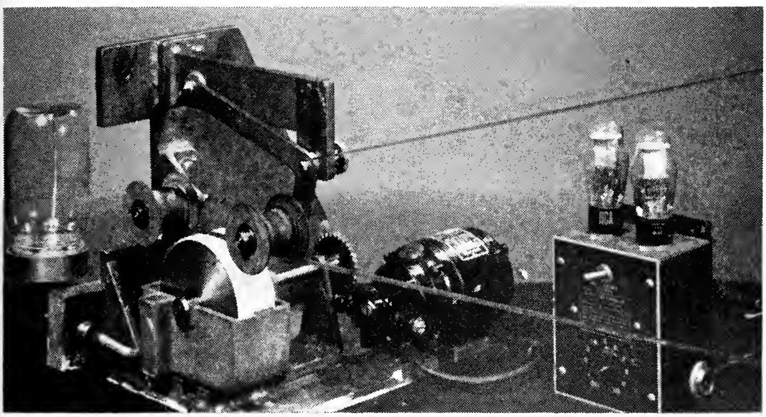

Fig. 1—Roller-wick applicator for wax solutions.

The apparatus consists of a plush-covered roll which is driven slowly, generally in a direction opposite to that of the film, by an alternating-current motor operating through a thyratron speed-controller. Provision is made for maintaining a constant liquid level and for varying the extent of wrap of the film on the drum. In general, the film speed is fifty times that of the plush, but this varies somewhat with the lubricant used and the condition of the film. The extent of wrap also varies with the lubricant and the film; in general, the smallest amount of wrap that permits uniform coverage of the film should be used.

All of the lubricants presented in the tables have been applied at a film speed of 100 feet per minute. This is the upper speed of the machine and there is no apparent reason why higher speeds cannot be attained with adequate drying capacity.

The best of these carbon tetrachloride-wax mixtures at their most suitable concentrations are given in Table I. It is a well-established fact that ethyl cellulose will raise the melting point and impart hardness and toughness to wax mixtures and that the mixture will have properties different from those of the individual components.[3, 4] It is for this reason that ethyl cellulose has been incorporated into some of the formulas.

TABLE I

CARBON TETRACHLORIDE-WAX SOLUTIONS FOR 16-MM FILM

Wax	Max. Useful Per Cent Conc. in CCl_4	Film Friction, Ounces
Carnauba*	0.03	4.3
Pentawax 217†	0.125	4.0
Johnson's WM 169C‡	0.125	3.9
Beeswax (0.025%)-Ethyl Cellulose (0.075%)§	0.10	4.5

* No. 2 North Country Carnauba Wax obtained from Sprahl and Pitsch, 141 Front Street, New York City.

† Obtained from the Heyden Chemical Company, 393 Seventh Avenue, New York City.

‡ Obtained from S. C. Johnson and Son, Inc., Racine, Wisconsin.

§ Type T-200 Ethyl Cellulose obtained from Hercules Powder Company, Inc., Wilmington, Delaware.

B. The Evaluation of Lubricants

A good over-all application of wax to 16-mm film will leave an invisible coating on the film, will not pick up dust, nor show fingerprints, and will provide good steady projection even after the film has been subjected to conditions of high relative humidity. Inasmuch as many projectors will not project freshly processed, unlubricated films of high moisture content without damage to the film, either in respect to the scuffing off of emulsion particles, or damage to the perforations, or both, these observations may serve as a means of evaluation of film lubricants. Freshly processed rolls of 16-mm film are treated with the lubricant to be tested, and these rolls, along with rolls of untreated film, are festooned in an atmosphere of high humidity, such as 70 per cent relative humidity at 70 degrees Fahrenheit for two hours. At the end of this time, the rolls are reeled and tested for behavior on various 16-mm projectors. Care is taken to see that the projectors are in perfect working condition and that the gates of these projectors are cleaned with solvent-moistened plush after each test. Each projection is rated for steadiness of image, noise level, operation of film around snubbers, and for any deleterious effect on the sound quality. After the projection, the film is examined for scuffing of the

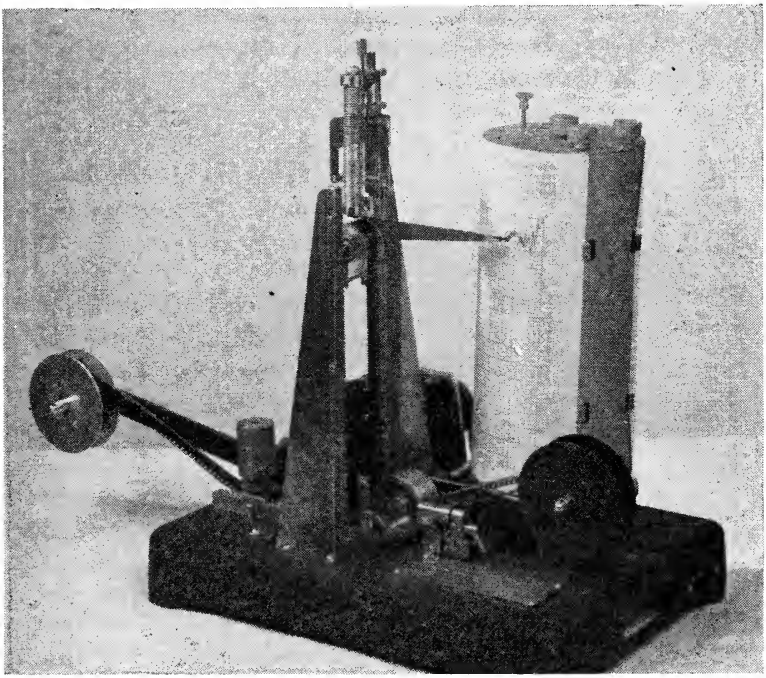

Fig. 2—Film-friction recorder.

emulsion in those areas where the film comes in contact with the metal parts of the projector and for any damage to the perforations.

There is no alternative to projection for the evaluation of a film treatment. However, it is time-consuming, since many tests are necessary in order to verify preliminary findings. Moreover, some of these ratings, such as noise level and action of film about snubbers, are a matter of opinion and hence the ratings will vary from one observer to another. An independent method has, therefore, been developed for the evaluation of film-lubrication processes. The samples of film to be tested are drawn through a film-friction recorder, such as that shown in Fig. 2. The film to be tested is drawn through a gate at a rate of eight frames per second. The gate is loaded with a weight of six ounces. The film, before going to the constant-speed take-up reel, is passed over a float roll which registers the pull in ounces per single strand of film. A footage-tension recording is made by a pen on a slowly revolving drum. Before such a recording of tension is usable, it must be correlated with the behavior of the film on projectors. Fig. 3 shows the tracings made by an untreated sample of film and one which has been adequately lubricated. Projection tests show that films whose friction force lies between 2 and 5 ounces usually will project satisfactorily. The upper limit for safe operation is about 6 ounces. All the carbon tetrachloride-wax lubricants shown in Table I gave films whose frictional forces were $4^1/_2$ ounces or less, and all gave films of satisfactory projection performance.

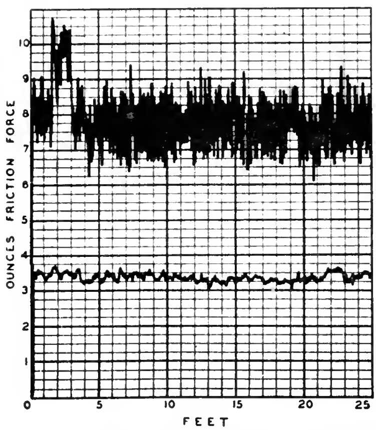

Fig. 3—Film-friction graphs of lubricated and unlubricated films. Lower curve is for lubricated film.

C. *New Solvents for Waxes*

If ample space can be allotted for the lubrication operation, a wax solution of slower rate of evaporation than the carbon tetrachloride-wax mixture may be used and thus the precautions necessary with the latter can be avoided. Certain waxes are sufficiently soluble in anhydrous isopropyl alcohol to offer effective lubrication for 16-mm film. Anhydrous isopropyl alcohol is readily available, inexpensive, nontoxic, and almost free from explosion hazards. The evaporation rate of isopropyl alcohol is four times slower than that of carbon tetrachloride. Examples of isopropyl alcohol-wax lubricants are given in Table II.

Within recent years, a new chemical compound has appeared which may end the long search for a nontoxic, noninflammable, rapidly evaporating solvent. This compound is Freon 113 or trichlorotrifluoroethane. It has an evaporating rate faster than that of carbon tetrachloride, is completely noninflammable, and has a very low order of toxicity. Freon 113 will dissolve beeswax or cetyl alcohol in concentrations sufficient to provide good lubrication, as shown in Table III. The addition of 6.7 per cent cyclohexane will permit a greater amount of beeswax to be dissolved. This gives slightly better lubrication and yet does not materially change the nonexplosive nature of the solvent. At present, Freon 113 is considerably more expensive than carbon tetrachloride. It should be mentioned, however, that the cost of all the lubricants described in this paper, with the exception of the Freon mixtures, is less than $0.01 per 400 feet of 16-mm film. The cost in the case of the Freon mixtures at the present time is approximately $0.06 per 400 feet of 16-mm film. There is reason to believe that these Freon lubricants may provide the means for safe and effective film treatment.

TABLE II

ISOPROPYL ALCOHOL-WAX SOLUTIONS FOR 16-MM FILM

Wax	Max. Useful Per Cent Conc. in Isopropyl Alcohol	Film Friction, Ounces
Beeswax (0.04%)-Ethyl Cellulose(0.035%)*	0.075	2.8
Armid HT†	0.05	4.2

* Type T-200 Ethyl Cellulose obtained from Hercules Powder Company, Inc., Wilmington, Delaware.

† Obtained from Armour and Company, 1335 W. 31 Street, Chicago 9, Illinois.

TABLE III

FREON 113-WAX SOLUTIONS FOR 16-MM FILM

Wax	Max. Useful Per Cent Conc. in Freon 113*	Ounces
Beeswax	0.1	3.5
Cetyl Alcohol	0.1	4.1
Beeswax	0.2 (Freon 93.3%, Cyclohexane 6.7%)	2.2

* Obtained from Kinetic Chemicals, Inc., Wilmington, Delaware.

III. Treatment of Films for Use on Repeater Mechanisms

Considerable attention has been given to the surface treatment of films intended for use on repeater mechanisms. Several types of these have been studied—some to a considerable extent. In one instance, a film of approximately 400 feet in length was prepared as an instructional aid for the manufacturer's service organization.

In the course of these investigations many types of surface treatments were studied, including several well-known products. Many of these film-treating processes which offered some degree of protection against film failure upon normal projection were found to be inadequate for repeater-projection operation. It has been found that the simple carbon tetrachloride-carnauba wax treatment of both surfaces of the film gives excellent film performance on all types of repeaters, and this treatment has been the standard in the investigations by which all other treatments are judged.

Substantially flat film is also a prerequisite for good film performance on repeater mechanisms. Film can be made to remain flat by proper control of the relative humidity. No surface treatment can assure successful film performance on repeaters unless the film is maintained essentially flat.

Acknowledgments

The film-friction recorder described in this paper was developed by Mr. E. Seymour, of the Development Department, at the Camera Works of the Eastman Kodak Company, and has been used for some time by Mr. John T. Parker, of the Department of Manufacturing Experiments, at Kodak Park Works, for studying film friction in cameras and projector gates.

The author wishes to express his sincere appreciation to Dr. C. R. Fordyce, for his helpful suggestions and for continued guidance in the preparation of the paper, and to his colleague, Mr. Thomas J. McCleary, who aided materially in the assembly of the data presented.

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Proposed American Standards—16- and 8-Mm

The three standards which appear on the following pages are being published for 90 days' trial and criticism. Any comment you may have should be addressed to the Staff Engineer at the Society's office, 342 Madison Avenue, New York 17, New York, before January 1, 1950.

Proposed American Standard for Mounting Threads and Flange Focal Distances for Lenses on 16- and 8-mm Motion Picture Cameras

During the war the Armed Services wanted to be able to use lenses for 16-mm cameras interchangeably between cameras of one manufacturer and, if possible, between cameras of different manufacturers. Consequently the War Committee on photography, Z52, drew up a War Standard Z52.50-1946 which specified the mounting threads and registration distances for 16-mm camera lenses.

After the war the standard was reviewed by the peacetime committee on Motion Pictures Z22 and referred to the SMPE for revision and resubmittal for approval as a regular American Standard.

Consequently in due course the Society's Technical Committee on 16- and 8-Mm Motion Pictures reviewed this standard and revised it so as to apply to 8-mm as well as 16-mm cameras.

It will be noted that a second mounting thread, the $^5/_8$-inch, 32 thread, makes the standard apply to several 8-mm cameras, whereas the 1-inch, 32 thread is used primarily for 16-mm cameras. The committee, however, did not wish to label the threads 8-mm and 16-mm, respectively, because there may be cases where the larger thread will be desirable for 8-mm cameras and, less likely, where the smaller thread may be useful for 16-mm cameras.

One of the chief objects of this standard is to establish dimensions for the threads in cameras and on lenses that will provide the proper fit between the corresponding parts, thus ensuring mechanical interchangeability. This is covered by the data given for Dimension *A* and by the specification of 32 threads per inch. A second object is to control the lengths of the threads so that the lens will seat properly, be in proper registration, and yet have enough threads in engagement to hold the lens securely. This is covered by Dimension *B* and the notes that apply to it. The last note in this group indicates that manufacturers have already experienced some difficulty with the fairly recent $^5/_8$-inch size. This emphasizes the desirability of having a clear-cut standard early in the development of such equipment.

Next, it is important to specify the distance from the lens seat to the plane of best focus, which is covered by Dimension *C* and its notes. This part of the standard is believed to be an advance over the methods sometimes used in the past. In specifying that *C* is the distance from the lens seat to the plane of the best photographic image, the standard makes it clear to the camera manufacturer that the distance is to the actual surface of the emulsion, not to some arbitrary plane in which the emulsion is supposed to lie. Thus in locating the surfaces of the gate, the camera manufacturer must allow for the slight bowing or buckling of the film that is almost always present. As the proposed standard states, this buckling may require a compromise setting in order to obtain the best average results over the whole field.

Although not mentioned in the draft published herewith, there was discussion in the committee regarding the necessary compromise between the focus that is best for a wide-open lens and the focus that is best when the lens is stopped down. One suggestion was that the setting should be made with the lens closed two stops from its wide-open position. Whether or not that procedure is satisfactory depends a great deal on the lens openings most commonly used.

Finally, Dimension *D* of the standard provides information about the diameter of the lens seat, with particular reference to prevention of interference between the lens and the front of the camera when the lens seat is recessed.

Approval of this standard will not bar the use of other methods of attaching lenses to motion picture cameras. Some lenses are mounted by means of bayonet mounts or threads of a different size. Furthermore, these proposed standards are obviously unsuited to some cameras, for example high-speed cameras with rotating prisms, which require considerable space between the film and the lens mount. The intent of this proposal is to remove the 1-inch, 32 thread and the $^5/_8$-inch, 32 thread from the category of "unwritten" standards and to associate them with the definite registration distances of 0.690 inch and 0.484 inch, respectively. Great confusion would result if different cameras had the same thread, but quite different registration distances. Similarly, too many sizes of mounting threads would limit the possibility of interchanging lenses.

In the first discussions of the Z52 committee, a new mount with $1^3/_4$-inch or $1^1/_2$-inch threads was considered because of its greater potential strength and rigidity. It was dropped, however, when it became evident that a new larger size would entail great expenditures of time and money for tools, and that providing adapters to accept the larger lenses on old cameras and the 1-inch lenses on new cameras would be difficult and confusing.

In the proceedings of the committee, one or two of the dimensions were questioned and either changed or amended by notes. Most of the discussion and criticism was about the terms used for the various components and dimensions. As far as practicable, all these suggestions were included in the proposed standard.

Proposed American Standard Base Point for Focusing Scales on 16-Mm and 8-Mm Motion Picture Cameras

This proposed standard is also a revision of a former War Standard Z52.51-1946 developed under the War Procedures of the ASA for the use of the Armed Services. The War Standard, however, was limited to 16-mm motion picture cameras and so when the revision was undertaken by the 16- and 8-Mm Committee of the Society, it was believed desirable to extend this standard to apply to 8-mm cameras as well. This was believed desirable because many lenses are used interchangeably on both 16-mm and 8-mm cameras.

The main purpose of the proposed standard is to remove all doubt about the point from which measurement is made when the subject, or object, distance is determined. Past practice had not been uniform in this respect. In some cases focusing scales *were* based on measurements made from the focal plane, but in other cases the front gauss point of the lens, the front of the camera, or some special index line engraved on the barrel of the lens was the base point. It was considered better to settle on the focal, or film, plane because that is common to all cameras and lenses. Moreover, it is a plane that can be located readily.

When the object distance is great, it is not necessary to specify the base point with great exactitude. Current lenses, however, can be focused on extremely short object distances. That, combined with their high speed results in limited depth of field. Then it is important to place on the camera a conspicuous index mark for the base point, and to have it located with some precision. That is why the second paragraph of the standard specifies the shape of a distinguishing index mark for the camera and states the accuracy with which it shall be located with respect to the film plane.

The note suggests a way to indicate on a lens that the base point for its focusing scale is in the focal plane. Most lenses are engraved "Feet" or "Inches" and there is usually room to add the words "From Film." Unfortunately there is no corresponding way to state this simply on metric lenses, in terms that will be clear to all the nationalities employing the metric system.

In the discussions by the committee, there has been no divergence of opinion on the location and identification of the base point. Several changes in the wording of the standard have been suggested, and some have been made, but they were merely to clarify the meaning and preclude misunderstanding of the terms.

Proposed American Standard Winding of 16-Mm Sound Film

While this is the first time the matter of winding 16-mm sound film has been proposed for adoption as an American Standard, it has been followed in practice by the film manufacturers for a number of years. In addition, in 1941 the SMPE recognized the method of designating the two types of winding by publishing an SMPE recommendation which was substantially the same as the recent proposal. The only difference is that two sentences of explanation have been added to the present draft in an effort to clarify the meaning.

It is believed this standard fills a recognized need for a uniform way of designating the direction of winding of 16-mm sound film. It is definitely not the intent of this standard to indicate any preferred choice in the direction of winding since existing equipment is designed to use both styles.

Proposed American Standard

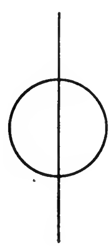
Base Point for Focusing Scales on 16 Millimeter and 8 Millimeter

Motion Picture Cameras

Z22.74
Sept. 1949

1. Focusing scales for 16 millimeter and 8 millimeter motion picture cameras and associated lenses shall indicate object distances measured to the film plane; i.e., the zero point for the focusing scale shall be in the plane of the film.

2. An index mark to indicate the film plane shall be placed on the outside of the camera. This mark shall consist of a circle crossed by a line having a length of between two and three times the diameter of the circle (see illustration blow). The line shall be in the plane of the film within 0.040 inch.



Note: One way to distinguish focusing scales made in accordance with this standard is to have the words "From Film" appear after the word "Feet" or other unit designation.

NOT APPROVED

Proposed American Standard
for Winding of

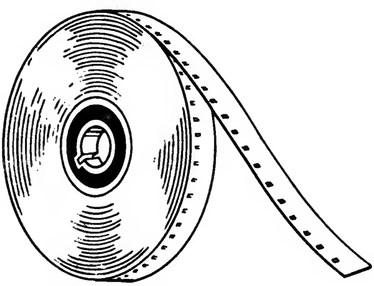
16-Millimeter Sound Film

Z22.75
Sept. 1949

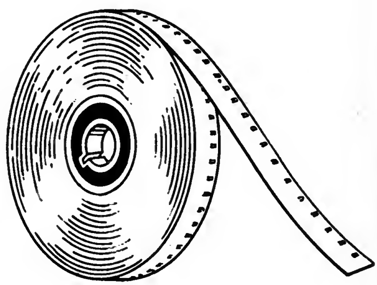
The purpose of this standard is to insure a uniform method of designating the direction of winding in ordering or in describing 16-millimeter sound film. There is no preferred direction of winding because the operation of existing equipment may require film wound in either direction.

Winding "A" of 16-millimeter sound motion picture film shall have the perforations toward the observer when the roll is held with the outside end at the top, toward the right, and emulsion side in.

Winding "B" of 16-millimeter sound motion picture film shall have the perforations away from the observer when the roll is held with the outside end at the top, toward the right, and emulsion side in.



Winding A
Emulsion side in



Winding B
Emulsion side in

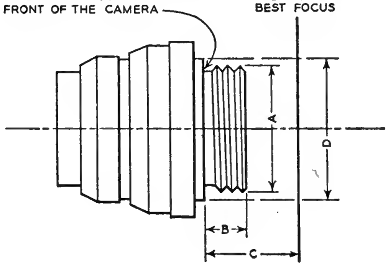
The drawings show film wound on cores. When film is wound on reels having square holes on one side and round holes on the other, it is understood the square hole will be on the side away from the observer.

NOT APPROVED

Proposed American Standard Mounting Threads and Flange Focal Distances for Lenses on 16 Millimeter and 8 Millimeter Motion Picture Cameras

Z22.76
Sept. 1949

The purpose of this standard is to describe the two sizes of screw threads and the related flange focal distances in common use for mounting objective lenses on 8 millimeter and 16 millimeter motion picture cameras. The external thread is on the lens, and the internal thread is in the camera.



Nominal (Major) Diameter of Lens Attaching Thread	Threads Per Inch	Length from Shoulder to End of Thread	Flange Focal Distance	Diameter of Lens Seat
(A) Inch		(B) Inch	(C) Inch	(D) Inch
0.625	32	0.115	0.484	1.000
1.000	32	0.156	0.690	1.187

Dimension A: The American National Thread Form should be used.

Dimensions and tolerances shall conform to those established for a Class 2 Fit by the National Bureau of Standards Handbook H28, Screw Thread Standards for Federal Services (Section V, Screw Threads of Special Diameters, Pitches, and Lengths of Engagement).

Dimension B: The values given for this dimension in the above table are to be considered as the maximum for the lens; a little additional length, for clearance, should be provided in the camera.

NOT APPROVED

Proposed American Standard
Mounting Threads and Flange Focal Distances for
Lenses on 16 Millimeter and 8 Millimeter
Motion Picture Cameras

Z22.76
Sept. 1949

With some lenses a section of the mount, with a diameter smaller than the root of the thread, necessarily extends closer to the film than is indicated by the above drawing. In those cases, the mechanical clearance in the camera must be determined individually.

In the past, a number of lenses with the 1-inch thread had a "B" dimension of 0.187 inch. This is considered to be an obsolete practice.

Past practice has not been entirely consistent so far as the "B" dimension of the 0.625-inch thread is concerned; some existing cameras will not accept a thread longer than 0.115 inch; some lenses have been made with a length of 0.120 or 0.125 inch.

Dimension C: This dimension is defined as the distance from the lens seat to the plane of the best photographic image. It should be determined photographically with panchromatic film and with the camera operating normally. Sometimes a compromise is necessary between best central definition and best over-all definition.

The tolerance acceptable for dimension "C" is dependent on the depth of focus and on a decision as to what portion of the depth can be used for the focus tolerance. In some cases, the tolerance is very small. For example, with a 25-millimeter f/1.4 lens and a 0.001 inch circle of confusion, the depth of focus is 0.0014 inch; only part of this is available for the sum of the lens and camera focusing tolerances.

Dimension D: The values given in the table are to be considered as the maximum diameter of the seat on the lens; the seat on the camera should provide clearance for these diameters.

If any part of the lens mount has a larger diameter, it should be checked for mechanical interference with the camera on which it is to be used. Some lenses with the 1-inch thread have been made with a flange diameter of 1.500 inches.

Note: This standard does not apply to continuous-type motion picture cameras because of the type of optical system employed in these cameras.

NOT APPROVED

66th Semiannual Convention
SOCIETY OF MOTION PICTURE ENGINEERS

Hollywood-Roosevelt Hotel • October 10–14, 1949 • Hollywood, California

• • •

OFFICERS IN CHARGE

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Ralph B. Austrian . . . . *Treasurer*

General Office, New York

Boyce Nemec . . . . *Executive Secretary*
Helen M. Stote . . . . *Journal Editor*
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Sigmund M. Muskat . . . . *Office Manager*

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Publicity Committee Chairman . . . . Harold Desfor
  Vice-Chairman, West Coast . . . . Announced Later
Registration and Information . . . . C. W. Handley
  Assisted by W. L. Farley and R. H. Duval
Luncheon and Banquet . . . . J. P. Livadary
Hotel Housing and Reservations . . . . Watson Jones
Membership and Subscriptions . . . . Lee Jones
  West Coast Vice-Chairman . . . . G. C. Misener
Ladies' Reception Committee Hostess . . . . Mrs. Peter Mole
Transportation—Rail, Plane, Local . . . . Herbert Griffin
Public-Address Equipment . . . . Lloyd T. Goldsmith
Projection Program Committee—35-Mm . . . . R. H. McCullough
  Assisted by Members of Los Angeles Projectionists Local 150
Projection Program Committee—16-Mm . . . . H. W. Remerscheid, E. C. Fritts

GENERAL INFORMATION

HOTEL RESERVATIONS AND RATES The Housing Committee, under Watson Jones, chairman, will make reservations for members and guests. Inform him at 1560 North Vine Street, Hollywood 28, California, of the accommodations you desire. He will book your reservations and confirm them.

TRAVEL Make your train or plane reservations early because West Coast travel in October normally is quite heavy.

PAPERS PROGRAM Authors who plan to prepare papers for presentation at the 66th Convention should write at once for Authors' Forms and important instructions to the Papers Committee member listed below who is nearest. Authors' Forms, titles, and abstracts must be in the hands of Mr. Grignon by August 15 to be included in the Tentative Program, which will be mailed to members thirty days before the Convention.

N. L. Simmons, *Chairman*
6706 Santa Monica Blvd.
Hollywood 38, California

J. E. Aiken, *Vice-Chairman*
116 N. Galveston St.
Arlington, Virginia

Lorin Grignon, *Vice-Chairman*
20th Century-Fox Films Corp.
Beverly Hills, California

E. S. Seeley, *Vice-Chairman*
Altec Service Corp.
161 Sixth Ave.
New York 13, New York

R. T. Van Niman, *Vice-Chairman*
4501 Washington Blvd.
Chicago 24, Illinois

H. S. Walker, *Vice-Chairman*
1620 Notre Dame St., W.
Montreal, Que., Canada

CONVENTION GET-TOGETHER LUNCHEON The 66th Semiannual Convention Get - Together Luncheon for members, guests, and ladies attending the Convention will be held in the Blossom Room on Monday, October 10, at 12:30 p.m. There will be eminent speakers and entertainment.

Most important—Luncheon seating will only be guaranteed and assured if tickets have been procured prior to the Convention from W. C. Kunzmann, Convention Vice-President, or before 11:00 a.m. on October 10 at Registration Headquarters.

Checks or money orders issued for Registration fees, Luncheon, or Banquet tickets should be made payable to W. C. Kunzmann, Convention Vice-President, and *not to the Society*.

BANQUET AND COCKTAIL HOUR The Convention Cocktail Hour for holders of Banquet tickets will be held in the Redwood Room on the mezzanine floor, on Wednesday evening, October 12, between 7:15 p.m. and 8:15 p.m.

The Banquet (dress optional) will be held in the Blossom Room on Wednesday evening, October 12, promptly at 8:30 p.m.

There will be entertainment and dancing, and at this time the Annual Awards will be made.

Note: Tables for the Banquet can be reserved at Registration Headquarters prior to noon on October 12.

LADIES AND GUESTS Members are encouraged to invite their friends to attend the Convention. There will be eleven Technical Sessions open to all who wish to be on hand, and for the ladies who accompany their husbands, the Ladies' Committee is arranging a week of sight-seeing and special events. The Ladies' Registration Headquarters will be located in parlor suite 420–421 in the Hollywood-Roosevelt Hotel. The ladies attending the Convention should register and receive their badges, identification cards, and programs. Mrs. Peter Mole will serve as Hostess.

RECREATION The identification cards issued to members and guests who register for the Convention will permit them to attend Grauman's Chinese and Vogue Theaters of the Fox West Coast Circuit, the Hollywood Paramount, the Pantages, and Warner Theaters, all of which are located on Hollywood Boulevard and near the hotel. Convention Headquarters will have a wealth of information on places to visit in or near the Los Angeles area.

TENTATIVE PROGRAM

Monday, October 10, 1949

9:30 A.M. REGISTRATION
Convention Headquarters

12:30 P.M. LUNCHEON
Blossom Room

3:00 P.M. BUSINESS AND TECHNICAL SESSION
Blossom Room

8:00 P.M. COLOR SESSION
Blossom Room

Tuesday, October 11, 1949

9:30 A.M. REGISTRATION
Convention Headquarters

10:00 A.M. COLOR SESSION
Blossom Room

2:00 P.M. COLOR SESSION
Academy Theater

8:00 P.M. COLOR SESSION
Academy Theater

Wednesday, October 12, 1949

9:30 A.M. REGISTRATION
Convention Headquarters

10:00 A.M. HIGH - SPEED PHOTOGRAPHY SESSION
Aviation Room

2:00 P.M. HIGH - SPEED PHOTOGRAPHY SESSION
Aviation Room

7:15 P.M. COCKTAIL HOUR
Redwood Room

8:30 P.M. BANQUET
Blossom Room

Thursday, October 13, 1949

10:30 A.M. HIGH - SPEED PHOTOGRAPHY SESSION
Aviation Room

2:00 P.M. FIELD TRIP TO MOUNT WILSON
Television Transmitters and 100-inch Telescope

8:00 P.M. TELEVISION SESSION
Carnegie Assembly Hall, Mount Wilson Observatory

Friday, October 14, 1949

10:00 A.M. SYMPOSIUM ON MAGNETIC RECORDING
Blossom Room

2:00 P.M. MOTION PICTURE PRODUCTION SESSION
Blossom Room

8:00 P.M. STUDIO-LIGHTING SESSION
Blossom Room

ADJOURNMENT

Proposed New Constitution and Bylaws

A RECENT ACTION taken by the Society's Board of Governors requires that certain matters be submitted to the Society members for their consideration and decision. A special committee, which the then incumbent President Loren Ryder appointed on October 24, 1948, considered the advisability of acknowledging in some formal way the growing interest of the Society and its members in the relatively new field of television. On April 3, 1949, the Committee reported to the Board of Governors that agreement had been reached —only one member dissenting—on a proposal to change the name of the association from "Society of Motion Picture Engineers" to "Society of Motion Picture and Television Engineers." This change of name requires a change in the Constitution.

Another special committee was also appointed by the then President Loren Ryder, on January 23, 1947, to study the Society's fundamental purposes and its methods of operation.

This Committee was also asked to reconcile certain inconsistencies that exist between the Constitution and Bylaws, and in addition to reword certain paragraphs, or articles, which were obscure or redundant.

The Board has endorsed these proposals and now, as required by Article VII of the Constitution, the proposed name change, with the other recommended changes, will be submitted for discussion by the members at the Annual Meeting of the Society (which is a part of the Fall Convention); and then, immediately following the meeting, the proposals, with a letter ballot and a transcript of the meeting discussion, will go to all voting members for their formal action.

The new Constitution, which has been proposed, is published here in advance of its distribution to the voting membership, since it is of interest to all the Society members. Comparison between the old and the new Constitutions may be readily made by referring to page 463 of the JOURNAL for April, 1949. The change-of-name question will be included with the Constitution letter ballot, which will be mailed shortly after the Fall Convention.

The important proposed changes in the Constitution can be summarized briefly as follows:

Article I provides for the change of name.

Article II covers the addition of the television art to the scope of the Society.

Article III now covers "Meetings," formerly covered by Article VI, and is reworded to be more explicit.

Article IV has been reworded for clarity.

Article V assigns the executive duties of the President in his absence to the Executive Vice-President, instead of to the Past-President, as is now the case, and has been further reworded for clarity.

Article VI is new and defines "Sections."

Article VII provides for twelve elected Governors, allowing the Atlantic Coast, Central, and Pacific Coast Sections each to be represented by four elected Governors. Previously, representation of the Central Section was not assured.

Article VIII clarifies former Article VII and deals with amendment procedures.

The work of the Committee on the revision of the Bylaws is not as yet complete; substantial progress has been made, however, and it is expected that the proposed revision will be printed as amendments to the Bylaws in the issue of the Journal immediately preceding the 67th Semiannual Convention to be held at the Drake Hotel in Chicago, April 24–28, 1950, at which meeting formal action may then be taken on their proposals.

It is suggested that all voting members who find it possible to attend the 66th Convention in Hollywood from October 10 to October 14 should do so and should be on hand for the Business Meeting at which these changes will be discussed.

Proposed New Constitution of the Society of Motion Picture Engineers

CONSTITUTION

Article I

Name

The name of this association shall be SOCIETY OF MOTION PICTURE AND TELEVISION ENGINEERS.

Article II

Objects

Its objects shall be: Advancement in the theory and practice of engineering in motion pictures, television, and the allied arts and sciences; the standardization of equipment and practices employed therein; the maintenance of a high professional standing among its members; and the dissemination of scientific knowledge by publication.

Article III

Meetings

There shall be an annual meeting and such other regular and special meetings as provided in the Bylaws.

Article IV

Eligibility for Membership

Any person of good character is eligible to become a member in any grade for which he is qualified in accordance with the Bylaws.

Article V

Officers

The officers of the Society shall be a President, an Executive Vice-President, a Past-President, an Engineering Vice-President, an Editorial Vice-President, a Financial Vice-President, a Convention Vice-President, a Secretary, and a Treasurer.

The term of office of all elected officers shall be for a period of two years.

The President shall not be eligible to succeed himself in office.

At the conclusion of his term of office the President automatically becomes Past-President.

Under conditions as set forth in the Bylaws, the office of Executive Vice-President may be vacated before the expiration of his term.

A vacancy in any office shall be filled for the unexpired portion of the term in accordance with the Bylaws.

Article VI

Sections

Sections may be established in accordance with the Bylaws.

Article VII

Board of Governors

The Board of Governors shall consist of the President, the Past-President, the five Vice-Presidents, the Secretary, the Treasurer, the Section Chairmen, and twelve elected Governors. An equal number of these elected Governors shall reside within the areas included in the Eastern time zone; the Central time zone; and the Pacific and Mountain time zones. The term of office of all elected Governors shall be for a period of two years.

Article VIII

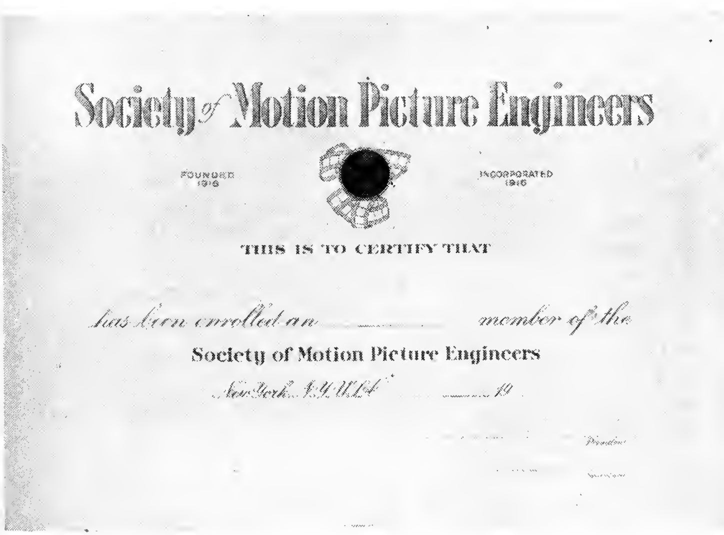
AMENDMENTS

This Constitution may be amended as follows: Amendments may originate as recommendations within the Board of Governors, or as a proposal to the Board of Governors, by any ten members of voting grade; when approved by the Board of Governors as set forth in the Bylaws, the proposed amendment shall then be submitted for discussion at the annual meeting or at a regular or special meeting called as provided in the Bylaws. The proposed amendment, together with the discussion thereon, shall then be promptly submitted by mail to all members qualified to vote, as set forth in the Bylaws. Voting shall be by letter ballot mailed with the proposed amendment and discussion to the voting membership. In order to be counted, returned ballots must be received within sixty (60) days of the mailing-out date. An affirmative vote of two thirds of the valid ballots returned subject to the above time limitations, shall be required to carry the amendment, provided one fifteenth of the duly qualified members shall have voted within the time limit specified herein.

Membership Certificates

Would you like a certificate of your membership in the SMPE? Many members hang them in their offices or homes.

They are available from Society Headquarters for $1.50.



Society Announcements

Committee Changes

On pages 481–495 of the April, 1949, issue of the JOURNAL, the names of the members of the Society's Committees were published. Since that date, several changes have been made as listed below. Where there is no mention of a Committee, it is because there have been no changes.

Committee

COLOR
Add—F. T. Bowditch

HIGH-SPEED PHOTOGRAPHY
Add—C. W. Wyckoff

HISTORICAL AND MUSEUM
Add—
W. H. Offenhauser, Jr., *Vice-Chairman*
G. J. Badgley
J. A. Ball
L. W. Bonn
H. T. Cowling
W. A. Jamison
Beaumont Newhall
Terry Ramsaye
E. I. Sponable
Randall Terraneau

LABORATORY PRACTICE
Change Address—
J. G. Stott
Du Art Film Laboratories
245 W. 55 St.,
New York 19, N. Y.

PAPERS
Add—W. H. Rivers
Delete—
G. M. Best
P. E. Brigandi
J. P. Corcoran
G. R. Crane
C. R. Daily
Correct Address—
R. T. Van Niman
4431 W. Lake St.
Chicago 24, Ill.

Committee

PRESERVATION OF FILM
Add—J. B. McCullough

PROCESS PHOTOGRAPHY
Add—A. C. Robertson

PROGRESS
Add—R. T. Van Niman
Correct Address—
C. R. Sawyer
Western Electric Co.
175 Chambers St.
New York 7, N. Y.

16-MM AND 8-MM MOTION PICTURES
Add—J. L. Forrest

STANDARDS
Add—L. W. Davee

TELEVISION
Add—
Willy Borberg
R. V. Little
Delete—Frank Goldbach

TEST-FILM QUALITY
Change Address—
F. S. Berman
Movielab Film Laboratory
619 W. 54 St.
New York 19, N. Y.

THEATER ENGINEERING
Add—O. P. Beckwith
Delete—A. G. Ashcroft

THEATER TELEVISION
Add—
Richard Hodgson
W. W. Lozier

Notice to Authors and Publishers Desiring to Reprint Material Appearing in the Journal

While the policy of the Society is to encourage distribution of engineering information, it has been found necessary to establish a few simple rules regarding reprinting of material published in the JOURNAL. All papers submitted to and accepted by the Society become Society property and when published in the JOURNAL are subject to the copyright laws of the United States of America, and the International and Pan-American Copyright Conventions. Permission to republish material from the JOURNAL must be obtained in writing from the General Office of the Society. Such permission ordinarily is granted upon receipt of approval by the author. The Society makes no charge for permission to reprint JOURNAL material but requires that credit be given to the JOURNAL, preferably by reference to the original publication date. However, if the material consists only of illustrations, a blanket credit in the preface or introduction may be sufficient.

When the material originally copyrighted by another organization is printed in the JOURNAL by permission of the copyright holder, the Society of Motion Picture Engineers does not have authority to grant permission to a third party for further reprinting. The third party should obtain permission from the original copyright holder. For example, approved American Standards are copyrighted by the American Standards Association and reprinted in the JOURNAL by permission of the ASA. However, the SMPE does not have authority to give a third party the right to reprint American Standards. This also applies to Proposed American Standards when the proposed changes to a previously copyrighted standard are minor or editorial even if the proposed changes have not been approved by the ASA.

C. R. KEITH
Editorial Vice-President

SMPE Officers and Committees

The names of Society Officers and of Committee Chairmen and Members are published annually in the April issue of the JOURNAL. Changes and corrections to these listings are published in the September JOURNAL.

Section Meetings

Atlantic Coast

On June 28, 1949, the Atlantic Coast Section of the Society presented "A Study in Television Lighting."

This was the largest and most ambitious Eastern Section program ever held. Over 500 people watched the demonstration on direct-view monitors at the same time the action took place on the stage of the Adelphi Theater. In addition, the complete program was viewed by the Chicago Section through coaxial-cable facilities, and the general television audience in Baltimore, Washington, and Detroit saw the demonstration as an air show from their local DuMont stations.

A special film section was produced by the Gray O'Reilly Studios to demonstrate present knowledge of the rights and wrongs of film production for television. Walter Kiernan served as master of ceremonies, and with Mr. O'Reilly told the audience exactly how the film was made and why certain lighting techniques produce better television pictures.

Richard Blount of the General Electric Company demonstrated on the stage of the theater the known rights and wrongs of television studio lighting, using the same talent as the film section so that the audience could see why some people are more difficult to light than others.

Representative samples of poor and good lighting on original studio programs recorded on film via video recording techniques were viewed by the audience.

Central

The June 28, 1949, Central Section meeting was held in joint session with the Atlantic Coast Section via television and resulted in a large-screen television demonstration for many in the Chicago and midwest areas.

The program, "A Study in Television Lighting," as televised is covered by the report of the Atlantic Coast Section. Total attendance at this meeting was around 500 and many were turned away at 7:00 when all the house lights were turned out to view the television screen.

Following the one-hour demonstration from New York, A. H. Brolly of Television Associates gave a paper, "Television Studio Lighting." This paper was presented before the Society at the 65th Semiannual Convention in New York.

Toledo Regional Meeting

On June 10, 1949, an all-day Central Section Regional meeting was held in Toledo, Ohio. The first feature of this meeting was an inspection trip through the Strong Electric Corporation. After the tour, R. T. Van Niman, chairman of the Central Section, presided over the first technical session. Lloyd Thompson, of the Calvin Company, reported on the 65th Semiannual Convention and reviewed some of the papers presented at that time.

A. J. Hatch, Jr., vice-president in charge of engineering of the Strong Electric Corporation, presented the first paper, "A Portable Device for Measuring Radiant

Energy at the Projection Aperture." The instrument described permits a value of total center aperture energy to be read directly from an indicating meter.

The next paper, "The Future of Drive-in Theaters," by Charles R. Underhill, Jr., Product Sales Manager, Theater Equipment Sales, RCA Victor Division, was read by J. D. Phyfe. The construction of drive-in theaters from about eight a year before the war to about two hundred and fifty a year since the war has been largely due to the development of the in-car speaker.

"University Productions in 16-Mm" by Robert W. Wagner, Department of Photography, Ohio State University, was presented by R. E. Buchanan, a director cameraman in this group. A production crew of four, using professional recorders and cameras, is producing one picture a month.

"A New Portable High-Intensity Arc Spotlight," was presented by Russell Ayling of the Strong Electric Corporation. The "Trouper" a new 215-pound spotlight features an automatic carbon feed and produces a clear-cut spot which may be varied in size. A two-element variable-focal-length lens system which continuously focuses on the aperture is used to project the desired spot sizes. Individual color filters are held in place by a permanent magnet located at the top of the holder.

"A Precision Lens Testing and Copying Camera," by M. W. LaRue, Jr., of Bell and Howell, was well illustrated with excellent slides. A special back has been designed to hold the photographic material in very exact alignment and a special means of focusing was also described.

The meeting was then turned over to R. T. Van Niman who acted as moderator for a "Symposium on Visible Music," the report of which is given below.

At 8:00 P.M. an evening technical session was held at the Macomber Vocational High School. The session started with the projection of a 16-mm Technicolor print, "Carbon-Arc Projection," a film produced by the National Carbon Company. Introductory comments were made by C. E. Heppberger of that company.

"The 4-Mm Film: Its Evolution and Future" by B. A. Aughinbaugh of the Ohio State Department of Education, makes a plea for the use of 4-mm film in some type of personal viewer that could be used for communication and education on a par with the printed book.

Visible Music Symposium

Section chairman Van Niman, acting as moderator, briefly outlined the general subject of visible music, citing the work of Ralph Potter of Bell Telephone Laboratories, Norman McLaren of the National Film Board of Canada, Robert E. Lewis of Armour Research Foundation, Cecil Stokes of the Crosby Research Foundation, and mentioned that some of the sequences in Walt Disney's "Fantasia" came close to what is now being considered as falling into this classification.

The first item was a showing of several sections of one of the "Auroratone" films made by Cecil Stokes for the Crosby Research Foundation, and lent for the occasion by Mr. Crosby. These films, which are being used extensively in mental therapy to produce relaxation, consist of symphonic or vocal music recordings accompanied by slowly changing color patterns on the screen, more or less keyed to the mood of the music. According to the information furnished with the film, the abstract patterns are etched on glass plates and the color is produced optically, probably by a polarization process as light is projected through the moving plates into the camera. The films shown also included foreground patterns indicative of the subject of the musical selection.

In discussion following this showing, Mr. Lewis pointed out that while such films undoubtedly have a place in the general field of visible music, the lack of close correlation between visual and audible stimuli and the unvarying tempo of the changing color patterns makes them come somewhat short of realizing the full capabilities of the art.

The next items on the symposium were Norman McLaren's two short films, "Dots" and "Loops." These were made in the manner outlined in the March, 1948, JOURNAL paper, "Synthetic Sound on Film," by McLaren and Lewis, and both the picture and the sound track were hand-drawn on 35-mm blank leader. The pictures, as the titles imply, are simple geometrical designs which change in form, color, and location in time with the sounds produced.

In the discussion following the showing Mr. McLaren stated that the films have no purpose other than entertainment and relaxation, and that the principal value of the technique lies in the resulting close connection between the artist and the end result of his work because of the elimination of camera and recording equipment. Furthermore, sound effects not present in nature can be produced, and they can be closely correlated with the visual effects for greatest dramatic impact.

The next feature on the symposium was the United States première of Mr. McLaren's latest visible music film, "Be Gone Dull Care." The music for this film is not synthetic but is instead a special recording of a piano, drum, and double-bass trio playing selections varying from waltz to boogie. The visuals, however, are strictly abstract color, line pattern, shape, and texture animated to the music.

Extensive discussion followed the showing and Mr. McLaren answered numerous questions regarding the technique, processing, and general philosophy of his version of visible music. The latter formed a natural introduction to Mr. Potter's portion of the symposium, which he gave under the title, "Abstract Visuals with Music." He pointed out that music is purely an abstract type of art and that if it can be combined with equally abstract forms in an attractive manner, something of fundamental importance in tomorrow's screen and sound entertainment has been created. Such abstract art forms may be used over and over without losing their appeal.

Mr. Potter stated that one of the few things powerful enough to make music and abstract visual displays belong together is movement, and that so far as information to the brain is concerned, sounds move just as definitely as visible things do. A pitch change is like visible movement *across* the field of view, and loudness changes correspond to visible movement *toward* and *away from* the observer. This basic concept has been employed in the sound spectroscope now being employed for speech studies; it shows on the scope screen an instantaneous picture of the various frequency components in complex sounds, with frequency on the horizontal axis and component intensity indicated by the vertical displacement. The picture and the sound, if it is of a musical nature, are visible music and are generally considered an acceptable combination, even though the picture is completely inartistic and only two-dimensional, because they inherently *belong* together.

Meetings of Other Societies

September—	
Illuminating Engineering Society National Technical Conference	September 19 through September 23 French Lick, Indiana
National Electronics Conference	September 26 through September 28 Chicago, Illinois
October—	
Photographic Society of America Convention	October 19 through October 22 St. Louis, Missouri
Optical Society of America Annual Meeting	October 27 through October 29 Buffalo, New York
October-November—	
Radio Fall Meeting Joint IRE-RMA	October 31 through November 1 Syracuse, New York
March, 1950—	
Institute of Radio Engineers National Convention	March 6 through March 9 New York, New York
Optical Society of America Winter Meeting	March 9 through March 11 New York, New York
April, 1950—	
Armed Forces Communications Association Annual Meeting	April 26 through April 28

Armed Forces Communications Association

Society members, who are also members of the Armed Forces Communications Association, or who served with the military photographic services, will be interested in this report of recent AFCA activities. The first change of Association leadership took place July 1 when Western Electric Vice-President Frederick R. Lack, succeeded RCA President David Sarnoff as the President of the AFCA.

The Third Annual National Convention of the Association was held at Washington, D. C., March 28–29, 1949, where visiting members and officers were the guests of the Navy. The Signal Corps had previously served as host for the First Annual Meeting, while the second such meeting was under the auspices of the Air Force. Nearly 500 members were on hand in Washington to take part in numerous discussions and to view the many displays which the Navy had prepared. Ships, naval communications, and photographic equipment were featured, and those who attended reported that a fine time was had by all.

The next Annual Meeting is scheduled for April 26–28, 1950, and will be held in New York City and Fort Monmouth, New Jersey.

Meetings af Other Societies

TESMA Trade Show

The Theater Equipment and Supply Manufacturers Association extends to the members of the Society of Motion Picture Engineers a cordial invitation to attend the Annual TESMA Trade Show and Convention to be held at the Stevens Hotel in Chicago, Illinois, September 26–28, 1949. On Wednesday, September 28, in the Grand Ballroom of the Stevens Hotel, there will be a demonstration of the latest in large-screen theater television. Technical addresses, many of which will be of interest to SMPE members, will be delivered during this meeting.

Current Literature

The editors present for convenient reference a list of articles dealing with subjects cognate to motion picture engineering published in a number of selected journals. Photostatic or microfilm copies of articles in magazines that are available may be obtained from The Library of Congress, Washington, D. C., or from the New York Public Library, New York, N. Y., at prevailing rates.

American Cinematographer

30, 5, May, 1949

Calibration of Photographic Lens Markings (p. 163)

High-Speed Cineradiography (p. 164) H. M. Grooms

Photographing the 16-mm Commercial Film (p. 168) C. Loring

Endurance Test (p. 172) J. G. Roark

American Photography

43, 7, July, 1949

Testing Shutters by Television (p. 408) B. B. Bauer

Electronics

22, 6, June, 1949

Minimizing Television Interference (p. 70) P. S. Rand

International Projectionist

24, 5, May, 1949

TV Film Projectors (p. 9) G. W. Tunnell

Psychological Elements in Projection (p. 14) R. A. Mitchell

Audio Engineering

33, 6, June, 1949

Magnetic Tape and Head Alignment Nomenclature (p. 22) N. M. Haynes

33, 7, July, 1949

Auditory Component Control for the Legitimate Theatre (p. 15) J. H. Beaumont

Importance of Groove Fit in Lateral Recordings (p. 18) D. R. Andrews

Photographic Age

4, 5, May, 1949

Telephoned Television Has Industrial Future. The Story of Remington Rand's Lightweight Video Camera (p. 17)

Radio and Television News

41, 6, June, 1949

A Three-Dimensional Reproducer System (p. 44) M. Wolfe

Book Reviews

Elements of Sound Recording, by John G. Frayne and Halley Wolfe

Published (1949) by John Wiley and Sons, 440 Fourth Avenue, New York 16, N. Y. 674 pages + 12-page index + vii pages. 463 illustrations. $6^1/_4 \times 9^1/_4$ inches. Price, $8.50.

Here at last is a book, for both the student and experienced recording engineer, that contains a wealth of up-to-date, useful information in a field which is so specialized—as most everything is nowadays—that very little outside of the professional journals is available in book form. The authors are well qualified to prepare such a volume, and have succeeded in presenting under one cover much of the meat of the subject. Diagrams and illustrations are profusely employed to supplement the text. Mathematical analyses are sparingly used and then only to illustrate basic principles.

Briefly to orient the newcomer to the field, the first few chapters deal with the nature of sound, sound waves, electrical, acoustical, and mechanical circuits. Chapter III, and the several following, cover microphones and their uses, vacuum tubes, audio amplifiers, network theory, filters, and equalizers. And here it is well to add that there are many charts and tables which are useful in determining constants for mixer circuits, loss pads, and filters.

Chapter X begins the discussion of practices largely unique in recording: compression and limiting, recording systems, disk recording, disk records and their processing. There follows, in considerable detail, subject matter on variable-density and variable-area film recording. Noise-reduction methods are thoroughly described.

The chapter on film laboratory processes contains much information on modern laboratory processing methods for sound film. A chapter is included on recording techniques. Film reproducing systems, both 35-mm and 16-mm, are described with much helpful information on theater sound systems and how to obtain the best quality from 16-mm sound films.

Of timely interest in the present state of the recording art is a chapter on magnetic recording—its basic principles, types of systems, and professional uses. There are chapters on loudspeaker systems and acoustics of stages and theaters. The final subject looks to the future with a review of stereophonic recording and reproduction relating the work done to the present time. Systems are described and results discussed, together with the operating problems which were encountered.

The subject of sound recording has so many ramifications that it is difficult to cover all parts adequately. This fact is recognized by the authors, who include a number of pertinent references at the end of each chapter to enable the reader to go into many of the subjects at greater length. For a thorough grounding in sound recording and reproduction, this book is a worth-while addition to the reference library of the engineer in this field.

Lloyd T. Goldsmith
Warner Brothers Pictures
Burbank, Calif.

Book Reviews

Magnetic Recording, by S. J. Begun

Published (1949) by Murray Hill Books, Inc., 232 Madison Avenue, New York 16, N. Y. $6^1/_4 \times 9^1/_4$ inches. 223 pages + 7-page glossary + 8-page index + x pages. 146 illustrations. Price, $5.00.

"Magnetic Recording" is devoted almost entirely to a discussion of magnetic recording, both in its theoretical aspects and practical applications. The book is very timely and will be of great value to those interested in understanding the nature of the magnetic-recording process as well as to those who are interested in the more practical side of designing equipment for various commercial usages. The chapter on the theory of magnetic recording is extremely well written and explains in considerable detail the influence of the various parameters entering into magnetic recording. The discussion of the effect of the direct-current and alternating-current bias is very thorough, and in the case of the alternating-current bias represents, in the reviewer's opinion, one of the most lucid explanations yet offered. The chapter devoted to components of the magnetic-recording system gives a very detailed discussion of the various recording media that have been used to date in magnetic recording. In this chapter, and also in the next one on magnetic-recording equipment, undue emphasis may seem to have been placed on wire-recording systems. This apparent misplacement of emphasis, however, can very well be attributed to the necessary hiatus between the writing of the book and its publication. The very rapid adoption of the powdered iron-oxide coated tape in the last few years has, of course, recently tended to obsolete wire and steel-tape recorders, at least for professional applications.

The book is well illustrated and a very complete description, with appropriate photographs, is given of the various types of commercial recorders that had appeared on the market up to the time of preparation of the manuscript.

The chapter entitled "Applications of Magnetic Recording" describes applications to artificial-reverberation devices, speech-scrambling, recording of transients, applications to telegraphy and telephony, transcription recording, and motion pictures. The treatment of the last item is quite brief and is undoubtedly necessarily so because of the rather belated interest of the motion picture industry in the magnetic-recording method.

John G. Frayne
Western Electric Company
Hollywood 38, Calif.

EMPLOYMENT SERVICE

POSITION WANTED

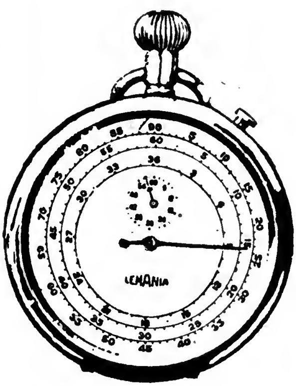
16-MM PRODUCTION SPECIALIST: Twelve years' experience in all phases of 16-mm production and distribution including camera, sound recording, editing, animation, and public relations. Seven years' experience in administration and supervision of production unit. Presently employed. Age 35 years. Desires position in television, educational, or industrial field inaugurating a motion picture program. Write Alfred Y. Lytle, 15 Sutton Road, Rocky Hill, Connecticut.

New Products

Further information concerning the material described below can be obtained by writing direct to the manufacturers. As in the case of technical papers, publication of these news items does not constitute endorsement of the manufacturer's statements nor of his products.

Stop Watch and Timer

Moss and Robinson, 8 W. 47 St., New York 19, N. Y., have designed a stop watch and timer especially for the motion picture industry. This watch enables the user instantly to ascertain either simultaneously or individually the amount of film footage needed in 16- or 35-mm film on a precheck or rehearsal of dialog or narration.



The dial has three scales as follows: Red scale divides the minute into 90 parts, synchronizing with 35-mm film (90 feet per minute). Blue scale divides the minute into 60 seconds. Black scale divides the minute into 36 parts, synchronizing with 16-mm film (36 feet per minute).

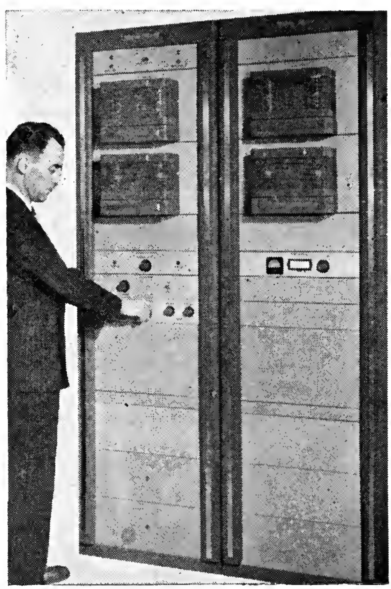
The watch can be used by script writers, directors, and in the editing room. The dial also serves as an immediate reduction table from 35 to 16 mm.

Two models are offered. The illustration shown is $1^1/_4$ inches in diameter and is regulation pocket size. The second model is $2^1/_4$ inches in diameter for those who find a larger size watch more to their liking.

100-Watt Class A Amplifier

A new 100-watt Class A amplifier built as a single unit has been designed by the **Westrex Corporation,** 195 Broadway, New York 7, N. Y. It is said to be the first amplifier of its kind available for theater use.

The Class A push-pull power stage reduces harmonic distortion to less than



New Products

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one and one-half per cent at the full rated output. Microswitches automatically provide full protection against high-voltage hazards.

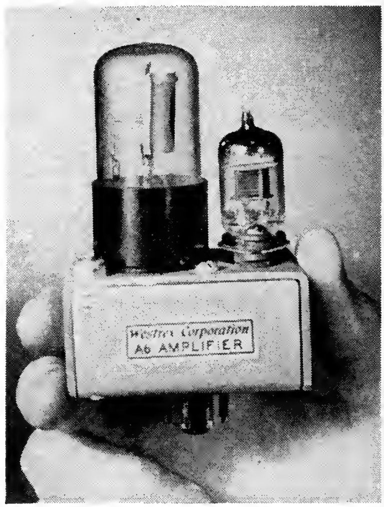
The voltage driver unit is identical to that used in all Westrex high-powered amplifiers and may be completely replaced, in the event of failure, simply by the use of a screw driver. Only one electrolytic capacitor is used in amplification, that being of the plug-in type. All resistors, except those in the power stages, are of a precision type with a maximum permissible tolerance of one per cent.

Mounted in an attractive floor-type cabinet, this 100-watt system permits maximum flexibility in the arrangement of components to meet individual theater requirements. Full-length double doors at the rear provide easy access, while spare tubes and plug-in capacitors are stored within the cabinet in easy reach.

New Theater Amplifier System

Westrex also announces a new line of theater amplifier systems which provides standard relay-rack panels in a floor-mounted cabinet for all but the smallest system. As an aid to servicing the deep amplifier chassis a door switch automatically turns on a light inside the chassis when the front mat is removed. A standard voltage amplifier, which may be mounted on a 15-, 40-, 50-, or 100-watt amplifier chassis, is connected by means of small metal straps so that it may be disconnected and replaced with only a screw driver. Normal space currents are indicated at 11 points in the system by means of a "100 per cent" meter.

Another feature is a small plug-in phototube amplifier, as shown in the photograph. Change-over between



machines is effected by interlocking relays operated by a push button which may be placed at any convenient location. When stand-by amplifiers are provided, they may be put in use by means of a single switch which simultaneously cuts over amplifiers, rectifiers, and horns. Accessories such as mixing panels and nonsynchronous reproducer amplifier-equalizers are also available.

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Theater Television Today*

By JOHN EVANS McCOY†

Federal Communications Commission, Washington, D. C.

and

HARRY P. WARNER†

Segal, Smith, and Hennessey, Washington, D. C.

Summary—**An historical review of theater television's growth from 1930 to 1949 is presented. The authors outline the status of theater television equipment used for direct or "film storage" projection, including an analysis of the radio-frequency requirements, methods of program distribution, and capital costs of a nation-wide theater television system. Some aspects of theater television programming are also presented.**

I. Introduction

There are strong signs that the motion picture industry, in facing the problems created by the spectacular boom in home television and its impact on motion picture attendance, intends to "fight television with television." Primarily this means that large-screen theater television may soon be brought out of the laboratory and private-demonstration stage and revealed full-blown to the motion picture going public.[1] The creation of what amounts to a new medium of mass entertainment and communication involves numerous technical, economic, and legal problems, and calls for broad vision, clarity of thinking, and inspired leadership. The purpose of this article is to discuss the principal problems in the light of present knowledge in an endeavor to contribute to a wider understanding by the motion picture and television industry of the nature and scope of these problems.

Theater television involves the exhibition of visual and aural television programs on large screens (about 15 by 20 feet), in motion

* Reprinted from Vol. IV, No. 2, of *The Hollywood Quarterly* with its kind permission.

† Note: The opinions and conclusions stated are the personal views of the authors. John Evans McCoy is Chief, Television Branch, Law Bureau, Federal Communications Commission; Harry P. Warner is author of "Radio and Television Law," contributor to law journals and other periodicals on communications law, and is associated with Segal, Smith, and Hennessey.

picture theaters. These programs are photographed outside the theater by regular television cameras; transmitted to the exhibiting theater by television techniques over microwave radio relays, coaxial cables, or telephone wires; and received in the exhibiting theater by television receiving equipment. In the United States, two systems of theater television equipment have been developed for installation in the exhibiting theater for the purpose of projecting the television program as received in the theater to the screen: the *direct-projection system* and the *intermediate-film system.*

At the outset, theater television must be distinguished from television broadcasting or "home television." A television broadcast station, as contemplated by the Communications Act and as defined by the rules of the Federal Communications Commission, means, "a broadcast station utilizing both television and telephony to provide combination and simultaneous visual and aural programs *intended to be received directly by the general public.*" In other words, television broadcast stations licensed by the FCC are intended to transmit television programs to the public generally, primarily for reception in the home. Theater television does not come within this definition because its programs are beamed directly by means of closed-circuit coaxial cables or wires or by directional microwave relays to the exhibiting theater, and they are not intended to be received by the general public.

II. Theater Television History

Large-screen projection television is nearly as old as the direct-view television that predominates in home television reception. In the year 1930, only two years after the Federal Radio Commission authorized the first experimental television broadcast stations, television on a 6- by 8-foot screen was shown by the Radio Corporation of America at RKO-Proctor's 58th Street Theater in New York City. Large-screen theater television on 15- by 18-foot screens was exhibited in London, England, in 1939, and by the end of that year five theaters were equipped for theater television. In 1941, a Madison Square Garden prize fight and a Brooklyn Dodgers baseball game were demonstrated to the public on a 15- by 20-foot screen in the New Yorker Theater by RCA. The onset of the war interrupted the further development and the commercialization of theater television both in England and in the United States.

During the general frequency allocation hearings held before the

FCC in 1944 and 1945, Paul J. Larsen on behalf of the Society of Motion Picture Engineers appeared before the FCC and requested the allocation of frequencies to theater television.

At the termination of hostilities, Paramount Pictures, Inc., under the direction of Paul Raibourn, directed its research to the development of the intermediate-film method of theater television, which culminated on April 14, 1948, in the surprise public exhibition of a 15-minute televised newsreel at the Paramount Theater in New York. The television pictures were transmitted via a 7000-megacycle microwave relay from the Navy YMCA, Brooklyn, to the top of the *Daily News* Building on East 42 Street, thence to the Paramount Building at Broadway and 43 Street, and from there down a coaxial cable to the receiving and film-making equipment. The pictures were filmed on regular 35-mm film and, because of the new rapid film-developing process, reached the 18- by 24-foot screen 66 seconds after the scenes were shot. On June 25, 1948, the same process was employed in a showing of the Louis-Walcott prize fight on the screen of the Paramount Theater, and since that date similar exhibitions have been held in the Paramount Theater on an almost weekly basis.

Meanwhile, RCA Laboratories, Inc., collaborating with 20th Century-Fox Film Corporation and Warner Brothers Pictures, Inc., proceeded with the development of the direct-projection system of theater television. In July, 1947, Earl I. Sponable, technical director of 20th Century-Fox, and Colonel Nathan Levinson of Warner Brothers, signed research and development agreements with RCA for joint participation in the development of this system. The three organizations sponsored a private showing of theater-size television (15- by 20-foot), at Warner's Burbank Studio in May, 1948, during the National Association of Broadcasters' Convention, and on June 25, 1948, history was made by the public showing in the Fox-Philadelphia Theater of instantaneous television pictures of the Louis-Walcott prize fight using an intercity relay from New York to Philadelphia. The program was picked up at the Yankee Stadium New York, and relayed by microwave relays successively to WNBT, Empire State Building, New York City, WPTZ, Wyndmoor, Pennsylvania, and the Fox-Philadelphia Theater, a total distance of about 100 miles. From the roof of the theater the program was run to the receiving and projecting equipment by coaxial cable. The reactions of the audience in the 2400-seat theater were described as highly enthusiastic. Recently, on April 4, 1949, the RCA-Fox-Warner system was demonstrated at the Convention of the Society of Motion Picture Engineers at the Statler Hotel, New York, the programs being relayed in part via balanced telephone wires, furnished by the telephone company, from the Empire State Building to the hotel. The RCA-Fox-Warner group has also developed intermediate-film equipment.

III. Theater Equipment Required

The equipment required for theater television falls into two general categories, the equipment installed *in the theater* for receiving the program and projecting it to the screen, and the equipment used *outside the theater* for pickup of programs and relay to the theater.

The first problem undertaken by the engineers in developing theater television was the development of equipment for installation in the theater. This equipment has now reached the point where two systems of equipment are reported to be substantially ready for commercial use: the *direct-* (*or instantaneous-projection*) *system,* and the *intermediate-film* (*or film-storage*) *system.*[2]

The direct-projection system, developed in the United States by the RCA-Fox-Warner group, consists of (1) the receiver-projector, which includes a projection cathode-ray tube as the source of the light image, and the optical system which projects the image to the screen by a reflective process; (2) a viewing screen; (3) a television control console; and (4) a power-supply rack and high-voltage power unit.[3] If the television program is brought to the theater by a microwave relay system, the theater installation will also include a receiving antenna, receiver, and a transmission line to carry the program from the antenna to the receiver.

RCA's new projector, demonstrated to the SMPE Convention on April 4, 1949, utilizes a 12-inch cathode-ray picture tube inclosed in a barrel about the size and appearance of a Bendix home washing machine. The optical system enclosed in the same barrel employs a 21-inch spherical mirror and a correcting lens, employing the Schmidt-type optical system. As installed, the picture tube faces the rear of the theater and projects the picture on the spherical mirror which reflects it toward the screen. The picture passes through the correcting lens on its way to the screen. The picture tube operates with 80,000 volts as compared to the 9000 volts used in most home television receivers. The optical system is capable of projecting a screen image 18 by 24 feet, which is larger than the average motion picture screen. The entire projector unit weighs about 180 pounds and is designed for installation either suspended from the balcony or mounted on a platform in front of the theater mezzanine rather than in the regular projection booth. The "throw distance" can be varied from 45 to 80 feet. RCA plans to manufacture pilot models before the end of 1949 for sale to theaters at a price under $25,000. The first such unit has been ordered for installation in the Fabian Fox Theater in Brooklyn, New York. The installation of microwave receiving equipment and a transmission line would cost approximately $3500 at present prices.

The viewing screen is an important element of the direct-projection system. The cathode-ray tube, which is the light source for projection television at this stage of development cannot compete with the carbon arc which is the light source in conventional motion picture projectors. Thus, while standard motion picture screens are generally not directional in distributing the light, much research has been devoted to the development of directional screens for theater television.

The Paramount intermediate-film system consists of (1) television receiving equipment, (2) a specially developed recording camera, (3) rapid film-processing equipment, capable of developing film in less than a minute, and (4) a conventional 35-mm motion picture projector. If the program is received over microwave relay, receiving equipment and a transmission line must be installed.

The television receiving equipment is contained in one unit, which houses both video and audio equipment, and high- and low-voltage power supplies.

The receiver utilizes a 10-inch cathode-ray tube, aluminum-backed, and with a flat-face screen, from which the picture is photographed. A 15-inch cathode-ray tube is provided for monitoring purposes. The special recording camera utilizes an electronic shutter, rather than a mechanical one, and is synchronized at the standard film rate of 24 frames per second. Twenty frames before exposure of the picture the sound track is impressed on the film. One of the amazing features of this system is the high-speed film-processing unit, into which the film passes by chute directly from the recording camera. The film is lead by vertical chutes into solutions which develop, fix, and wash it, and into a compartment which dries it in a maximum period of 66 seconds. The processed film either may be wound on reels or fed directly to the conventional 35-mm film projector by chute. The equipment requires a room of about 10 by 20 feet floor space, which is usually located directly above the projection booth. It has been reliably, and probably conservatively, stated that the cost of the receiver, camera, and processing unit will be approximately $35,000 plus installation. Units of this type have been installed in Paramount theaters in New York, Chicago, and Los Angeles. It is likely that the price of the three units may be in the $15,000 to $20,000 range, plus installation, when available in commercial quantities. The microwave receiving equipment and transmission line would add an additional $3500.

Theater television equipment has not yet attained the perfection of class A motion pictures, although engineering opinion supports the conclusion that such perfection is attainable. However, 20th Century-Fox recently advised the FCC that in its opinion "the generation of a theater television picture of suitable quality is not only possible but practical."[4] The final arbiter of picture quality is the audience, and theater television has been received favorably by the public. There is some danger that in waiting for technical perfection, the motion picture industry may lose the opportunity to secure the radio frequencies and other transmission facilities that would make theater television possible.

IV. Distribution of Theater Television Programs

The most critical and urgent problems facing the proponents of theater television involve determination of methods and means for transmitting television programs to the exhibiting theaters. Theater television essentially is a system of distribution of programs by television. It is well known that television programs may be transmitted by radio relays, by coaxial cable, and by telephone wires for short distances. The opportunity to use these avenues of program distribution cannot be had merely for the asking. The use of radio relays requires approval by the Federal Communications Commission. The use of coaxial cable and telephone wires requires the co-operation of the American Telephone and Telegraph Company and the Bell System. Wherever theater television applies for transmission facilities it must prove a demand for the facilities and it must overcome strong competition for the same facilities by broadcast television networks and stations, and by other users of the same facilities.

Theater television may be carried out as an independent enterprise by one theater which provides or obtains all of its own transmission facilities, or it may be carried out as a common enterprise by several theaters in a city sharing certain facilities and co-operating together. Such a co-operative theater television group is described hereafter. Since the capital and operating expenses of any television enterprise are substantial, it is assumed that some or all the theaters in a city will form a co-operative group, and that this organization will be predominant in the theater television industry. The present discussion, therefore, is limited to a description of theater television in cities where it will be promoted and carried on by one or more co-operative groups.

Theater television envisioning co-operative action by several theaters in a single city needs television transmission facilities for five purposes:

1. For distribution of programs from a central distributing point to groups of theaters. Such facilities may be described as "Multiple-Addressee Systems."
2. For transmission of programs from studios and regular origination points to the central distributing point. In broadcasting terminology, such fixed circuits are termed "Studio-Transmitter Links."
3. For mobile remote pickup of programs and transmission to the central distributing point. In broadcasting terminology, these mobile units are known as "remote pickups," and are used for the origination of programs such as sports events, parades, news events, and stage shows.
4. For transmission of programs to intercity relay points. These fixed circuits also may be classified as "Studio-Transmitter Links."
5. For intercity relay of programs.

The use of transmission facilities by co-operative theater television groups is most easily explained by reference to Fig. 1, which is a diagram of a typical theater television system in two imaginary cities, City A and City B. City A is assumed to be located on the A. T. and T. coaxial cable, and City B is assumed to be located off the coaxial cable about 35 miles east of City A. City A contains 25 motion picture theaters which are part of the co-operative theater television group and receive programs from it. City B contains 15 such theaters.

In each city the key point of the theater television system is the central distributing point where the multiple-addressee system is located (marked on the diagram, "MAS"). The co-operative group in City A maintains studio-transmitter links (STL) from one studio or theater which produces a daily stage show, and from the Municipal Auditorium. It also utilizes two mobile remote pickup units, which are available for use in appropriate scenes of action throughout the area. It maintains a microwave relay transmitter (M/W Relay), which is used to transmit programs to City B on a one-way circuit. In City A a studio-transmitter link (STL) connects the main distributing point with the intercity relay.

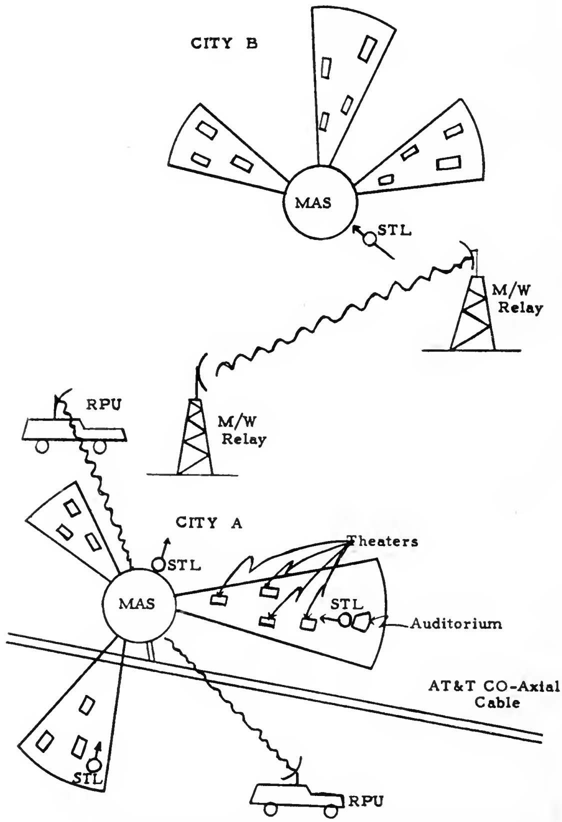

Fig. 1—Typical two-city theater television relay system.

The co-operative group in City B, running a "barebones" operation and depending on City A and the theater network for substantially all programs requires fewer transmission facilities. It must maintain a multiple-addressee system (MAS) at the central distributing point, a microwave relay receiver (M/W Relay), and a studio-transmitter link (STL) to connect the two points. It requires no other transmission facilities.

V. CAPITAL COSTS

What investment will be required to install the theater television systems described, in the two cities? The price of the theater installations required in each theater has been estimated above to be approximately $25,000 per theater, regardless of whether the direct-projection or the intermediate-film system is used. The following discussion endeavors to fix estimated costs of the equipment required by the co-operative group of City A.

1. *Multiple-Addressee System*—The basic elements of this system are a television transmitter, associated control and power equipment, film-recording and film-camera equipment, and a multibeam, highly directional, antenna array. If live programs are to be produced locally, studio video camera equipment and studios with proper lighting must be provided. Programs would be beamed in the necessary directions to permit reception by each of the theaters equipped to receive the transmissions. Three such directional beams are pictured in Fig. 1 at City A. In the frequencies involved, a low-power video transmitter would provide satisfactory signals to cover the area in which the associated theaters were located. While no such multiple-addressee television system is in operation in this country, the engineering principles underlying it are not new, and there is no doubt that it could be designed and manufactured within a reasonably short period after order. With the exception of the directive antenna, the other equipment would be adapted readily from television broadcast equipment now in use. The directive antenna presents no exceptionally difficult problems, although it would have to be engineered on a custom basis to fit the problems of the particular city involved, with the location of theaters in view. The capital cost of such a system, without studio-camera equipment and studios, is estimated at approximately $175,000. This includes $25,000 for the acquisition of instantaneous film-recording equipment, and $50,000 as the cost of the directive-antenna array. With studio-camera equipment and studios, about $100,000 would be added to the cost. These estimates do not include expenditures for acquisition or remodeling of buildings or land.

2. *Studio-Transmitter Links*—The necessary facilities to connect studios or program origination points with the central distributing point would be substantially the same as the equipment used by television broadcast stations to link studio and transmitter. These connections may be made by microwave relay, coaxial cable, or by

balanced telephone wires over distances from one or two miles. If studio-transmitter radio links are deemed desirable, their cost would be approximately $15,000 per installation. If coaxial cable or television wires are used, the telephone company will provide the service at regular rates, and capital costs to the theater television system will be nominal.

3. *Remote Pickups*—The two remote pickup units contemplated for City A would cost approximately $50,000 per unit. This includes two portable camera units, audio equipment, a small truck, and the video-link equipment. The audio link is a telephone circuit. The video relay may be used over distances of from 10 to 15 miles, but only over line-of-sight in the high frequencies used. This equipment may be owned and operated, or may be leased from the telephone company, or, perhaps, from local television broadcast stations.

4. *Intercity Relays*—The one-way intercity relay circuit from City A to City B, contemplated in Fig. 1, is estimated to cost from $25,000 to $50,000. This figure includes both the transmitting and receiving units. As described above, the relay transmitter in City A and the relay receiver in City B would be connected with the central distributing point in each city by studio-transmitter links, costing approximately $15,000 each. However, given an appropriate location of the relay units, coaxial-cable connections might be provided by the telephone company.

On the above basis, a rough estimate of the capital investment required by the co-operative theater group in City A would total approximately $445,000, consisting of (1) multiple-addressee system and associated equipment including studio equipment, $275,000, (2) three studio-transmitter links, $45,000, (3) two remote pickup units, $100,000, and (4) 50 per cent of the cost of the intercity relay installation, $25,000.

The capital investment required in City B would be substantially less. The cost of the multiple-addressee system, eliminating $100,000 as the cost of items of studio equipment and studios that full-scale program production would require, would come to $175,000 or less. If an intermediate-film recording unit were not used in City B, this cost would be reduced by another $25,000. The studio-transmitter link and intercity relay receiver installations would add approximately $40,000. Thus, the total investment at City B would approximate from $190,000 to $215,000.

VI. TRANSMISSION FACILITIES FOR THEATER TELEVISION

Availability of Relay Facilities—Theater television programs may be relayed by microwave radio relays, coaxial cables, or balanced telephone wires. The telephone company in certain areas is already equipped to furnish all three types of transmission facilities, and is furnishing these services on a rental basis to certain television broadcast stations and networks. The services furnished by the telephone company include intercity transmission of programs by coaxial cable or by microwave relay; studio-transmitter links and remote pickups by cable, relay, or wire. Other organizations also are equipped to furnish intercity microwave relay service in certain areas. The principal problems concerning the three methods of relay will be described briefly.

A. T. and T.'s Coaxial Cable—By May, 1949, the A. T. and T. coaxial cable provided the primary means of transmission of television programs from New York to Richmond on the east coast (through the cities of Philadelphia, Baltimore, and Washington); from Philadelphia to Chicago (through the cities of Pittsburgh, Cleveland, and Toledo); from Cleveland to Buffalo; and from Chicago to St. Louis. By the same month, A. T. and T. also had in operation microwave radio relays for transmission of television programs from New York to Boston; Toledo to Detroit; and Chicago to Milwaukee. Before the end of 1949, A. T. and T. plans to complete network links (either coaxial cable or radio relay) from Boston to Providence; New York to Syracuse (through Schenectady and Utica); Buffalo to Rochester; Milwaukee to Madison; Philadelphia to Wilmington; and from Toledo south to Dayton, Cincinnati, and Columbus. Likewise, in 1949 a radio relay between San Francisco and Los Angeles is planned.

At the present time, the Bell System does not contemplate extension of its television relay facilities across the continent in the near future. The means for a transcontinental television network, however, now exist since the coaxial cable, equipped for long-distance telephone service, has been completed between St. Louis and Los Angeles. Telephone company officials have recently stated that a television channel from New York to Los Angeles could be made ready in about a year after the service is ordered.

The Bell System coaxial cable, first authorized by the FCC in 1936 on an experimental basis,[5] is primarily used to multiplex telephone transmission. As many as 480 telephone conversations can be transmitted simultaneously on a single channel of each 8-channel cable without mutual interference. The relay and terminal equipment installed was originally designed for this purpose. However, it was recognized from the first that the bandwidth of each cable channel was sufficient to permit television transmission. New terminal equipment must be installed to convert the cable for television transmissions. The present equipment now used on the coaxial cable for television transmission will permit transmission of a television band of 2.7 megacycles. This is not sufficient to carry the full requirements of the present 525-line, 4.5-megacycle standard television broadcasts, but recent developmental work will make possible wider-band television transmission (up to 8 megacycles) when the demand arises. While current theater television has adopted the 525-line standard used by television broadcast stations, full utilization of the possibilities of theater television may require the use of higher definition and wider-band transmissions, which would raise a problem as to the suitability of the coaxial cable for intercity transmission of the theater television programs. If color television is desired by the theater television interests, bandwidths of from 8 to 16 megacycles probably would be desirable if not essential. At the present time, no extensive intracity coaxial-cable system is available, but some coaxial-cable links are in operation in New York and other cities.

The current coaxial-cable television rates filed by the A. T. and T. and associated Bell System telephone companies and effective May 1, 1948, contemplate charges which raise a serious economic question both for television broadcast stations and theater television. A single television channel between two cities costs the user $35.00 a month per airline mile for eight consecutive hours each day, and $2.00 a month per mile for each additional consecutive hour. Thus, for 240 hours of service in one month, the rate would be $35.00 per airline mile. For occasional or part-time service, the rate is $1.00 per airline mile for the first hour and 25 cents per mile for each additional consecutive 15 minutes. Additional charges are made for the use of terminal equipment; $500 per month is charged for a connection to the television network for eight consecutive hours daily. This interconnection charge for occasional service is $200 per month, plus $10.00 per hour of use. To complete the service, a Bell System sound channel must be used, at the regular rates applicable to the frequency-modulated service. If two users share time on the same channel, $25.00 a month per airline mile is charged for four consecutive hours of daily service, with an interconnection charge of $350 for each user.

Table I tabulates these charges for the service between certain principal cities. These same charges apply to intercity relay of television programs over microwave relay facilities.

Returning to our typical theater television operation in Cities A and

TABLE I

A. T. AND T. INTERCITY COAXIAL-CABLE RATES (ESTIMATED)

	MONTHLY SERVICE					
Service Points	Video, Allocated (4 hrs.)	Audio	Total	Video, Nonallocated (8 hrs.)	Audio	Total
Boston–New York	$5,450	$1,290	$6,740	$7,650	$1,290	$8,940
New York–Philadelphia	2,775	648	3,423	3,905	648	4,553
Philadelphia–Baltimore	2,950	690	3,640	4,150	690	4,840
Baltimore–Washington	1,600	366	1,966	2,260	366	2,626
Washington–Richmond	3,150	738	3,888	4,430	738	5,168
Richmond–Charlotte	6,900	1,638	8,538	9,680	1,638	11,318
New York–Pittsburgh	8,500	2,022	10,522	11,920	2,022	13,942
Pittsburgh–Cleveland	3,550	834	4,384	4,990	834	5,824
Cleveland–Detroit	2,975	696	3,671	4,185	696	4,881
Detroit–Chicago	6,600	1,566	8,166	9,260	1,566	10,826
Chicago–Milwaukee	2,725	636	3,361	3,835	636	4,471
Chicago–St. Louis	7,450	1,770	9,220	10,450	1,770	12,220
St. Louis–Kansas City	6,575	1,560	8,135	9,225	1,560	10,785
New York–Los Angeles	61,650	14,778	76,428	86,330	14,778	101,108

	OCCASIONAL SERVICE					
	1st Hour in Month			Each Additional Hour in Month		
Service Points	Video	Audio	Total	Video	Audio	Total
Boston–New York	$610	$72.00	$682.00	$210	$32.00	$242.00
New York–Philadelphia	503	55.95	558.95	103	15.95	118.95
Philadelphia–Baltimore	510	57.00	567.00	110	17.00	127.00
Baltimore–Washington	456	48.90	504.90	56	8.90	64.90
Washington-Richmond	518	58.20	576.20	118	18.20	136.20
Richmond–Charlotte	668	80.70	748.70	268	40.70	308.70
New York–Pittsburgh	732	90.30	822.30	332	50.30	382.30
Pittsburgh–Cleveland	534	60.60	594.60	134	20.60	154.60
Cleveland–Detroit	511	57.15	568.15	111	17.15	128.15
Detroit–Chicago	656	78.90	734.90	256	38.90	294.90
Chicago–Milwaukee	501	55.65	556.65	101	15.65	116.65
Chicago–St. Louis	690	84.00	774.00	290	44.00	334.00
St. Louis–Kansas City	655	78.75	733.75	255	38.75	293.75
New York–Los Angeles	2858	409.20	3267.20	2458	369.20	2827.20

B, and assuming that City A on the coaxial cable is located 89 miles from the nearest network city, and that City B is located 35 miles from City A, the monthly charges for use of Bell System facilities for receiving television programs would include:[6] City A would pay a monthly charge of $4840 for use of 240 hours per month on an 8-hour per day basis, or $3640 for 120 hours per month on a 4-hour per day basis, if the channel were shared with another theater television group or a television broadcast station in City A. Likewise, if the theater television group in City B utilized a Bell System microwave relay system to obtain programs from City A, it would pay a monthly charge of $2626 for use of 240 hours per month on an 8-hour per day basis or $1966 for the shared use of the channel on a 4-hour basis.

Concern over the economic problems raised by the A. T. and T. coaxial cable rates led the Television Broadcasters Association, Inc. (TBA), to file a petition with the FCC requesting suspension of the rates, and a hearing upon the reasonableness of the rates and legality and other provisions of the tariffs filed. On April 28, 1948, the FCC ordered the hearing, but refused to suspend the rates. A determination on the reasonableness of the rates has been postponed indefinitely.

Meanwhile, in the same proceeding (Docket 8963) the FCC has taken evidence and is considering one of the issues which also is of concern to theater television. This issue involves the validity of the provision in the A. T. and T. tariff that a customer may not connect *intercity* channels of the telephone company with *intercity* channels of others except where the telephone company cannot make facilities available upon reasonable notice.[7] If sustained by the FCC, this provision would effectively preclude the use of *intercity* radio-relay facilities built by the theater television groups, such as the radio relay contemplated in Fig. 1 between City A and City B. It would also limit the use that theater television might make of the radio-relay facilities offered on a common-carrier basis by Western Union.

The substantial capital costs required for construction of intercity coaxial-cable installations, together with other difficulties, appear to make it improbable that theater television will turn to the construction of its own intercity coaxial cable to provide a national theater television service. According to A. T. and T.'s own figures, submitted to the FCC, by the end of 1948, about 4600 miles of intercity television channels had been put into operation at a cost of approximately $20,000,000. These figures include the A. T. and T. intercity radio-relay circuits described hereafter.

Intercity Radio-Relay Services—The second method available today for intercity relay of television programs is afforded by microwave radio relays. Radio relays constructed by A. T. and T. extend the coaxial-cable system from New York to Boston, from Toledo to Detroit, and from Chicago to Milwaukee. A. T. and T. has a radio relay under construction between New York and Chicago, and has applied for FCC consent to construct other radio relays between San Francisco and Los Angeles. In addition, Western Union has a radio-relay system available for use between New York and Philadelphia, and contemplates an extension of its system to the Midwest and South. These radio relays are operated on a "common-carrier" basis and are open to use by television broadcasters under tariff schedules filed with the FCC. The A. T. and T. rates are the same as those in effect for coaxial-cable intercity service. The Western Union rates are somewhat different. Other privately owned and operated radio relays are in operation in various localities.

The A. T. and T. intercity radio relays operate on the frequency band 3700 to 4200 megacycles, and the Western Union relays operate on 5925 to 6425 megacycles. Both these bands are allocated by the FCC to "Common-Carrier Fixed Circuits." The A. T. and T. relays can provide a bandwidth of 4 megacycles, while the Western Union New York to Philadelphia relay is equipped to provide a 5-megacycle bandwidth. Intercity television relays are based on line-of-sight transmissions from station to station, with intermediate stations separated by about 30 miles between cities. The problems involved in theater television use of intercity relays are substantially the same as the problems stated above as to use of the coaxial cable.

Bell System Telephone Wires—The third available system for transmission of television programs is the use of so-called "balanced" telephone wires. A network of such telephone wires extends under the streets of our cities, and across the continent operated by the Bell System telephone companies. Over moderate distances of from one to two miles, these telephone wires may be adapted to the purpose of television transmission. They thus are useful for intracity transmission, including remote pickup, STL, and possibly as the basis for a multiple-addressee system. The telephone wires may also prove to be the most economical method for distribution of theater television sound.

VII. Radio Frequencies for Theater Television

As we have seen, radio frequencies may be expected to constitute an integral part of a theater television system under present conditions. Remote pickups of sports and news events are dependent upon microwave frequencies, since only by use of radio relay can theater television pickup units get the necessary mobility and flexibility. Multiple-addressee systems for simultaneous distribution of programs to numerous theaters could use coaxial cables or even paired telephone wires, but there is no assurance that the telephone company will be in a position to furnish these services, or that the rates for the service would be within reach of potential theater television systems. It is also possible that theater television will consider the establishment of an intercity relay system using radio.

Under the Communications Act, the use of radio frequencies by theater television or by any other nongovernmental service must be preceded first by the *allocation* by the FCC of a frequency band or bands for the use of theater television; second, by the *promulgation* by the FCC of rules and regulations governing the assignment and use of the allocated frequencies by individuals or organizations within the service; and third, by the *assignment* by the FCC of the frequencies within the general band allocated to theater television to licensees upon proper application.

Theater television has never jumped the first hurdle. It has never obtained an allocation of frequencies by the FCC for other than experimental use. At the present time, no frequencies are even available under the FCC allocation table and rules for experimentation by theater television for the purpose of developing this new service, except the 475- to 890-megacycle band (ultra-high-frequency) which is earmarked for television broadcasting, and the frequency bands 16,000 to 18,000 megacycles and 26,000 to 30,000 megacycles, for which no equipment is available for the purpose of theater television relays. The five theater television authorizations now in existence (four of which are held by Paramount Pictures, Inc., and one by 20th Century-Fox) are solely experimental special temporary authorizations (STA's), issued for 90-day periods, and terminable by the FCC without advance notice. These authorizations are for frequencies allocated either to the use of television broadcast stations, not to theater television, a distinct and separate service, or to various nonbroadcast services. Theater television cannot expect to use these frequencies for a regular theater television service.

The motion picture industry since 1944 has made sporadic efforts to obtain the allocation of relay frequencies to theater television by the FCC. The first such bid, spearheaded by Paul J. Larsen on behalf of the Society of Motion Picture Engineers, was made in the general allocation hearings held in the fall of 1944 and the spring of 1945 when the end of the war was in sight.

The general allocation hearing (FCC Docket 6651) covering the "Allocation of Frequencies in the Radio Spectrum from 10 Kilocycles to 30,000,000 Kilocycles" was an open invitation to all who desired to obtain new frequencies or the recognition of new radio services to come before the FCC and present their cases. The hearing was the greatest in scope ever held by the FCC or its predecessor, the Federal Radio Commission. Two hundred and twenty-three witnesses, plus FCC staff members, appeared and testified. Claims for frequencies were presented by some 30 services, including many new radio services. One witness, Mr. Larsen, appeared for theater television. It is interesting to note that 26 witnesses appeared for television broadcasting, 22 for forestry and conservation radio, 17 for police radio, and 12 for commercial frequency-modulated broadcasting.

Mr. Larsen, on behalf of the SMPE, requested for theater television an allocation of 1500 megacycles in 20-megacycle-wide channels in the radio spectrum between 300 and 6300 megacycles for the "immediately necessary postwar Theater Television service." This recommendation was keyed to the situation in New York City where Mr. Larsen stated 25 independent producing and exhibiting agencies might compete in the theater television service. For the initial period, however, he assumed that 15 of these agencies should be provided with frequencies, including for each of the 15 agencies one remote pickup channel, one studio-transmitter channel, one multiple-addressee channel, and one intercity relay channel. Mr. Larsen took the position that coaxial cable and wire facilities were not sufficient for the multiple-addressee system since channels 20 to 60 megacycles wide would be required and only 4 megacycles were available on the coaxial cable. Mr. Larsen presented the argument that, in view of the relative size and importance of the motion picture industry ($1,600,000,000 gross income compared to $280,000,000 gross income for the broadcast industry) theater television should be treated on a "parity of opportunity" with radio broadcasting. By this phrase he meant "an equality of opportunity to develop both arts" giving each "equal opportunity to experiment, to commercialize, to improve, and to expand to its proper and demonstrable limits."

In its final report of May 25, 1945, in the general allocation hearing, the FCC allocated certain frequency bands to theater television on a shared basis with other services for experimental use only. It made no exclusive allocation to theater television. The bands on which experimental theater television were permitted included the 480- to 920-megacycle band (on which experimentation with multiple-addressee systems was permitted), subject to the understanding "that the band 480 to 920 megacycles will be used primarily for television broadcasting to the public, with higher frequencies being more properly utilized by theater television and relay operation." In addition, the following bands, allocated to the Fixed and Mobile service were made "available for theater television experimental use, including multiple-addressee purposes if the need for such use can be established": 1325 to 1375; 1750 to 2100; 2450 to 2700; 3900 to 4400; 5650 to 7050; 10,500 to 13,000; 16,000 to 18,000; and 26,000 to 30,000 megacycles. The FCC's final report thus opened the door for theater television experimentation in a large portion of the radio spectrum. As a practical matter, however, even in 1949 equipment is available for radio relay only on the frequencies up to the 7000-megacycle band, and equipment is actively being developed in the 10,000- to 13,000-megacycle band. Development of equipment for use in the 16,000- and 26,000-megacycle bands must await the future.

The 1945 allocations in the spectrum between 1000 and 13,000 megacycles did not remain "final" for long. In November, 1945, the 4000- to 4200-megacycle band was allocated to Air Navigation Aids. In July, 1946, the FCC proposed an extensive reallocation of frequencies in the 1000- to 13,000-megacycle band. A hearing was held on this proposal, as amended October 22, 1946, and Mr. Larsen again testified on behalf of theater television and the SMPE on February 4, 1947. He took the position that theater television should be classified by the FCC as a "common-carrier" service, entitled to use the frequencies allocated to "Common-Carrier Fixed Circuits." If this classification was not made by the FCC, Mr. Larsen objected to the proposal of the FCC that television pickup and STL stations "will be licensed only to licensees of television broadcast stations and to common carriers." Finally, Mr. Larsen objected to the failure of the FCC to include in its proposal frequencies for intercity television relay, which the FCC stated could not be accommodated in the 1000- to 13,000-megacycle band since there was not sufficient spectrum space available. In addition, Mr. Larsen urged the FCC to classify theater television as a separate nonbroadcast service.

On the important question of whether theater television could use coaxial cable or wire lines for intercity or intracity transmission of programs, Mr. Larsen stated that at the present time theater television would not be able to use coaxial-cable or wire facilities of the A. T. and T. because the 2.7-megacycle band provided by A. T. and T. was insufficient for theater television. He estimated that approximately 6- or 7-megacycle-wide bands would be required. He conceded that eventually it would be more economical *in a city* to distribute programs by wire line, rather than by radio, and that eventually the common carriers would have wider-band coaxial cable and wire facilities. But he felt that for an indefinite period theater television would have to use radio for program distribution.[8]

The upshot of the 1947 allocation hearing was to make no allocation in the 1000- to 13,000-megacycle band for theater television, even on an experimental basis, and to indicate that the experimental authorizations in this band for operation on frequencies not allocated to the service involved might be "renewed on a strictly temporary basis for a period not to exceed one year from February 20, 1948." These conclusions were contained in the FCC's report of February 20, 1948 (Docket 6651), in which the Commission stated that, "*The requirements for theater television are still not sufficiently clear to indicate the need for a specific allocation for its exclusive use at this time. The Commission is of the opinion, from information now available to it, that a large part, if not all, of the functions required by theater television should be handled by stations authorized to operate on frequencies allocated to the use of communications common carriers.*"[9]

The FCC ruling, however, has not completely terminated theater television experimental use of radio frequencies. Since November 18, 1947, Paramount Pictures, Inc., has held special temporary authorizations for theater television relay in the New York area (in the 2000- and 7000-megacycle bands), and it was granted two additional temporary authorizations on May 4, 1948, for use of the 7000-megacycle band in the New York area. Likewise, in September, 1948, 20th Century-Fox Film Corporation was granted an experimental STA for theater television relay in New York in the 7000- and 12,000-megacycle bands.

It is apparent from the above discussion that theater television is at the crossroads. It must determine its own future by deciding four main questions: (1) Will theater television rely on radio, coaxial cable, or wire for intercity and intracity distribution of programs? (2) If radio frequencies are to be used by theater television, does it desire the FCC to allocate frequencies for the use of theater television or does theater television expect to use the frequencies allocated to "Common-Carrier Fixed Circuits," relying on the existing common carriers to provide service to theater television? (3) If radio frequencies are needed, and theater television is not content to rely on the services of established common carriers, what steps should it take to obtain the use of such frequencies? (4) If theater television is to use common-carrier radio coaxial cable and wire lines, what steps should it take to obtain the use of such facilities?

If theater television groups decide to apply to the FCC for allocation of radio frequencies to theater television, or for authorization as a television common carrier, they must sustain the burden of convincing the FCC that a grant of their requests will serve the public interest, convenience, or necessity. In meeting this burden, theater television must establish to the satisfaction of the FCC:

1. That the service requires the use of radio frequencies, and that coaxial cable and wire lines will not provide a practical substitute.

2. That the frequencies requested are not more urgently needed by other radio services, particularly those services necessary for safety of life and property.

3. That there is a substantial public need for the service, and a strong likelihood that the service will be established on a practical working basis.

In prior appearances before the FCC, theater television has not met the burden of proof in these matters. It seems clear that another attempt to secure FCC authorization of the service and allocation of frequencies should be preceded by active steps by the motion picture industry to obtain quantitative data on the public acceptance of theater television, and to obtain definite commitments from qualified theater television groups in as many areas as possible to the effect that they have positive plans to institute the service at an early date. Data obtained by actual experimentation with a multiple-addressee theater television system would be advisable. A clear indication of how theater television could serve the public interest is essential. In the latter connection, it is suggested that a multiple-addressee system, serving not only privately owned theaters, but rendering service on a public-service basis to local, religious, educational, and governmental groups in the area, could present a strong showing of service to the public. Television broadcast stations are not available in sufficient numbers to make possible their ownership by any substantial number of religious, educational, or civic groups. Theater television potentially is one means whereby such public service organizations may participate directly in the wonders of television.

On June 30, 1949, the FCC addressed letters to Paramount Television Productions, Inc., Twentieth Century-Fox Film Corporation, and the Society of Motion Picture Engineers, inviting statements to be submitted by September 2, 1949, concerning theater television. Without limiting the scope of the statements, the Commission requested expression of views covering six specific subjects:

1. What the minimum frequency requirements would be for a nation-wide, competitive theater television service;
2. What specific frequency bands you would propose to be allocated to a theater television service; reasons therefor;
3. The exact functions which would be performed in each such frequency band in a theater television service;
4. Whether and to what extent such functions could be performed, in whole or in part, by use of coaxial cable, wire, or other means of transmission not using radio frequencies;
5. Whether and to what extent existing common carriers have or propose to have facilities available capable of performing such functions, in whole or in part, by radio relay, coaxial cable, or wire;
6. Plans or proposals looking toward the establishment of a theater television service.

Organization of Co-operative Groups—To make theater television economically feasible it may be necessary for numbers of theaters in a city to join together in co-operative theater television groups. Since these groups in all likelihood will find it necessary to qualify as licensees of radio facilities, and possibly as common carriers of television programs, it is important that these co-operative groups be owned and organized to comply with the licensing requirements of the Communications Act and the FCC.[10]

An example of a co-operative organization that is operating in the common-carrier field with FCC sanction is Press Wireless, Inc. This corporation was organized in 1929, with its stock held primarily by newspaper and news associations. It has been licensed or authorized by the FCC to engage in various forms of communications, including program transmission, radiophoto, facsimile, and message telegraphy.

It conducts a public-press service on a multiple-addressee basis, transmitting news items and other material intended for publication by press agencies and newspapers. Similarly, a theater television group might be organized to provide a limited common-carrier service to theaters, educational, and public-service organizations.

VIII. Color Television

From the early beginnings of television, the idea of television in color has intrigued the imagination. As the motion picture industry has discovered, the mere fact that a production is offered in color rather than in black and white increases the public's interest and makes for far greater salability. In the television field, the first proponent of color was the Columbia Broadcasting System, Inc., which for many years operated both black-and-white and color stations in New York City. Shortly after the end of hostilities, CBS felt that its color-television system was ready to emerge from the laboratory and experimental stage, and on September 27, 1946, it petitioned the FCC to promulgate rules and engineering standards authorizing commercial television in color in the ultra-high-frequency band (480 to 920 megacycles).[11] The CBS proposal, based on developmental work by CBS's Peter Goldmark at a cost of some $2,000,000, looked toward the creation of 27 color television channels in the ultra-high-frequency band, each channel being 16 megacycles wide. This proposal would have appropriated substantially all of the ultra-high frequencies for color television.

After lengthy hearings on the CBS proposal, the FCC on March 18, 1947, denied the petition, primarily for the reason that "many of the fundamentals of a color-television system have not been adequately field-tested and that need exists for further experimentation." The FCC commended CBS and Dr. Goldmark for their great strides made in the field, and concluded: "It is hoped that all persons with a true interest in the future of color television will continue their experimentation in this field in the hope that a satisfactory system can be developed and demonstrated at the earliest possible date."[12]

The CBS proposal contemplated authorization of the so-called sequential system in which each picture is scanned through separate color filters—red, green, and blue, in turn. Under that proposal the transmissions in the separate colors followed each other at the rate of 48 per second. The three colors were accepted by the receiver by means of a color wheel containing filters of red, green, and blue, which rotates in front of the television screen in synchronization with a similar color wheel at the transmitter. The eye saw the picture in full color. At the same hearing, RCA gave evidence concerning a different system of color television but did not request the FCC to approve its system at that time. In the RCA system, known as the simultaneous system, each picture was scanned simultaneously in three colors—red, green, and blue—and these transmissions were sent simultaneously on three different channels and were combined at the receiver to produce a color image.

After the issuance of the March, 1947, report denying CBS's color proposal, CBS turned its attentions in the television field mainly to the building of its monochrome network. But both CBS and RCA continued color experiments. In October, 1948, CBS demonstrated to FCC staff members a sequential color system, using only 6 megacycles of bandwidth. The system could be operated either with a rotating color drum or with stationary color filters. At the same time CBS demonstrated that an ordinary commercial 10-inch table television receiver (monochrome) could be converted so as to receive the color transmissions either in black and white or in color.

Interest in color television flared brightly in May, 1949, when the FCC issued a public notice in which it stated that in reopening the pending television allocation proceedings it planned "to afford an opportunity *for the submission of proposals* looking toward utilization of all television channels (both very-high-frequency and the ultra-high-frequency) to 6 megacycles monochrome or color on an optional basis in such a way as to permit reception on the ordinary television receiver with relatively minor modifications." Following up this announcement, the FCC on July 11, 1949, issued its notice of further proposed rule-making in the allocation proceedings and stated definitely that it would give consideration to proposals for color television on both the very-high-frequency and the ultra-high-frequency television channels, provided that any such proposal must permit operation in a 6-megacycle channel and must be such that existing television receivers will be able to receive color transmissions "simply by making relatively minor modifications in such existing receivers." In a recent speech, one FCC Commissioner explained that the FCC would not authorize color (1) until color can be received satisfactorily on today's ordinary television receiver with only relatively minor modifications, and (2) until color-television pictures can be received in black and white on present-day receivers, with perhaps no, or only relatively minor, modifications.

While it is impossible to predict what evidence concerning color television will be presented to the FCC in the now scheduled hearings, and it is likewise impossible to foretell what action the FCC will take on color television, the motion picture industry obviously must consider color in connection with its planning concerning theater television.

Not only must theater television interests be aware that broadcast television in color will be a much stronger competitor than black-and-white television, but they must take into account that theater television in color may well be much more attractive to the public than either monochrome film or monochrome theater television. Theater television in color, therefore, deserves careful investigation by the theater television interests. Such an investigation may reveal that theater television in color holds sufficient promise of becoming a box-office attraction in its own right to justify the conclusion that the motion picture industry should enter the theater television field on a broad scale.

From the technical viewpoint, color would require further development of the theater television equipment mentioned in this article, but it is not unreasonable to expect that color could be adapted to theater television with at least no greater difficulty than it could be applied to broadcast television.

Theater television in color would also have its impact on the frequency-allocation problems now facing theater television. While it appears that broadcast color television, if sanctioned by the FCC, will be limited to a 6-megacycle bandwidth, the theater television interests will be forced to inquire whether they should limit their interests in color to a system of this bandwidth. The advantages of a wider bandwidth, including greater definition, greater frame rate, greater picture brightness, and less flicker, may well make it desirable for theater television to seek more than a 6-megacycle band for theater television relays. However, before a bandwidth wider than 6 megacycles is adopted for theater television it will be necessary to consider whether the existing common-carrier facilities for intercity relay of television programs could be adapted for such a wide-band video transmission.

Color television faces many obstacles before it can be expected to take its place beside monochrome television. But the place it holds in the imagination of the public makes it a factor to be considered carefully by the motion picture industry.

IX. PROGRAMMING

The foregoing discussion indicates that theater television is technically feasible and within the pocketbook range of the majority of exhibitors. Our next inquiry is what can be done with a co-operative system of theater television from a programming standpoint, will theater television be economically feasible and can it compete with television broadcasting, and what effect and impact will theater television have on motion pictures and television broadcasting. A word of caution is appropriate at this time. Theater television is just emerging from the laboratory stage; its experimental phase is just about to begin. We have no statistical data to buttress our conclusions. The latter are of necessity tentative and may warrant revision in the light of future developments.

Program material for theater television can be derived from:

1. Television broadcasting, or
2. Independent sources. The latter term has reference to programs secured by and through the co-operative group engaged in theater television.

If the co-operative group seeks program material from the television broadcast station or network, it is beset with certain legal problems.

Section 325(a) of the Communications Act of 1934 prohibits a station from rebroadcasting the programs of another broadcast station without the express authority of the originating station. This tenders the question of whether the pickup and transmission of a television program to a theater is a "rebroadcast" requiring the permission of the originating station. This point has not been adjudicated either by the FCC or the courts. It is believed that when Section 325(a) was enacted into law, it was the intention of Congress that the originating station or system should have the right "to control its program after it has been thrown onto the air." This suggests that the co-operative group of television theaters would be required to secure the permission of the television broadcast station or network.

In the event that Section 325(a) is construed by the FCC and the courts as not to require the consent of the originating station, the theater television group would be precluded by common law and statutory copyright from retelevising the programs transmitted by a television broadcast station. The court undoubtedly will hold that the production of any television program, i.e., news, sports, variety show, and so forth, involving as it does the expenditures of skills in the use of the television camera, effort, and monies, results in the establishment of a common-law copyright. This common-law copyright is the exclusive property of the station and network and the former may prohibit the co-operative group of television theaters from retelecasting such programs. Common-law copyright is illustrated by the litigation arising out of the Louis-Walcott fight. A Pennsylvania court enjoined a motion picture exhibitor from picking up and retelecasting the Louis-Walcott fight in his theater, because of the common-law copyright in the telecast which was the property of the sponsor, network, and station.

A television station or network can protect its programs by copyrighting the same. The copyright of a dramatic program prohibits the reproduction of the same unless a license is obtained from the copyright proprietor. The unauthorized exhibition of a copyrighted program would subject each exhibitor to minimum statutory damages of $250 for each unauthorized telecast.

Thus, the co-operative group of television theaters would be precluded from using the program material of a television broadcast station or network, unless the latter consented. A television network might find it economically feasible to make its commercial or sustaining program service available in theaters for a stipulated fee. On the other hand and as will be subsequently developed, theater television may be a competitive threat to television broadcasting and the television network may refuse to make its program service available to theaters. This means that the latter must obtain its own programs. This raises the next question: what independent programs are available to the theater television group?

An excellent source of programming would be local or national news. Since a news event, i.e., a political address, parade, or fire, is a public event, any organization may transmit its own version of the event to the public via television broadcasting or to theaters by theater television. All that is required to carry a news program is a mobile unit to transmit the program to the central distribution point, for redistribution to the theaters. If co-operative theater groups are interconnected on a national scale, outstanding national events such as a presidential inauguration could be made available to all theaters.

A second source of programming is sports events. Thus, boxing bouts and baseball and football games could be brought into the theater. The use of sports events in theater television tenders certain economic and legal issues which warrant discussion.

Not only are the television broadcast rights to an athletic contest available for sale to a sponsor, but the promoter likewise may sell the theater television rights to a co-operative group. The question tendered is whether it is economically feasible for the television broadcast sponsor and the theater television group to carry the same program. If a boxing bout can be viewed on home television receivers, there would be no need to attend a motion picture house which would carry the same program. On the other hand, the motion picture exhibitor could integrate the boxing bout into his scheduled evening show and thus offer an added attraction to his patrons. Whether the television broadcast of an athletic event would curtail the box-office returns of the theater television group, carrying the same sports program, cannot be answered at this time. We have neither the data nor experience to buttress our conclusions.

But suppose 10,000 exhibitors were to band together and purchase on an exclusive basis the television rights to the World Series. The cost of such exclusive rights could be defrayed by an admission charge to view the World Series. In this connection, there are in excess of 19,000 theaters in the United States; their total seating capacity is close to 12,000,000 seats; their monthly revenues are in excess of $100,000,000; their yearly revenues produce a minimum revenue of $1,500,000,000. Compare these figures with an approximate $500,000,000 yearly gross broadcast revenues. It is apparent that the theater television group could outbid the television broadcast industry for the right to exhibit the World Series. Whether there will be competitive bidding between theater and broadcast television cannot be determined at this time. Theater television does not exist on a local, let alone national, level. We do know that television broadcasting, particularly in the East, is one of the factors which has caused a diminution in the box-office returns of motion picture houses. It may well be that theater and broadcast television are noncompetitive. But certainly the theaters must do something to offset their diminishing box-office returns. Theater television may be the answer.

A third source of programming for theater television is "live" acts. This term has reference to variety or vaudeville shows, concerts, and plays. Theater television would enable all members of a co-operative group or theater chain in a city to furnish their patrons with vaudeville. Thus, a variety show could be presented in a local neighborhood theater as well as in a "downtown showcase." Since programs for theater television can be distributed via film, the latter gives flexibility to the program schedule of a motion picture house engaged in theater television.

The financial resources of the theater television group on a national scale, suggest that it could sponsor a repertory company which would produce different plays each week. An exhibitor could charge an increased admission fee for exhibiting such a play. The recording of such plays on film would enable the theaters to exhibit the play or plays at a time or times convenient to its patrons.

Theater television is available to enlarge the concert audience. Thus, a concert by a distinguished pianist could be made available in motion picture houses. Undoubtedly, financial arrangements could be effected among the promoter, the concert star, and the exhibitor.

Theater television likewise may be employed as a new means for the distribution of film. Thus, a feature-length attraction could be distributed on a national, regional, or local basis to exhibitors. The electronic method of distributing motion picture film could furnish the producer with an efficient method of "trade-showing" film; it could reduce the number of positive prints, and thus costs. Theater television may conceivably result in far-reaching changes in the trade practices of the motion picture industry and effect substantial economies in the distribution of film.

Theater television is not limited to entertainment; it can render a public service to the community. Thus, in the forenoon, the theater television system in its entirety could be made available to the school system. The latter could install receivers in the schools; in addition it could use the theaters as classrooms. Lectures and motion pictures could be made available to the entire student body of a community. It has been suggested that theater television might be the medium or means whereby the schools can use television without undertaking the costly job of constructing and operating a television broadcast station.

This discussion indicates that theater television is technically and economically feasible, that there are adequate sources of program material which can and will be made available to the theater television group. Theater television will stimulate and help the box-office returns of the motion picture exhibitor. Theater television which is nonexistent today constitutes no economic threat to television broadcasting. But if theater television is organized on a local, regional, and national basis, it could become a challenge to television broadcasting.

Whether theater television ever will achieve its potentialities as an entertainment and public-service medium depends on the willingness and determination of the motion picture industry to develop this new art. Failure to accept this opportunity may well spell the doom of theater television since the motion picture industry has the resources and can adapt its technical knowledge to this new art. The time to act is now.

APPENDIX

(1) Other uses of television by the motion picture industry might include (1) ownership of television broadcast stations, and (2) development of pay-as-you-see television schemes such as Zenith Radio Corporation's "Phonevision."

(2) Electronic-storage, as opposed to film-storage, methods are also under development, using the Skiatron tube (or *P10* phosphor) and the so-called Swiss or AFIF Method, developed by Dr. F. Fischer of the Swiss Federal Institute of Technology. Electronic-storage methods, however, are not expected to be available for commercial use in the near future.

(3) A similar direct projection system has been developed in England. See A. G. D. West, "Development of theater television in England," *J. Soc. Mot. Pict. Eng.*, vol. 51, pp. 127–169; August, 1948.

(4) The 20th Century-Fox report to the FCC of its experimental theater television operations contained the tentative conclusion: "The quality of a television picture having a total of 525 scanning lines per frame and a horizontal resolution in excess of 600 lines, with good picture contrast ratio, will approach that of 35-mm professional motion picture film, provided there is good half-tone reproduction, accurate line interlace, and specified minimum of geometric distortion. Such a value of horizontal resolution would require a video band-pass of between 7 and 8 megacycles."

(5) See 2 FCC Reports 308.

(6) The airline distance from Philadelphia to Baltimore is about 89 miles; from Baltimore to Washington, D. C., is about 35 miles.

(7) By A. T. and T. tariff filings made on January 14, 1949, effective March 1, 1949, this restriction on interconnection was relaxed somewhat. For example, if the customer orders service for a period longer than three months, in an area where the telephone company has no intercity channel facilities, the customer must give the telephone company 12 months' notice. But he will be informed within three months whether it will have facilities between the service points within a year. If such facilities will not be available, the customer may connect his facilities with those of the telephone company until three years from the service date, and he may continue to connect thereafter until the telephone company has facilities, subject to three months' notice from the telephone company. However, the FCC has suspended this tariff provision pending its consideration of the restriction on interconnection.

(8) Former FCC Commissioner E. K. Jett asked Mr. Larsen if any theater television was on the air. When Mr. Larsen answered that none was on the air, Commissioner Jett, pointing to the other demands for the frequencies in the 1000- to 13,000-megacycle band, stated: "Apparently, you would want all the other radio services to stop dead in their tracks and wait for the development of theater television service until they can go ahead."

(9) Apparently the frequency bands 16,000 to 18,000 and 26,000 to 30,000 megacycles still remain open for theater television experimentation, but the development of these frequencies is in the embryonic stage.

(10) Currently the FCC is studying the effect of the decision of the United States Supreme Court in *United States* versus *Paramount Pictures, Inc., et al.*, 334 U. S. 331, upon the qualifications of the major motion picture companies to hold broadcast and television licenses. In that case, Paramount Pictures, Inc., Twentieth Century-Fox Film Corporation, Warner Brothers Pictures, Inc., Loew's, Inc., and Radio-Keith-Orpheum Corporation were found to have violated the Federal antitrust statutes.

(11) CBS first publicly demonstrated color television in September, 1940. In May, 1941, it inaugurated regularly scheduled color-television programs over experimental Station W2XAB in New York City operating in the very-high-frequency band. In October, 1945, W2XCS resumed color broadcasts from the Chrysler Building in New York City operating at about 490 megacycles. CBS has also relayed color transmissions between New York City and Washington, D. C.

(12) The FCC Report and Order stated: "Before approving proposed standards, the Commission must be satisfied not only that the system proposed will work, but also that the system is as good as can be expected within any reasonable time in the foreseeable future. In addition, the system should be capable of permitting incorporation of better performance characteristics without requiring a change in fundamental standards. Otherwise, the danger exists that the standards will be set before fundamental developments have been made, with the result that the public would be saddled with an inferior service, if the new changes were not adopted, or if they were adopted, receivers already in the hands of the public would be rendered useless.

"Judged by the foregoing tests, the Commission is of the view that the standards for color television proposed by Columbia Broadcasting System should not be adopted. In the Commission's opinion the evidence does not show that they represent the optimum performance which may be expected of a color-television system within a reasonable time. The Commission bases this conclusion on two grounds. In the first place, the Commission believes that there has not been adequate field-testing of the system for the Commission to be able to proceed with confidence that the system will work adequately in practice. Second, the Commission is of the opinion that there may be other systems of transmitting color which offer the possibility of cheaper receivers and narrower bandwidths that have not been fully explored." The Report expanded on the FCC's view of the need for further experimentation follows: "The evidence before the Commission shows that 27 channels ultimately may not be enough to provide for a truly nation-wide competitive television system. Every effort must, therefore, be made to narrow the bandwidth required for color television. It should be emphasized that narrowing the bandwidth should not be at the expense of picture brightness, picture detail, color fidelity, or other features of television performance. The objective should be a narrower bandwidth while retaining and even improving the quality of television performance."

FCC Allocation of Frequencies for Theater Television*

Editorial Note: **On February 20, 1948, the Federal Communications Commission issued a Public Notice (48-481, Mimeo. 17266) reporting under Docket No. 6651 on radio-frequency allocations to nongovernment services between 1000 and 13,200 megacycles, as a result of hearings held on January 15 and May 26, 1947. On June 29, 1949, the Commission invited the Society, Paramount, and Twentieth Century-Fox to file Statements concerning the allocation of bands of frequencies for commercial theater television service, requesting that these Statements be presented by September 2, 1949.**

The Commission classifies fixed and mobile services in this region in the following categories:

(1) Common-carrier fixed circuits. In this region television relaying usually would be provided for in such service.

(2) Fixed circuits except common carrier, television studio-transmitter links, and interim television relay. These are miscellaneous fixed services not in the other categories.

(3) Mobile, except television pickup.

(4) Television pickup, television studio-transmitter links, and interim television relay. The interim private television-relay service is added to this category pending permanent service by common carriers.

On theater television, and regarding the probable permanence of the allocations, the report states, "The Commission reaffirms in this report its position regarding the specific allocation of frequency bands for theater television, as set forth on pages 128 and 129 of the 'Report of Allocations issued in Docket No. 6651 on May 25, 1945' (published in the Journal, vol. 45, pp. 16–19; July, 1945). The requirements for theater television are still not sufficiently clear to indicate the need for a specific allocation for its exclusive use at this time. The Commission is of the opinion, from information now available to it, that a large part, if not all, of the functions required by theater television should be handled by stations authorized to operate on frequencies allocated to the use of communications common carriers ....

"The Commission is not convinced that all the services proposing

* Including a condensed version of a report delivered by Paul J. Larsen on May 17, 1948, at the SMPE Convention in Santa Monica and a report of more recent action initiated by the Commission on June 29, 1949.

to operate in this portion of the spectrum will prove to be justifiable, particularly in view of the limited frequency space available for all the nongovernment fixed and mobile services. However, the Commission is making frequency space available in this manner at this time in order to permit experimentation and a demonstration by stations in each of the categories of the value and need for the service they render."

The allocations are shown in Table I.

Table I

Frequency Band, Mc	Allocation, Category	Frequency Band, Mc	Allocation, Category
1850–1990	2	5,925– 6,425	1
1990–2110	4	6,425– 6,575	3
2110–2200	2	6,575– 6,875	2
2450–2500	General fixed and mobile, limited radio-location	6,875– 7,125	4
		10,700–11,700	1
		11,700–12,200	3
2500–2700	2	12,200–12,700	2
3500–3700	3	12,700–13,200	4
3700–4200	1		

The February 20, 1948, Public Notice of the FCC on radio frequencies for theater television use was the second of three such actions with which the SMPE has been concerned. The first was a Public Hearing held in 1944 and the third was initiated by the Commission by its letters of June 29, 1949, addressed to the Society, Paramount, and Twentieth Century-Fox. The Commission, in these letters and in its Public Notice 37951, dated July 1, 1949, asked that the Society and the two motion picture companies file Statements with the Commission by September 2, 1949, outlining the industry's need for allocation of bands of frequencies for theater television use. This time, operation of such a service was to be considered on a *commercial* basis, however, rather than *experimental* as before.

In the eight weeks which followed receipt of the FCC request, the SMPE Theater Television Committee, under the Chairmanship of D. E. Hyndman, prepared such a Statement, outlining the public-service aspects of a nation-wide theater television system, the physical nature of such a system, and the immediate and future needs of our industry for theater television frequencies.

The Report which appears on the following pages was filed with the Commission on August 29, 1949, and requests that the Federal Communications Commission allocate a broad band of radio frequencies which should ultimately be assigned as a number of specific theater television channels to individual exhibitor, producer, or distributor companies.

The Society has thus undertaken to point the way for growth of a theater television service and to provide the Commission with a broad general picture of a nation-wide theater television service, furnishing such technical details as the Commission will require in order to make its basic decisions of policy. The Statement, per se, is a single communication from one group within the industry. To insure further that the entire motion picture industry's views are presented and that those views favoring the allocation of bands of theater television frequencies at this time are in substantial agreement, the Society has asked industry associations and groups of producer, distributor, and exhibitor companies to endorse the stand which the Society has taken.

Also, to insure an adequate Statement of the industry's position before the FCC, the Society asked these organizations—

1. To endorse the SMPE's formal Statement.
2. Outline the benefits that would accrue to the American public from the formation of a theater television service.
3. Request an FCC Public Hearing on the matter in the near future.

The Motion Picture Association, a trade group of motion picture producing and distributing companies; the Theatre Owners of America, an association of independent exhibitors; and the Society have all made their views clear to the Commission by filing Statements within the time limit established and the industry is now awaiting further action by the FCC.

Statement on Theater Television

This statement was prepared by the Theater Television Committee of the Society of Motion Picture Engineers, under the chairmanship of Donald E. Hyndman, and was filed with the Secretary of the Commissian on August 29, 1949.

THIS STATEMENT is in reply to a letter from the Federal Communications Commission dated June 29, 1949, concerning the allocation of frequencies for theater television. In its letter and in Public Notice 37951, dated July 1, 1949, the Commission asked that the Society of Motion Picture Engineers answer six questions relating to a nation-wide theater television service.

The Society's answers presented here are intended to demonstrate the *importance to the American public* of such a service and are based on four prime considerations.

Point 1—The motion picture industry in years past has provided ready communications with the peoples of the United States through the medium of film. During times of emergency, this medium has been exploited for purposes of public morale and governmental information essential to our national welfare and economy. A nation-wide theater television system will be able to render a similar service of even greater effectiveness because of its instantaneous nature.

Point 2—Theater television as a service to the public in general is not restricted to any particular group and presents numerous educational as well as entertainment possibilities. Events of outstanding historical importance or of great social significance may be viewed in schools, public auditoriums, and theaters at the moment they occur. Thus its appeal to the public, and the likely size of the resultant audience, are such that the people of the United States as a whole will be the beneficiaries of any thoughtfully established, well-maintained, and ably administered theater television service.

Point 3—Theater television is as important as any other entertainment medium and should receive the same study, sanction, and support by the government as any comparable entertainment enterprise.

Point 4—Theater television deserves the opportunity for development and expansion which is the right accorded any new industry in the United States. It will afford marked industrial aid to the country by providing employment and personal opportunity to many people.

It is desirable to outline briefly the nature of a theater television service in order to emphasize more clearly the need for frequency allocations. In its simplest form, such a service would consist of one program-originating organization which provides theater television programs to theaters within a given city or within a single market area. Facilities will be required to serve broadly two functions: PICKUP and DISTRIBUTION of programs. These programs must be produced, brought to a central point, and then distributed on an intracity basis to the various theaters or auditoriums within the area served by that particular program-originating organization. If service thus offered locally is to be extended to other cities as well, a third function is involved.

PICKUP—Referring to the pickup aspects of programming, if these originate at a point other than the central studios of the program-originating organization, it becomes necessary to carry them from the point of origin to the central studio location by flexible and rapid procedure.

DISTRIBUTION—Passing to the distribution of the programs from the central point to the theaters, an intraurban multiple-addressee distribution system is necessary. The channel which carries the program from the central point of origin to each of the served theaters would be somewhat similar to the multiple-addressee communications system used in the distribution of news from a press radio station on land to a multiplicity of ships at sea.

The distribution system required for theater television will not, however, be restricted to intraurban operation. In addition to serving a given group of theaters, in a specific city or market area, it may be desirable and economical to distribute such programs more broadly. Such interurban channels must carry the picture and accompanying sound from city to city, and ultimately on a nation-wide basis.

TRANSMISSION FACILITIES—In order to provide the picture quality required by the theater, it will be necessary to use radio-frequency systems for the transmission of theater television signals. This is particulary true as the art develops and theaters require high definition and/or color programs.

It is possible, however, that other types of facilities may become available in the future through advanced developments (for example, special forms of long-distance wave guides).

INDUSTRIAL COMPETITION—Theater television will endeavor to offer material paralleling in a general fashion that presented by the legitimate theater, radio, and motion pictures, but adding the important element of immediacy. It will thus add a new medium and should stimulate these existing enterprises as well as theater television. As regards intraindustry competition, there will also be unrestricted competition among the various program-originating groups. It is anticipated that eventually theater television presentations in any given locality will be optionally obtainable by the exhibitors from a number of sources, each of whom will offer programs competing on the basis of their cost and merit.

The general facilities required for a nation-wide theater television service consist, therefore, of flexible and economical radio channels connecting remote program pickup points in each city with central studios and transmitters, as well as one or more channels connecting transmitters to the theaters which intend to reproduce the programs. In addition, channels between cities are required for more extensive distribution.

FCC REQUEST—The June 29 letter from the Federal Communications Commission to the Society of Motion Picture Engineers said, "Without limiting the scope of the statements, the Commission requests expression of views covering six specific subjects.

"1. What the minimum frequency requirements would be for a nation-wide competitive theater television service;

"2. What specific frequency bands you would propose to be allocated to a theater television service; reasons therefor;

"3. The exact functions which would be performed in each such frequency band in a theater television service;

"4. Whether and to what extent such functions could be performed, in whole or in part, by use of coaxial cable, wire, or other means of transmission not using radio frequencies;

"5. Whether and to what extent existing common carriers have or propose to have facilities available capable of performing such functions, in whole or in part, by radio relay, coaxial cable, or wire;

"6. Plans or proposals looking toward the establishment of theater television service."

Since the answers to some of the above questions are interrelated, no attempt has been made to separate them in the following statement. However, they are summarized briefly and in order, together with a few concluding remarks, at the end of this statement.

The following statements attempt to justify on technical grounds the views of the Society of Motion Picture Engineers favoring the allocation at this time of frequencies for commercial theater television use. Consideration of desirable *picture quality* and the related requirements for *bandwidths and channels*, as well as various *service classifications* of a nation-wide theater television service, are included.

PICTURE QUALITY—Theater television programs must be presented to the public on the basis of picture size and quality not likely to be attained in the home. Theater patrons have come to take for granted the superior detail and quality of present-day motion pictures and if they are to be served adequately, theater television must plan to present ultimately television pictures of detail and quality comparable to what they have become accustomed to expect. In addition, theater viewing conditions tend to suppress outside distractions, focusing the viewer's attention on the screen with the result that he becomes increasingly conscious of structural details of the picture.

Program material suitable for showing in theaters and auditoriums will eventually need the addition of color. Although monochrome broadcast service in the home has proved of extensive interest to the American public so far, and at the outset theater television will also be monochrome, the theaters should ultimately present high-quality color television pictures in a reasonably advanced state of development.

It should not be assumed that high-detail monochrome or color television for theater use is to be anticipated in the immediate future. On the contrary, theater television should evolve from the present broadcast standards of 525-line monochrome pictures to pictures of greater resolution and in color as new equipment and improved methods are made available. It is emphasized that immediate theater television operation *must* be based on the capabilities of equipment that exists today, but if future technical growth which is of critical importance to the long-term and stable success of theater television is to be allowed, these developments should not be hampered by severely restricting channel and bandwidths at this time.

BANDWIDTHS AND CHANNELS—If a competitive nation-wide theater television service is to be established, it is necessary to have available communication or syndicating facilities to distribute programs locally, regionally, and on a nation-wide basis from a point of origin.

At the present state of knowledge of the art, the Society estimates that distribution channels 50 megacycles wide will be required to transmit high-definition monochrome or color television programs satisfactory for theater use.

It is quite possible that theater television will require up to 60 channels, at least in the larger metropolitan areas. This allocation plan would then provide six channels for each of ten possible program-originating organizations.

In specifying that six channels would be required for each of the program-originating organizations, it is believed that each such organization would need two channels for program pickup (where necessary one of these channels will be employed as a studio-transmitter link and the other for remote pickup); two channels for distribution of programs to its theaters (which might well be divided into two groups requiring different programs or types of theater television at the same time); and at least two channels for intercity distribution (in long-distance transmission several relay points are necessary, and it usually is not practicable both to receive and transmit on the same carrier frequency from any single relay station).

While six channels would provide highly satisfactory distribution, it is possible that the two channels used for distribution of programs to theaters within a single urban area could also be used for relaying programs between cities. Practical answers to this question, however, can only be arrived at after experience is gained through future commercial operation.

SERVICE CLASSIFICATIONS—The Society is not in a position to estimate the number of types of program-originating organizations which should exist to provide a truly competitive nation-wide theater television service. However, in order that the Commission may have some idea of what would be expected with various types of operation, several possible classes of service are outlined below. Service grades and types, together with a table showing the bandwidths required for each type of operation, are included.

Grade 1 Service—Grade 1 program-originating organizations would require six channels: Two for remote pickup; two for simultaneous transmission of two events or programs to different classes of local theaters; and two for intercity connection.

Grade 2 Service—Grade 2 program-originating organizations would require three channels: One channel for transmission of programs to a local group of theaters; one for remote pickup; and one for intercity connection.

Grade 3 Service—Grade 3 program-originating organizations would require two channels. This would be a strictly local service since one channel would be used for remote pickup and one for transmitting programs to a group of theaters.

Depending upon the size and nature of the community, various numbers of program-originating organizations will be necessary. They are outlined as follows:

Type 1 Operation—The number of program-originating groups in a Type 1 competitive area would be 10.

Type 2 Operation—The number of program-originating groups in a Type 2 competitive area would be 6.

Type 3 Operation—The number of program-originating groups in a Type 3 competitive area would be 3.

Based on the foregoing classifications, Table I gives the total number of required channels and the total bandwidths which would be needed for the various combinations of particular grades and types of service. This table is based on the assumption that each channel will be 50 megacycles wide. Doubtless most transmission will be extremely directional and therefore identical channels may be used in relatively near-by cities and towns. Thus it may not be necessary to restrict the use of a single channel to widely separated areas as is the case with lower-frequency television broadcast channels.

TABLE I

Competitive Type	Type 1		Type 2		Type 3	
Grade of Service	Total Channels	Total Bandwidth	Total Channels	Total Bandwidth	Total Channels	Total Bandwidth
Grade 1	(A) 60	3000 mc	(D) 36	1800 mc	(G) 18	900 mc
Grade 2	(B) 30	1500 mc	(E) 18	900 mc	(H) 9	450 mc
Grade 3	(C) 20	1000 mc	(F) 12	600 mc	(I) 6	300 mc

Service A—would appear to be the type that will eventually be required for a truly competitive nation-wide service.

Service E—although somewhat restrictive, would serve as an interim measure and would be suitable for high-detail transmission.

Service I—would serve some present needs, but probably would be unsatisfactory and outmoded in a very short time.

It is recommended that as many of the channels as possible be set aside at this time in the region of 5925 to 7125 megacycles because equipment is now available for use in this region, and experience with transmission at these frequencies shows such service to be practical. Although Services *A* and *B* above require more channels than this region can furnish, future growth may provide experience and equipment making transmission at higher frequencies also practical.

NETWORK FACILITIES—As of today, no communications organization, whether common carrier or limited or private carrier, is in a position to provide intercity or network service for theater television. This holds true even for transmission of 525-line pictures of present-day television-broadcast quality. Indeed television broadcasting does not presently have sufficient network facilities to avoid channel sharing and consequent enforced network-channel scheduling.

The daily peak demand for network interconnection facilities for theater television will occur at the same time as the peak demand for facilities for television broadcasting. Since both services will require facilities between 11:00 A.M. and 12:00 MIDNIGHT, no apparent conservation can be obtained unless both services use the same programs.

Regardless of how many separate channels ultimately are required by a nation-wide theater television service, that number will remain the same whether distribution is by common, limited, or private carrier.

Opinions as to the relative feasibilities or economies of any one method of distribution are not within the scope of the Society's interest. It does seem appropriate, however, to outline for the Commission some of the factors which the theater television user might consider in determining the operating group best suited to supply theater television distribution needs.

FACTOR 1. TECHNICAL PERFORMANCE—The quality of the provided circuits or channels to a large extent determines the quality of the received picture.

FACTOR 2. OPERATIONAL FLEXIBILITY—Particularly in such fields as theater television, quick and effective responsiveness to program-scheduling requirements is required.

FACTOR 3. INTERCONNECTION AND CO-ORDINATED STANDARDS—The various pickup and distribution channels, both local and long-distance, may require frequent, rapid, and satisfactory interconnection. This procedure inherently involves acceptance and use of co-ordinated standards of equipment performance and operational methods.

FACTOR 4. AVAILABILITY—As theater television operations expand, the correspondingly required pickup and distribution means should keep abreast of such expansion, or even reasonably precede it as a stimulating measure.

FACTOR 5. RESPONSIVENESS TO SPECIAL NEEDS—It is likely that theater television will have numerous special requirements of equipment and operation, discovered as the result of practical operation. The program-carrier organization should be particularly responsive to such needs and in a prompt and sympathetic fashion.

FACTOR 6. NONADAPTATION TO OTHER SERVICES AND USERS—In certain cases, a group of services or number of users may come into conflict as to availability, or specifications, of the desired services. In its nature, theater television requires maximum freedom from such limitations and handicaps which, in practice, might otherwise be insurmountable.

FACTOR 7. PROTECTION OF PIONEERS—The theater television organizations which either authorize facilities construction through a firm order for the resulting service, or which themselves sponsor such facilities, seem entitled to the long-term and unrestricted use of such facilities. Pioneering in so complex and costly a field as theater television is not to be expected unless such reasonable protection or recognition is available.

FACTOR 8. COST—The construction and maintenance costs of limited or private carriers must be fully considered in comparison to any proposed rental or the other costs for equivalent service by a common carrier.

CONCLUSIONS—The Society's answer to the six specific questions can be briefly summarized as follows:

1. For a limited nation-wide theater television service, the *minimum* frequency requirements are three 50-megacycle channels

for each programming source. However, for a truly competitive nation-wide service, each source will require from four to six 50-megacycle channels. If only local operation is anticipated, each program-originating source could operate with two 50-megacycle channels.

2. As many channels as possible should be allocated for theater television service between 5925 megacycles and 7125 megacycles.

3. In brief, the functions to be performed in the channels assigned to each program-originating organization are remote pickup, transmission from a central studio or transmitters to local theaters, and transmission from the central studios or transmitters in one city to studios, transmitters, or theaters in another city.

4. At the present time, limited cable facilities might be made available for occasional transmission of low-definition monochrome theater television pictures, but would not be satisfactory for the type of theater television service considered necessary or for future high-detailed monochrome or color theater television pictures.

5. As of today, no existing common carriers have facilities fully available for theater television purposes.

6. The SMPE has no plans or proposals looking toward the establishment of a theater television service. Information on this phase of theater television should be secured from the various motion picture trade associations and producer or exhibitor companies now carrying on experimental work.

The Society of Motion Picture Engineers has previously submitted to the Federal Communications Commission proposals for the allocation of frequencies for theater television, and the Commission has issued statements in relation thereto. One of these was in connection with docket 6651 leading to the Commission's report of May 25, 1945. The other was treated in the Commission's report of February 20, 1948.

The Society of Motion Picture Engineers desires to express to the Federal Communications Commission its willingness to be of future service to the Commission along such lines as the Commission may indicate, within the purposes and scope of the Society.

Portable Device for Measuring Radiant Energy at the Projector Aperture*

By A. J. HATCH, JR.

Strong Electric Corporation, Toledo 2, Ohio

Summary—**Studies relating to the effects of radiant energy upon the film in the projector aperture have become of increasing importance with the use of higher volumes of projected light. A portable device for measuring the radiant energy at the center of the projector aperture is described and its construction outlined. Radiant energy in units of watts per square millimeter can be read directly from a self-contained indicating meter.**

Introduction

With the use of larger theater screens, requiring a higher level of illumination, consideration of the limitation of total energy that the film can withstand has become an increasingly important factor in the design and use of projection equipment.

A method of evaluating the total energy at the picture aperture, and also the energy in various bands of the projection spectrum has been reported by Zavesky, Null, and Lozier.[1] The flexibility and precision necessary for a complete evaluation of aperture energy in the laboratory is provided by this method, which entails the use of a water-cooled aperture, radiation shield, four-junction thermopile, and wall galvanometer. By exploring the light pattern obtained through a pinhole placed in the aperture plane, and integrating the readings, a value of total energy is obtained.

However, many times it is desirable either to make a quick evaluation in the laboratory or to obtain measurements on actual operating installations in theaters. For this purpose a faster method and a more portable device is needed.

One such portable instrument has been developed (Fig. 1) which permits a value of total center-aperture energy to be read directly

* Presented June 10, 1949, at the Central Section Regional Meeting, Toledo, Ohio.

from an indicating meter. This instrument measures 3 inches in diameter and $16^1/_2$ inches in length, and weighs $1^3/_4$ pounds, including the indicating meter. It is so constructed that it can be broken down into two parts for carrying, and will fit in a $9^1/_2$- × 7- × $3^1/_2$-inch carrying case.

Fig. 1—Portable radiant-energy measuring device showing lens barrel and indicating meter.

CONSTRUCTION

This radiant-energy measuring device is housed in a standard series II 35-mm projection lens barrel with a 4-inch shade tube added. (Fig. 2.) Tubular extensions are provided on both the large and small ends of the barrel. A pinhole aperture 0.080 inch in diameter is placed in the far end of the small-end extension of the lens barrel and a small aluminum block with a tapered hole is fastened to the outside of this pinhole aperture. The sides of this block are approximately 0.55 inch square, so that the entire block can be inserted into the 35-mm picture aperture to a point where the pinhole aperture will come to rest in the picture-aperture plane. The aluminum block serves as a heat baffle to the aperture plate, while the mass of the pinhole-aperture plate serves as an inertia element to prevent too high a temperature being reached on this element, while the reading is being taken.

A 10-mm diameter, 12.8-mm focal length, plano-convex lens is placed at a distance of approximately 0.524 inch from the pinhole aperture and is so adjusted to project an image of the pinhole to a plane 13.5 inches from the aperture.

In this image plane, which is at the far end of the large-end lens-barrel extension, the receiver element of a General Electric Type DW-60 radiation meter is placed. This extremely small radiation meter combines a single-junction thermocouple and an indicating meter in a single unit, and is held in the lens-barrel extension in a channel with a detent-type lock arrangement. The lens-barrel extension fits over the lens-barrel shade and is adjustable lengthwise in respect to the lens-barrel shade.

With nearly all motion picture arc projection systems, glass is used either in the form of reflectors or condensers between the arc and the

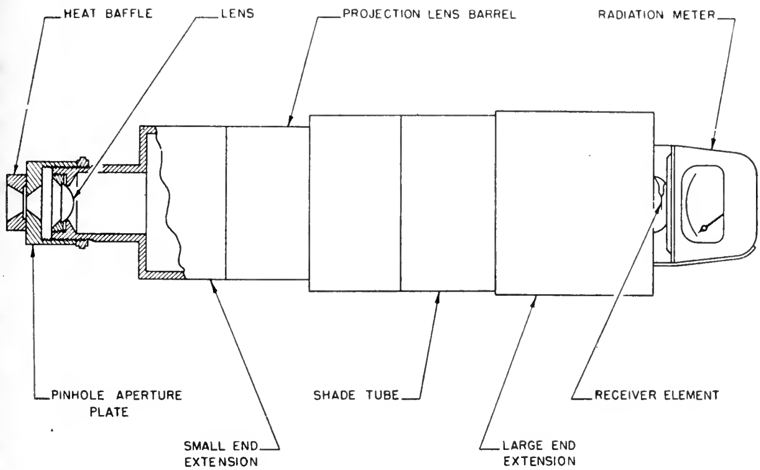

Fig. 2—Constructional details of portable meter.

picture aperture. Consequently, it is permissible to use a glass lens and a glass window for the meter receiver element, without introducing any appreciable error in energy measurement due to selective response.

Design Constants

The indicating meter scale is in units of gram calories per square centimeter per minute with a full-scale value of 2 units. As investigations of aperture energy have been made in units of watts per square millimeter at the aperture, it was decided to select the instrument constants, so that the meter full scale would indicate 1 watt per square millimeter total energy at the aperture. As 1 gram calorie per square centimeter per minute is equal to 0.449 watt per square inch, full-scale reading of the indicating meter is obtained when projecting 0.898 watt per square inch to the receiver plane (2 × 0.449). Converting 1 watt per square millimeter at the aperture to watts per square inch gives a value of 645 watts per square inch. With a lens-transmission efficiency of 85 per cent, the magnification constant necessary to convert 645 watts per square inch at the aperture to a full-scale meter reading of 0.898 watt per square inch at the receiver plane, is as follows:

$$M = \sqrt{\frac{645 \times 0.85}{0.898}} = 24.7.$$

CALIBRATION

An approximately correct calibration, utilizing the design constants, will result, if the receiver element plane is maintained at a distance of $13^1/_2$ inches from the pinhole aperture, and the distance between the pinhole aperture and lens varied to obtain either a sharply defined spot in the receiver plane, or a spot diameter 24.7 times the pinhole diameter. The accuracy of the receiver and millivoltmeter unit is ±5 per cent of full scale any place on the scale, which means an accuracy of ±0.05 watt per square millimeter at the aperture.

A more accurate calibration of the over-all instrument can be made by adjusting the lens setting, so that the readings obtained agree with the laboratory method already mentioned. With the meter calibrated for several points against the more exact laboratory method of measuring the aperture energy, and with the application of the resulting correction factors, an over-all accuracy of about 2 per cent can be expected.

METHOD OF USE

To obtain a measurement of total center-aperture energy, simply remove the projection lens and insert the aperture-energy meter into the lens holder so that the aluminum block enters through the picture aperture. Make sure that the projector-shutter blades are out of the light path and prop the fire shutter open. After checking the arc current and the setting of the positive carbon in relation to the lamp-house optical system, open the lamp dowser long enough for the meter needle to come to a steady position. Immediately upon reading the value, the dowser should be closed. The heat capacity of the pinhole aperture is small, and it will become a radiator of some proportion, if subjected to the radiant energy for any but the short period that it takes for the meter hand to reach a stable position. For measurements below 1 watt per square millimeter, it will not be necessary to operate the projector shutter. For measurements of over 1 watt per square millimeter the projector shutter can be operated, and the meter reading corrected for the shutter-transmission value. On projectors equipped with front and rear shutters, and when it is necessary to operate the shutter when taking a reading, the front shutter blade must be removed.

An interesting alternate use to which some of the basic elements of this instrument have been put has been the measurement of the visible light in lumens per square millimeter at the center of the aperture.

A measurement of this type is made by removing the radiation meter and substituting a photronic cell with viscor filter. By application of the proper calibration factors, the visible light at the aperture can be determined.

Knowing the width of picture, projection lens, and shutter-transmission efficiency, a figure of center screen illumination in foot-candles can be arrived at if desired.

Reference

(1) R. J. Zavesky, M. R. Null, and W. W. Lozier, "Study of radiant energy at motion picture film aperture," *J. Soc. Mot. Pict. Eng.*, vol. 45, pp. 102–108; August, 1945.

Report of Lens-Calibration Subcommittee

I. Introduction

This subcommittee of the Standards Committee was appointed primarily to establish a standard method of photometrically calibrating diaphragm openings for motion picture camera lenses as distinguished from the well-known f system of aperture markings. The demand for a photometric type of aperture calibration ("T stop") is becoming increasingly felt, and it has the advantage that diaphragms of any shape, pentagonal, scalloped, or irregular, can be correctly labeled with as much ease as a circular aperture. The presence or absence of antireflection coatings is automatically included in the calibration, and so also are factory variations in the focal length and in the iris mechanism. The illumination on the film in the center of the field will therefore be the same for all lenses at the same T stop, assuming that the object is a uniform plane surface perpendicular to the lens axis. It is implicit, also, that each lens shall be individually calibrated if the photometric method is used.

Lens speeds for distant objects only are considered in this report; the corresponding problem for lenses intended to be used with near objects will be discussed later.

II. Theory

Suppose we have a well-corrected lens satisfying the sine condition, and used with a very distant object. Then if at some given diaphragm opening the area of the entrance pupil is A and the focal length is f, the illumination at the center of the field will be E, where

$$E = tBA/f^2. \qquad (1)$$

In (1) t is the transmittance of the system (emerging flux divided by entering flux), and B is the brightness of the object in candles per square unit.

For the special case of a lens having a *circular aperture*,

$$E = \frac{tB(\pi y^2)}{f^2} = \pi tB \sin^2 \theta \qquad (2)$$

hence

$$E = \frac{\pi tB}{4(f \text{ number})^2} \qquad (3)$$

where

$$f \text{ number is equal to } 1/(2 \sin \theta). \qquad (4)$$

Equation (1) shows that for a very distant object of brightness B, the image illumination at the center of the field is proportional to tA/f^2. For a circular aperture, (3) shows that the central image illumination is proportional to $t/(f\text{ number})^2$.

Note also that in (4), the sine is correct and not the tangent, because in a lens satisfying the sine condition the "principal plane" is actually a sphere centered about the focal point.

III. DEFINITION OF *f* NUMBER

The definition of *f* number given in (4) above is in accordance with American Standard Z38.4.20-1948, paragraph 2.5. For a lens satisfying the sine condition and having a circular aperture, the *f* number

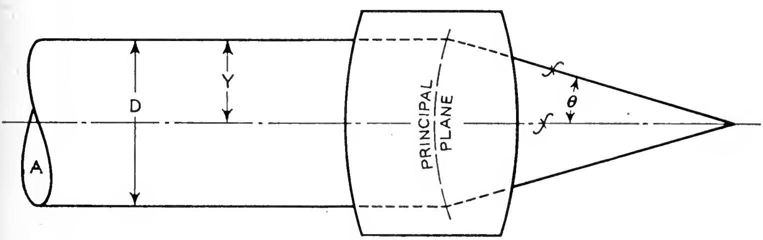

Fig. 1

is also equal to the ratio of the focal length to the diameter of the entrance pupil, thus

$$f\text{ number} \doteq \frac{f}{D} = \frac{1}{2\sin\theta}. \tag{5}$$

If the lens aperture is noncircular, as often happens when an iris diaphragm is partly closed, the area A of the entrance pupil must be measured instead of its diameter D. The effective diameter D' of the entrance pupil will then be defined as

$$D' = 2\sqrt{\frac{A}{\pi}} \tag{6}$$

whence,

$$f\text{ number} = \frac{f}{D'} = \frac{f}{2}\sqrt{\frac{\pi}{A}}. \tag{7}$$

IV. DEFINITION OF *T* NUMBER

In order to embody the lens transmittance and the area of the diaphragm into a single figure which can be engraved on the lens, it is proposed to adopt a new term to be known as the "T number" of a given lens at a given opening. This T number is to be defined as the f number of an open circular hole, or of a fictitious lens having 100 per cent transmittance and a circular aperture, which would give the same central-image illumination as the actual lens at the specified stop opening (assuming a very distant object).

Hence, for a lens with a circular aperture,

$$T \text{ number} = \frac{f \text{ number}}{\sqrt{t}} \tag{8}$$

and for a lens with an entrance pupil of any shape and area A, the corresponding formula is

$$T \text{ number} = \frac{f}{2}\sqrt{\frac{\pi}{tA}}. \tag{9}$$

In practice, however, it is expected that the normal procedure will be to re-engrave the iris-diaphragm ring on the lens at a series of definite T numbers, rather than to measure the T number corresponding to each of the existing marked f numbers.

It may be remarked that the T number is a photometrically determined quantity, whereas the f number is a geometrical quantity. Since the T numbers are determined photometrically, they automatically take account of the size and shape of the aperture, the actual focal length of the lens, the lens transmittance, and any internally reflected stray light which may happen to strike the film at the center of the field (such as in a flare spot).

V. STANDARD SERIES OF APERTURE MARKINGS

The iris-aperture ring of a lens shall be marked at every whole stop on either system. The diaphragm ring shall always be turned in the closing direction, and not in the opening direction. The whole stop numbers are accurately 0.71, 1.00, 1.41, 2.00, 2.83, 4.00, 5.66, 8.00, 11.31, 16.00, 22.63, 32.00, – – –

These marks shall be engraved on the lens as follows: 0.7, 1, 1.4, 2, 2.8, 4, 5.6, 8, 11, 16, 22, 32. The maximum aperture of the lens shall be marked with its measured f number or T number, stated to one decimal place. These recommendations follow the American Standard Z38.4.7-1943.

VI. SUBDIVISIONS OF A WHOLE STOP

In addition to the engraved values, each stop may be divided into three subdivisions by dots or marks (not numbered), the dots being at "thirds of a stop," namely, *0.7*, 0.8, 0.9, *1.0*. 1.13, 1.27, *1.4*, 1.6, 1.8, *2.0*, 2.2, 2.5, *2.8*, 3.2, 3.6, *4.0*, 4.5, 5.0, *5.6*, 6.3, 7.1, *8.0*, 9.0, 10.0, *11.3*, 12.7, 14.2, *16*, 18, 20, *23*, 25, 28, *32.0*, – – –

The reason for dividing each stop interval into three parts is so that the lens apertures will agree with the exposure-meter markings stated in American Standard Z52.12-1944, page 5. The same cube-root-of-two series is used for the Exposure Index of a film, see American Standard Z38.2.1-1947, page 11. One third of a stop represents a logarithmic illumination ratio equal to 0.1, which is the transmission of a neutral density of 0.1. It is worth noting that $\sqrt[3]{2}$ is equal to $\sqrt[10]{10}$, or 1.260. The ratio of successive circular stop diameters is equal to $\sqrt[6]{2} = 1.123$.

It is contemplated that a lens will be engraved with either the *f* numbers or the *T* numbers, but not with both sets of markings.

VII. SYMBOL

Lenses calibrated on the *f* system should bear the designation *f/* or *f:* followed by the numerals (see American Standard Z38.4.7-1943).

Lenses calibrated on the *T*-stop system should bear the designation *T* or *T*- followed by the numerals.

VIII. ACCURACY OF MARKING (*f* SYSTEM)

The *maximum* opening of a lens on the *f* system shall be marked with an accuracy of ±10 per cent of area, or ±5 per cent of diameter.* Since blanket calibrations are generally used for *f* apertures, the smaller openings may be in error by ±25 per cent of area, or ±12 per cent of diameter (one third of a stop). These figures are based on the assumption that the iris will always be closed down to the desired aperture and not opened up from a smaller aperture, to eliminate backlash effects.

* In Z38.4.4-1942 the engraved focal length *of lenses for still picture photography* must be within ±4 per cent of its true value, and in Z38.4.7-1943 the measured diameter of the maximum entering beam shall be at least 95 per cent of the quotient obtained by dividing the engraved focal length by the engraved *f* number. Thus by combining these tolerances we find that the diameter of the maximum lens aperture may be in error by as much as 9 per cent. This represents an error in area of 18 per cent, or one quarter of a stop, which is felt to be unnecessarily large for the maximum aperture. The proposed tolerance on aperture marking for motion picture objective lenses allows less latitude than that provided for still picture camera lenses by Sectional Committee Z38 (Photography), because of the stricter requirements in cinematography for uniform density of successive scenes photographed on the same continuous length of film using different lenses.

IX. Accuracy of Marking (T System)

Since each lens is individually calibrated, an accuracy of $^1/_{10}$ of a stop (7 per cent in illumination) becomes entirely possible throughout the whole range of the diaphragm scale. This is assuming that the diaphragm is always closed down to the desired aperture and not opened up from a smaller aperture, to eliminate backlash effects. Alternatively, the manufacturer should be prepared to guarantee this accuracy even though each stop marking may not be individually determined.

APPENDIX I

X. Measurement of f Apertures

The procedure for measuring the f number of any lens having a circular diaphragm aperture is described in American Standard Z38.4.20-1948, paragraph 3.

If the entrance pupil is noncircular, it is necessary to measure its area. Ths may be done conveniently by mounting a point source of light at the rear focal point of the lens, and allowing the light beam which emerges from the front of the lens to fall upon a piece of photographic material. After processing, the recorded area is measured with a planimeter and applied in (7) above. If the lens is too small for this procedure to be employed, it may be placed in a suitable projector working at a known magnification (a workshop profile projector equipped with a telecentric optical system is suitable), the back of the test lens being towards the source of light. The entrance pupil then will be projected onto the screen of the projector at a known magnification, whence its area can be determined with a planimeter.

APPENDIX II

XI. Photometric Calibration of a Lens

Since T stops are based on a measurement of the illumination produced by the lens at the center of the field, it is first necessary to define this term.

The term "center of the field" for illumination or flux measurements shall be taken to mean any area within a central circle approximately 3 mm in diameter for 35-mm or 16-mm films, or 1.5 mm in diameter for 8-mm films.

The light used in making the determination shall be white,* and the sensitivity characteristic of the photoelectric receiver shall approximate that of ordinary panchromatic emulsion.† It is not considered that these factors are at all critical, and that no closer specification than this is necessary. Obviously errors will arise if the light transmitted by the lens has a strongly selective transmission, but such lenses would be undesirable for other reasons.

The incident light shall fill a field not exceeding 10 degrees more than the angular field of the lens itself. During measurement, the light shall traverse the lens in the direction normally employed in photography. The lens should be carefully examined before calibration to ensure that there are no shiny regions in the barrel which would lead to flare or unwanted stray light, since this would vitiate the measurements badly. The lens surfaces should of course be clean.

XII. Corner-to-Center Ratio

Having calibrated the stop markings of the lens on the T system, the observer may, if desired, determine in addition the ratio of corner illumination to center illumination, at full aperture and preferably at other apertures also. For this purpose the 3-mm (or $1^1/_2$-mm) hole shall be used first at the center of the field, and then moved outwards until its rim is touching the top and side limits of the camera gate. This distance is shown in Table I.

Table I

Gate, Mm	Radial Shift of Hole, Mm
35 (16.03 × 22.05)	11.5
16 (7.47 × 10.41)	4.5
8 (3.51 × 4.80)	2.0

The corner-to-center ratio of illumination so determined will take care of $\cos^4$ and vignetting effects within the lens.

XIII. Extended Source Method of T-Stop Calibration

This method of lens calibration has been described by Gardner[13] and Sachtleben,[9] the underlying theory being given by McRae.[4] It is based

* Specifically a tungsten filament lamp operating between 2900 and 3200 degrees Kelvin.

† A suitable cell is one having an S-3 surface, combined with a Corning 9780 glass filter about 2.5 mm thick.

on filling the lens with light from an extended uniform source, and placing a metal plate *in the focal plane* of the lens with a 3-mm hole (or 1.5-mm for 8-mm film) at its center. The light flux passing through the hole is measured by a photocell arrangement. This flux is then compared with the flux passing through the same hole from an open circular aperture of such a size and at such a distance from the plate that it subtends the desired angle θ referred to in (2) above. The greatest care is necessary to ensure that the extended source is really uniform.

In practice, the photocell reading for each whole T-stop number is first determined for a series of open apertures, at a fixed distance from the plate. The lens is then substituted for the open aperture with the 3-mm hole accurately in its focal plane, and the iris of the lens is closed down until the photocell meter reading produced by the lens is equal to each of the successive open-hole readings. The full T-stop positions are then marked on the diaphragm ring of the lens. The intermediate third-of-a-stop positions may be found with sufficient accuracy by inserting a neutral density of 0.1 or 0.2 behind each open aperture in turn and noting the corresponding photocell readings.

The following table of aperture diameters may be useful. They are based on a distance of 50 mm from aperture to plate. (It is important to remember the difference between sine and tangent, and that the aperture diameter is *not* found merely by dividing 50 mm by the T number.)

TABLE II

Desired T Number	Value of θ = Cosec^{-1} (2 × T Number), Degrees	Diameter of Aperture = 100 tan θ, Mm
0.5	90	∞
0.71	45	100
1.00	30	57.74
1.41	20.708	37.80
2.00	14.478	25.82
2.83	10.183	17.96
4.00	7.181	12.60
5.66	5.072	8.88
8.00	3.583	6.26
11.31	2.533	4.42
16.00	1.791	3.12
22.63	1.266	2.21
32.00	0.895	1.56

A single set of apertures is sufficient to calibrate lenses of all focal lengths, since the only factor involved is sin θ, and that is fixed by the aperture used.

The extended source should be uniformly bright over its useful area to within ± 3 per cent. (This could be tested with a suitable telephotometer, or a small hole in an opaque screen could be moved around in front of the source, and any consequent variations in photocell reading noted.) The source conveniently may be a sheet of ground glass covering a hole in a white-lined box containing several lamps mounted around the hole and shielded so that no direct light from the lamps falls on the ground glass itself. The photocell receiver conveniently may be of the phototube type with a simple direct-current amplifier.* Care must be taken to ensure that the phototube sensitivity and the line voltage do not change between making readings on the open aperture and on the lens itself; to guard against this, some convenient turret arrangement is desirable with the lens on one side and the open aperture on the other so that the two may be interchanged and compared immediately with each other by merely turning the turret.

To measure the corner-to-center illumination ratio, the lens is set in position and the 3-mm hole and the photocell are displaced laterally by the desired amount. The photocell reading is noted at axial and corner positions, and the corresponding light ratio found from a calibration curve of the photocell meter.

Reference is made to the RCA patent to Sachtleben,[9] U. S. 2,419,-421, claim 3 of which covers this method of lens calibration.

XIV. COLLIMATED SOURCE METHOD OF LENS CALIBRATION

This method has been described by Daily[11] and Townsley,[14] the underlying theory being embodied in (1) above. Light from a small source (a 5-mm hole covered with opal glass and strongly illuminated from behind) is collimated by a simple lens, or an achromat if preferred, of about 15 inches focal length and 2 inches aperture. This gives a collimated beam which will be focused by the test lens to form a small circle of light in its focal plane. This circle of light will be less than the prescribed limit of 3 mm diameter for all lenses under 9

* Suitable systems are the "Electronic Photometer" model 500, (Photovolt Corporation, 95 Madison Avenue, New York, New York), and the "Magnephot" (W. M. Welch Scientific Co., 1515 Sedgwick St., Chicago, Illinois).

It is felt that a barrier-layer cell, although desirable for reasons of simplicity, has insufficient sensitivity for accurate determinations of the smaller apertures.

inches in focal length. Uniformity of the collimated beam can be checked by moving a small hole in an opaque screen across the beam, and any variations in the photocell reading noted.

For the comparison unit, an open aperture is used, of diameter equal to the *focal length* of the lens divided by the desired T number. This aperture is first mounted in front of an integrating sphere with the usual photocell detector, and the light from the collimator is allowed to enter the aperture. The aperture plate is now replaced by the lens, the iris diaphragm is closed down to give the same photocell reading, and the T-stop number is engraved on the iris ring. The intermediate thirds of stops can be added by using 0.1 or 0.2 density filters as in the method of Section XIII.

To guard against drift and line-voltage variations which might occur between the readings on the comparison aperture and on the lens. it is convenient to leave the known standard aperture in place in front of the sphere, and to insert the lens into the beam in such a position that the little image of the source falls wholly within the standard aperture. The meter reading should then remain the same no matter whether the lens is in or out of the beam. A second plate with a 3-mm aperture should be placed over the comparison aperture while the lens is in place to stop any stray light which may be reflected from the interior of the lens.

It should be noted particularly that if this method is used, the focal length of the lens must be measured separately, and a suitable set of open apertures constructed for use with it. However, by suitable devices, one single set of fixed apertures may be used for all lenses, as described by Townsley.[14]

The corner-to-center ratio at any desired aperture can be conveniently determined by simply rotating the lens through the desired field angle ϕ and comparing the photocell reading with its value for the lens axis. The light-flux ratio can then be read off a calibration curve for the photocell system, and converted to the desired corner-to-center illumination ratio by multiplying it by $\cos^3 \phi$. (Note that this procedure will be correct only in the absence of distortion, but no motion picture lens is likely to have enough distortion to cause any significant error.)

APPENDIX III

XV. USE OF T STOPS WITH EXPOSURE METERS AND GUIDES

Existing exposure meters, and all qualitative exposure guides, are based on the transmittance of an average uncoated lens,[17] say 76 per cent. Thus existing exposure-meter dials are necessarily incorrect for all lenses differing in transmittance from 76 per cent.

By using photometrically calibrated *T* stops in place of the purely geometrical *f* stops, the meter exposure will be in error by about 30 per cent, which is close to one third of a stop or one division on the dial. However, as the error resulting from the use of *T* stops instead of *f* stops is in the direction of overexposure, it is felt that no changes or corrections in exposure-meter dials will be necessary.

In this connection it is of interest to note that the exposure formula given in American Standard Z52.22-1944, namely,

$$\text{exposure time} = \frac{1.25\ (f\ \text{number})^2}{\text{brightness (in cdls per sq ft)} \times \text{exposure index}}$$

could be simplified for *T* numbers, as follows:

$$\text{exposure time} = \frac{(T\ \text{number})^2}{\text{brightness} \times \text{exposure index}}$$

XVI. DEPTH OF FIELD

It is the opinion of the subcommittee that either *f* stops or *T* stops may be used interchangeably for the computation of depth of field. This is because computed depth values are at best approximations, depending on an arbitrary value for the permissible circle of confusion in the image. Since the aperture diameter at any given *T* number is generally larger than the aperture diameter at the same *f* number, the actual depth of field at a given stop number will be slightly less on the *T* system than on the *f* system.

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Precision Lens-Testing and Copying Camera*

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Summary—The camera to be described was designed expressly for lens-testing and precise copy work. Its rigidity, method of photographic plate location, and focusing accuracy are such that it fully utilizes the capabilities of the high-definition lenses and photographic plates used with it. Its general construction is sturdy, and it has been demonstrated, by four years of continuous use, that little or no maintenance or repair will be required for many years to come.

Introduction

During the war it became necessary for Bell and Howell to make photographic reductions of unusual accuracy and sharpness. At this same time, it was being found desirable to improve on the lens-testing camera then being used. It was thus decided to design and make a camera for both lens testing and copying. The resulting camera satisfactorily accomplishes both of these functions, and it is believed to have combined several desirable features which are worthy of description.

Camera Requirements

The photographic reductions which were to be made often demanded accuracy of size to tolerances of plus or minus one ten thousandth of an inch and sharply defined lines as narrow as four ten thousandths of an inch. In order to obtain such accuracy, the following three requirements are essential: (1) the camera must be rigid; (2) the photographic plates must be consistently and identically located; and (3) there must be provision for accurately measurable camera focusing. These requirements are equally essential in a lens-testing camera.

Rigidity—Rigidity avoids the possibility of camera movement during the relatively long exposures used in this type of work. Even in a

* Presented June 10, 1949, at the Central Section Regional Meeting, Toledo, Ohio.

reinforced concrete building with no heavy machinery, it was found that there was sufficient vibration to reduce picture definition noticeably when using a commercial plate camera.

Plate Location—It was necessary to be able to examine the image visually, and then to obtain that identical image on as many photographic plates as desired. Commercial plateholders are normally made of wood, and it is seldom that two plateholders will locate a plate in exactly the same position. Even the same plateholder cannot be relied upon for consistency of location. As a result, even though we intended to use standard plateholders to carry the plates, the plates had to be directly located by the camera.

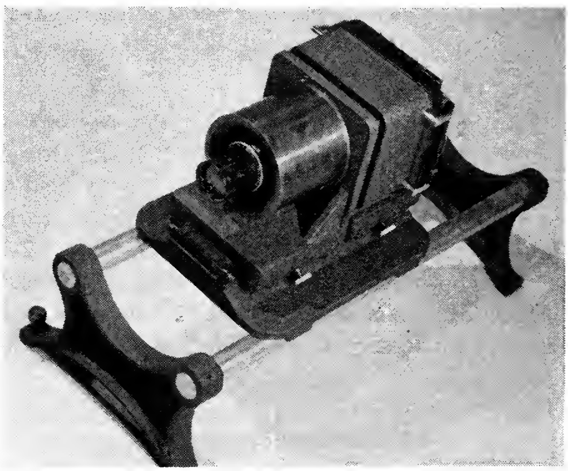

Fig. 1—Camera, front view.

Focusing—Another effect which is normally difficult to overcome is that the photographic focus and the visual focus of a lens are often different by as much as five or six thousandths of an inch. The reason for this difference is that the focal point of a lens varies somewhat with light wavelength. The high-resolution photographic plates used in this type of work are sensitive to wavelengths different from those of the eye, making the position of best focus for the plate different than is indicated when focusing visually. This focus shift of a lens can be closely measured, and can thus be compensated for by first focusing visually and then accurately moving the plate or lens through the known distance required to bring it into photographic focus. To be able to do this, it was necessary to provide means for accurately measured movement of both the lens support and camera back.

In addition to these three basic requirements of rigidity, direct location of the photographic plate by the camera, and accurate movement of both the front and back of the camera, several other features, though not required, were found to be desirable. These features included a single focusing knob for both the front and back of the camera, backlash-free focusing, means for locking both the front and back of the camera, and daylight loading.

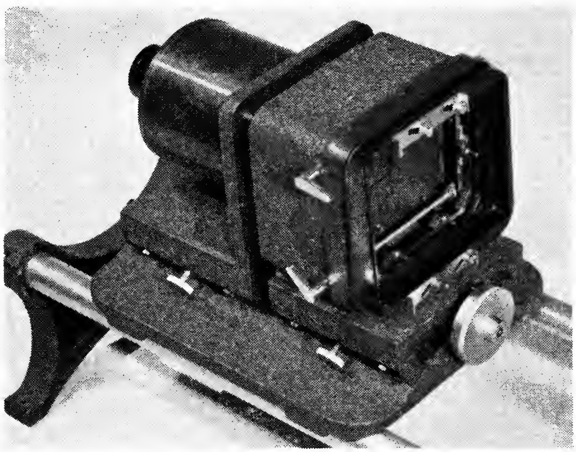

Fig. 2—Camera, rear view.

Description

It was realized, of course, that a camera such as this could not at the same time be made easily portable, and though every attempt was made to make it convenient for use, weight was not a primary consideration. Cast iron was thus used for the camera body and frame because of its desirable vibration-damping characteristics. In spite of this, the final weight of 53 pounds is quite reasonable. The camera uses standard 4 × 5 plates in standard plateholders, or in a special plateholder (described later) when the full extent of camera accuracy is desired. It would be possible to accommodate smaller sizes of plateholders with specially designed adapters.

The camera (Fig. 1) is adapted to fit the Bell and Howell standard optical bench which consists of two $1^1/_4$-inch diameter rods at a center distance of 8 inches. The camera base, lens support, and the upper and lower parts of the camera back are all iron castings. The lens support and camera-back castings slide independently on a steel dovetail which is mounted on the camera-base casting. These castings are fitted to the dovetail in the same manner as the cross-slide on a lathe, with the exception that the center adjustment screw and nut on each have been replaced by a thumbscrew. The thumbscrews are used to lock either the lens support or camera back in place when desired. The cast construction, together with the locking provision, contributes the utmost toward camera rigidity.

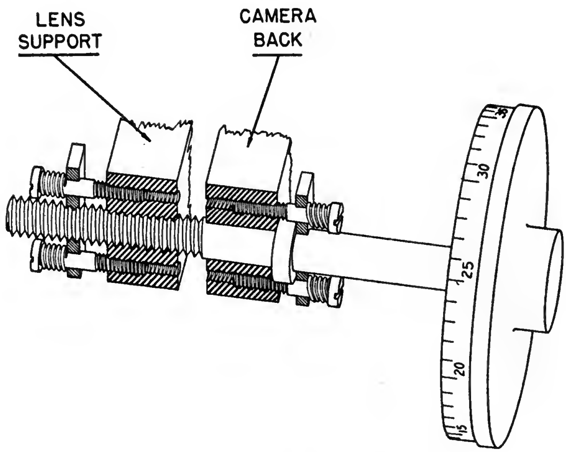

Fig. 3—Focusing mechanism.

At the rear of the camera (Fig. 2), convenient to the photographer, is the focusing knob. This knob is calibrated in thousandths of an inch, and moves either the lens support or camera back, whichever is desired. If the camera back is to be moved, the rear thumbscrew is loosened and the front thumbscrew tightened. The focusing knob then moves only the camera back. Loosening the lens support and tightening the back moves only the lens support.

Direct location of the photographic plate by the camera is accomplished by lightly holding it against six locating buttons in the camera while the exposure is being made. Since daylight loading was a convenient feature, it was necessary to be able to replace the dark slide of the plateholder before removing the plateholder from the camera. The plate, however, first had to be retracted from the locating buttons to allow the dark slide to enter the plateholder. This was accomplished by a cam-actuated plateholder mounting. The loaded plateholder is placed in this mounting and the dark slide removed. The cams, which are operated by external levers, are then rotated to bring the plateholder toward the lens until the plate contacts the locating buttons. When the exposure is completed, the cams retract the mount, the dark slide is replaced, and the exposed plateholder may then be removed. There is no danger of fogging the plate, since the camera back is lighttight throughout the entire operation. In order to prevent damage to the camera-locating buttons, when the plateholder is in shooting position the cam levers prevent removal or replacement of the dark slide.

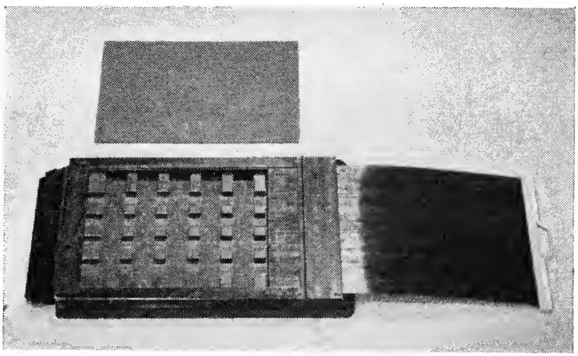

Fig. 4—Special plateholder.

The focusing adjustment (Fig. 3) is entirely free of backlash. The method by which backlash is eliminated is shown in the figure. The focusing knob shaft passes through a tab on the camera-back casting and is threaded into a tab on the lens-support casting. A collar on the shaft is held tightly against the camera-back tab on a small plate backed by two compression springs. The springs are retained in place by screws which are threaded into the tab and pass through clearance holes in the plate. This prevents the plate from turning with the shaft, and the screws serve also as adjustments for spring tension. Backlash is eliminated in the threaded end of the shaft in a similar manner, except that here the plate is threaded to the shaft. The provision for movement of both the lens support and camera back by means of a single backlash-free calibrated focusing knob completes the requirements of this precision camera.

A total relative movement between the lens support and camera back of $1^1/_2$ inches can be obtained with the focusing knob. (See Fig. 1.) Throughout this range of movement the camera is kept lighttight by interfitting metal baffles on the lens support and camera back. This eliminates the need for a relatively fragile cloth bellows. Additional separation between the lens and plate, when required for various focal lengths, is obtained by adapters and spacers which screw into the lens support. By the use of these adapters and spacers, a lens back focus (distance from lens seat to lens focal plane) of up to 18 inches can be accommodated.

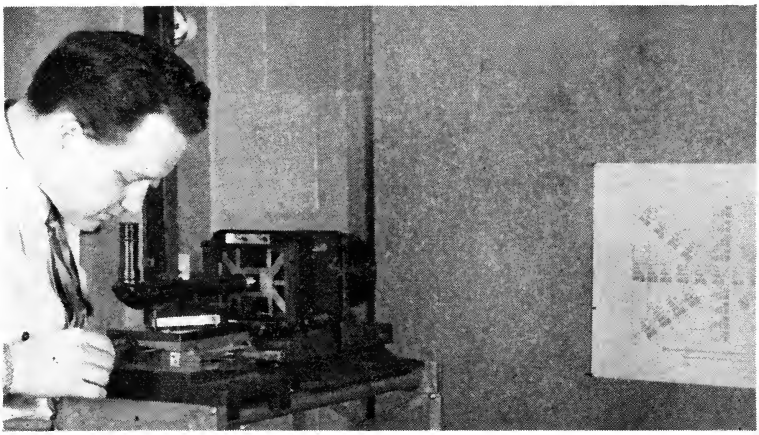

Fig. 5—Method of camera focusing.

After the camera had been made it was found that the photographic plates used were not sufficiently flat to take advantage of the accuracy which had been built into the camera. It was found that, in every case, the plates were warped so that they were concave toward the emulsion side of the plate, though any one plate was always very uniform in thickness. This difficulty was overcome by the use of a special plateholder in which a metal backing surface flattens the plate against the camera-locating buttons. (See Fig. 4.)

Method of Use

Photographic Copying—When the camera is used for photographic reduction, the camera-to-target and lens-to-plate distances are computed approximately. With the camera at the computed distance, an open-backed plateholder containing a clear-glass plate is inserted in the camera. (See Fig. 5.) A microscope, placed behind the camera on the same optical bench, is then focused on what corresponds to the emulsion side of the plate. The camera front is then adjusted until the image of the target is also brought into focus. This focuses the target image on the front surface of the plate. The microscope, which is mounted on a micrometer cross-slide, allows the image to be examined and its size measured. Minor adjustments are then made with the

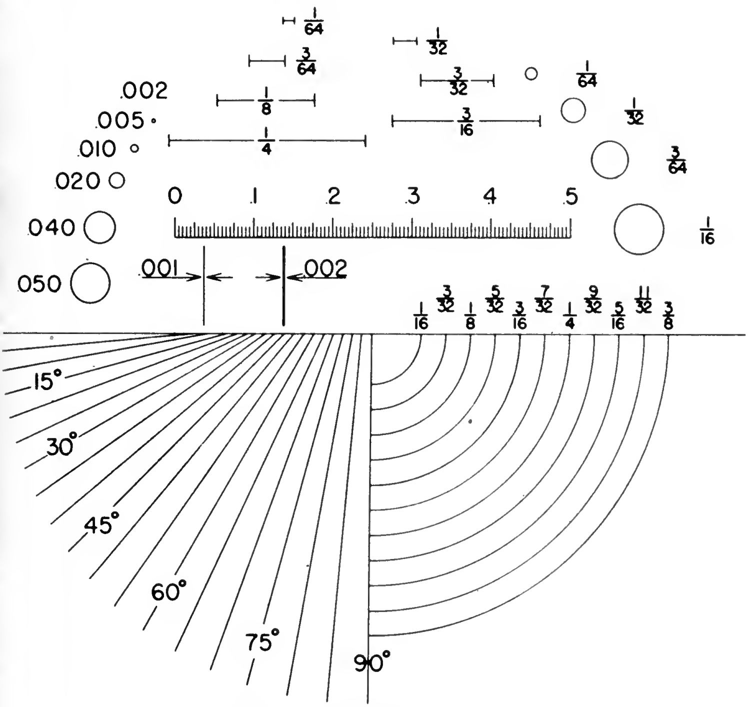

Fig. 6—Photoengraving master.

focusing knob to obtain the image size to the desired accuracy. When size and focus are satisfactory, the dummy plateholder is removed and the loaded plateholder is inserted in the camera. The dark slide is removed, and the plate brought into contact with the locating buttons by rotating the cam levers. The front surface of the plate is then in the same position as the clear-glass plate used for focusing the camera. At this point the correction for the difference between visual focus and photographic focus is made by movement of the camera back. The exposure is then made, the plateholder retracted, and the dark slide replaced. Any number of additional plates can be exposed at this same camera setting with the assurance that the results will be identical.

As an example of the type of work which is accomplished in this manner, Fig. 6 shows a photographic master which is used for photoengraving a Bell and Howell magnifier reticle. The reticles made from this master are mounted at the focus of a well-corrected magnifier. (Fig. 7.) The combination of reticle and magnifier is used for checking tool-bit angles, size of bubbles and flaws in optical elements, and accurate length measurements.

Fig. 7—Bell and Howell pocket comparator.

Lens Testing—When the camera is used for lens testing, the method of setting up the camera and lens combination is the same. The target, however, consists of a series of resolution charts, and several exposures are made while progressively moving the plate position through the plane of best focus of the lens. When desired, this series of exposures can be used to construct a contour map of the photographic image. Lens aberrations such as spherical aberration, astigmatism, and curvature of field may thus be accurately measured. Such a procedure is invaluable in evaluating lens quality and confirming the computations on a new lens design.

As an example of what is accomplished by this type of lens-testing procedure an enlargement of one resolution chart, at a considerable angle from the optical axis, is shown in the series of Figs. 8A to 8E. The exposures are spaced two thousandths of an inch apart, with the plates approaching and then passing through the position of best focus. This series of figures clearly shows the difference in focus between radial and tangential lines caused by astigmatism. Prints of such a series of exposures form a permanent record of lens performance which may be evaluated at any time without the presence of either lens, microscope, or optical bench.

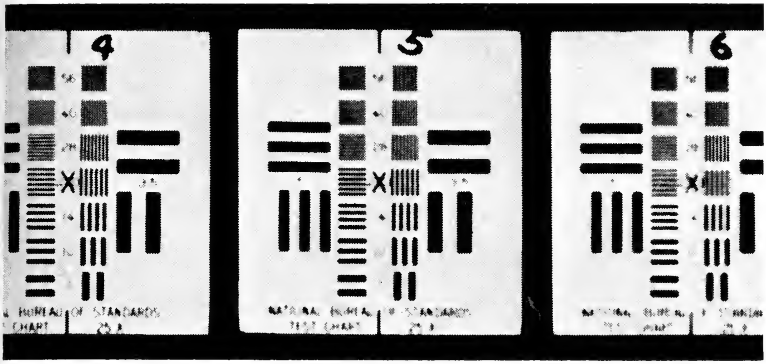

Fig. 8A

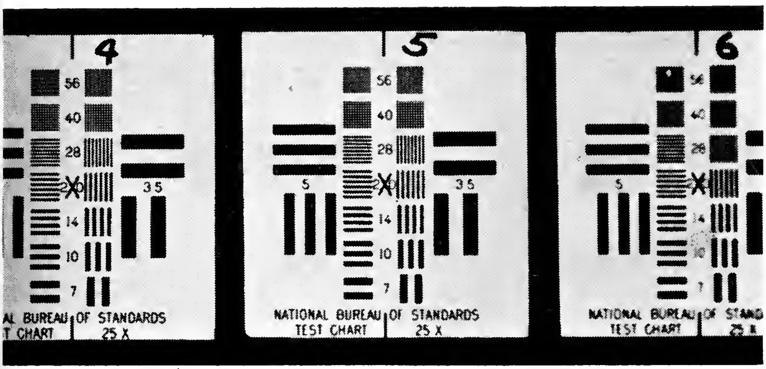

Fig. 8B

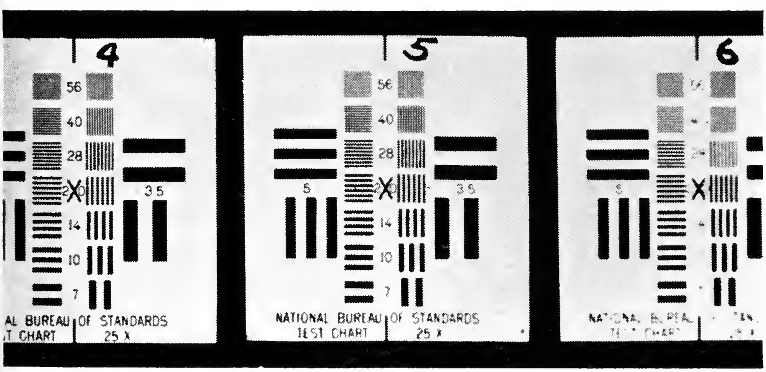

Fig. 8C—Resolution test plates.

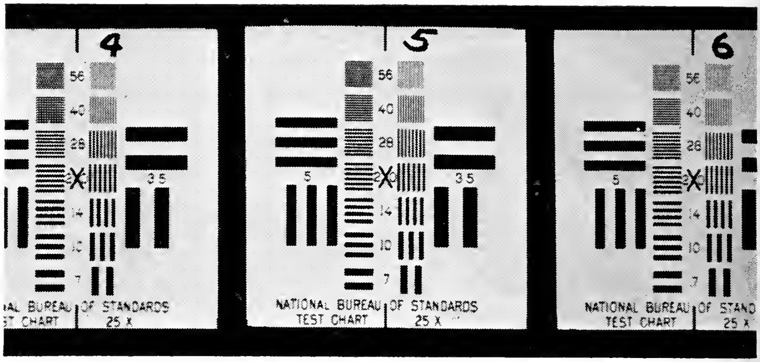

Fig. 8D

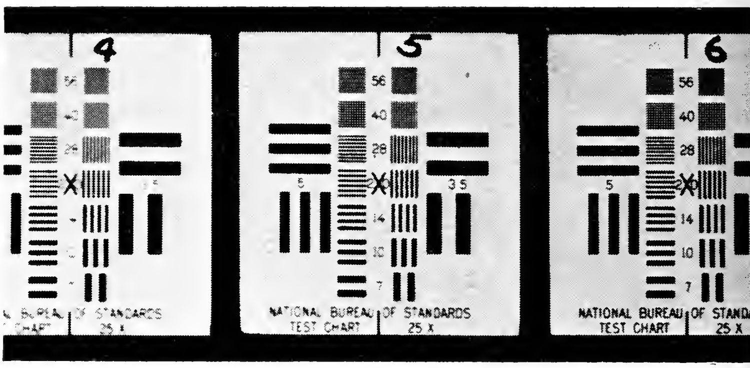

Fig. 8E—Resolution test plates.

35-Mm and 16-Mm Sound-on-Film Reproducing Characteristic*

By JOHN K. HILLIARD

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Summary—This paper reviews the activities and procedures used in the formation of the present 35-mm Motion Picture Research Council theater sound-equipment recommendations. Using this experience as a reference point, a 16-mm sound electrical characteristic is recommended. It is specified that in both 35-mm and 16-mm fields these recommendations apply only to a specific type of loudspeaker and individual response curves must be recommended depending on the type of loudspeaker used.

During the SMPE Semiannual Convention in Washington, D. C., in October, 1948, an informal discussion and demonstration was held to compile information that could be used in arriving at standards for 16-mm sound-on-film reproduction. Again at the Spring Convention in New York in April, 1949, a symposium was held to continue the discussion and to have demonstrations on a variety of prints and reproducing equipment.

The wide interest in standardizing 16-mm sound equipment would indicate the desirability of reviewing the activities which led up to the adoption of the 35-mm standard reproducing characteristic which has been very effective during the past twelve years.

There are many factors in the recording of sound for motion pictures which cause large variations in quality on the original recording. Some of these points will be briefly mentioned:

(1) The acoustic conditions in the various stages and out-of-doors vary over wide limits as regards absorption and reverberation.

(2) Restrictions are imposed by set designers, lighting effects, and camera angles which require compromise as compared to having the optimum microphone placement in all cases. Some sets have

* Originally presented October 27, 1948, at the SMPE Convention in Washington; revised later following the 65th Semiannual Convention in New York, April, 1949.

three walls, some have low ceilings, and very often one camera shot on the same scene will be made with a portion or all of the ceiling or wall removed in order to obtain the desired camera angle and/or lighting effect. In cases of exterior shots, the reverberation is extremely low and this is accompanied by a lack of both low and extremely high frequencies. These direct cuts from indoors to outdoors and back again are made at a pace which is faster than that encountered in real life. As a result, the individual scenes must be equalized so as to be more uniform in frequency characteristic.

(3) The various studios use different types of microphones depending upon the degree of directivity required to overcome set noise such as arc-light interference, wind machines, stage ventilators, and mechanical noise generated by props. These microphones have a considerable difference in response both in the low- and high-frequency ranges, and beam effects caused by changes in directivity require equalization in order to maintain uniform quality.

(4) The studio endeavors to do the best possible work on the original recording with a minimum of delays to the production, trusting that all these variations can be taken into consideration at the time of re-recording for release.

(5) Loye and Morgan[1] have pointed out the necessity of providing effort equalization to compensate for the fact that the speech is reproduced at a higher intensity in the theater than that which occurred at the time of recording. The typical studio re-recording console is equipped with variable low- and high-pass filters and a very effective set of midrange equalizers, capable of producing a proper subjective effect to the theater audience. It is not unusual to encounter variations in equalizer settings which approach a 25-decibel range on the low end in the neighborhood of 100 cycles and up to a 10-decibel change in the so-called "presence" region around 3000 cycles.

When all of these factors are taken into consideration, it is understandable that it is not practical to assign a recording characteristic in detail because of the many variables which occur during the process of recording and re-recording for release.

The following steps are recommended as a procedure for standardization in both studios and theaters:

(1) Derive the reproducing characteristic required to reduce the fundamental deficiencies of the medium such as noise and distortion.

(2) Install, adjust, and maintain theater-type reproducing equipment in the studio review rooms which have the optimum required reproducing characteristic.

(3) Adjust release film so as to have the required balanced frequency response and volume range required for theaters.

(4) Adjust equipment in all theaters so that it gives identical performance in so far as possible with that in the master review rooms in the studios. (This implies a definite frequency response, depending upon the exact type of loudspeaker used.)

(5) Maintain proper correlation between those responsible for studio and theater standards.

(6) Provide necessary test films which are considered standard and essential.

The first co-ordinated work in leading up to the adoption of a published theater reproducing characteristic for 35-mm film was started

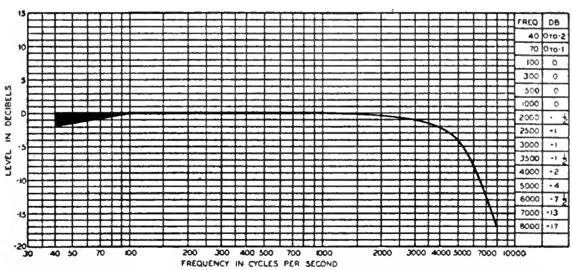

Fig. 1—Typical 35-mm Research Council recommended response curve.

in 1937. These standard electrical characteristics were arrived at by conducting listening tests in several theaters with the object in mind to obtain the most suitable characteristic which would suitably reproduce all of the current studio product then available. In arriving at this standard electrical characteristic, several fundamental factors had to be taken into consideration. It was recognized that the background noise on film made it necessary to use a characteristic favoring the reduction of this noise. This required that a certain amount of roll-off or droop in the high-frequency spectrum be used. This factor was evaluated by observing the characteristic required to reproduce unmodulated film with a gain setting which is normally encountered while running a picture. Having determined this characteristic, it was then necessary to analyze the recording characteristic and verify that this reciprocal amount of pre-equalization could be used. An example of a typical response curve recommended by the Motion Picture Research Council for 35-mm work is shown in Fig. 1. This response applies only to a specific type of loudspeaker.[2]

In order to make available adequate acoustic power it is necessary to determine the efficiency of the various loudspeakers. A typical curve showing the recommended power for a given number of seats has been published by the Research Council. This recommendation assumes a loudspeaker efficiency of approximately 25 to 35 per cent over-all.

Limitations in the region below 100 cycles are required because of the presence of noise reduction or shutter bumps. The timing constant of the noise-reduction equipment is such that this occurs below 50 cycles. It is the author's opinion that an ideal theater reproduction should include a high-pass filter which begins to cut off at 45 or 50 cycles. This would allow maintaining the characteristic more nearly flat down to cutoff.

By reviewing the procedure for creating the 35-mm standard, it should clarify the ideas considered necessary to formulate the 16-mm standard reproducing characteristic. A large amount of 16-mm output is derived from original 35-mm film. The general standard for film-laboratory development equipment in present 16-mm release has been lower than that for the 35-mm field. This undoubtedly has been influenced by the cost to the user. Recording characteristics have been largely influenced by high rates of flutter, wow, low amplifier capacity, low efficiency, and poor response of loudspeakers. The loudspeakers have been of the inexpensive type and usually small portable cabinets are used.

In Fig. 2 the solid line shows the response that has been used for many years in the re-recording channels to minimize the above deficiencies. The dotted curve is the re-recording channel curve that is now being considered for extensive use. These curves have been arrived at on the basis of listening to loudspeakers designed for 35-mm work and by taking into consideration the defects which have been present in 16-mm. These curves are re-recording curves only and should not be misconstrued as a recording characteristic.

Recently, demonstrations have been held which indicate that equipment is now, or will shortly be, made available, which removes many of the objections mentioned. Improved printers, direct positives, and 16-mm projectors incorporating 35-mm features demonstrate that much better 16-mm work will be done in the future. Optical slits, giving an effective scanning height of 0.6 to 0.7 of a mil, are now being employed. This means that response can be obtained up to 5000 cycles without excessive equalization. It seems logical and practical to have the electrical characteristic for 16-mm reproduction follow very closely that of 35-mm up to 5000 cycles. Low-pass filters can then be installed at 5000 or 6000 cycles, depending upon the nature of the material and application. As was considered on the 35-mm characteristic, the loudspeaker system must be taken into consideration when evaluating the final reproduction curve.

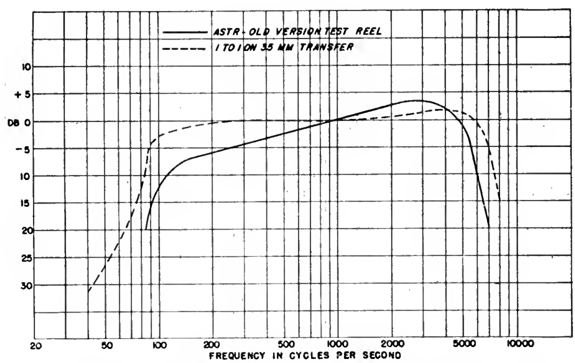

Fig. 2—Approximate re-recording characteristics; 35-mm release sound track for 16-mm release.

Fig. 3 shows the recommended optimum response which is easily obtained with simple networks, and the dotted line shows the ideal characteristic that is desirable. In portable equipment it naturally follows that the characteristic must be balanced around a geometric mean[3] of 800 cycles. It is not advisable to extend the high-frequency end when the loudspeaker enclosure will not maintain a balance at the low end. Where larger two-way systems are to be used, and are the equivalent of that being used in 35-mm, the over-all characteristic can approximate the 35-mm characteristic over a range of approximately 80 to 6000 cycles.

The Navy has recently indicated that all of their future planning for mobile or portable motion picture presentation will use only 16-mm release. As a result of this large single user, it seems desirable to have a committee of the Society of Motion Picture Engineers provide a recommended curve in the same manner that the 35-mm field has already been standardized.

In closing it is recommended that the following steps be taken to standardize 16-mm sound-on-film reproduction.

(1) Use a reproducing characteristic which is similar to the 35-mm characteristic except for minor deviations on the very low- and high-frequency bands.

(2) Provide recommended reproducer characteristics which will vary depending upon the type of loudspeaker used.

(3) Publish information about currently available test films in order to accomplish this standardization.

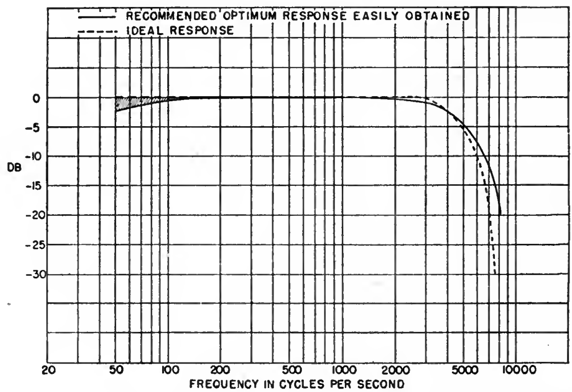

Fig. 3—16-mm electrical response for 2-way theater loudspeakers.

(4) Establish a responsible group to correlate recording and reproducing activities so that standards may be modified when the art permits.

This material has been presented in the hope that a discussion of the principles involved will enable workers in the field to arrive at an agreement which will promote higher standards of quality in the 16-mm field.

NOTE: Since this paper was presented, the Society of Motion Picture Engineers 16-Mm Sound Reproduction Subcommittee April 7, 1949, Report unanimously agreed to accept the electrical characteristics recommended in Fig. 3 solid line.

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(2) Motion Picture Research Council, Inc., Technical Bulletin, "Standard Electrical Characteristics for Theater Sound System," April 20, 1948.

(3) "Motion Picture Sound Engineering," D. Van Nostrand, New York, New York, p. 100, 1938.

DISCUSSION

MR. J. A. MAURER: Mr. Hilliard, how would a projector manufacturer go about measuring the equipment to determine that he has the response recommended.

MR. J. K. HILLIARD: The Society of Motion Picture Engineers has test films which are calibrated on the basis of what you might call constant modulation and certainly by placing those in the projector and measuring, you ought to be able to determine the performance conditions in so far as frequency response occurs. Other types of tests as used in the 35-mm field are also available for 16.

MR. MAURER: I wanted to make sure that you did intend those curves to be expressed in terms of the standard test films.

MR. J. K. HILLIARD: Yes. It should have been indicated on the slide that they were in terms of constant modulated films.

MR. ELLIS W. D'ARCY: Is there anything proposed to tighten up conditions with respect to quality and things like that? Is there to be a standard established at this time in that respect as well as frequency-wise?

MR. J. K. HILLIARD: Certainly we cannot extend the frequency range without improving the other techniques which are admittedly deficient up to this time. As you all know, such things as flutter and distortion have contributed to keeping the range as limited as it is now and we hope by co-ordinating the work of all those interested, from the manufacture of the film down to the final release in the theater, to get these people together on a common understanding as to where the bottlenecks now exist and, if possible, open up those to a point where the present handicaps will not be maintained.

Desirable Locations for Theater Sites*

By E. G. FALUDI

Planning Consultant, Toronto, Ontario, Canada

Summary—Land economics, sociology, and physical planning have enabled us to determine with scientific exactness the characteristics of the urban retail structure, of which the theater is a part. Today, the selection of the location of the theater is more important than ever before because of various new trends adversely affecting the motion picture industry. The following is the basic information required to determine the suitability of a location and site for a theater: size of the tributary population; living and spending habits; the retail pattern; physical characteristics; and the anticipated development of the area. Once these factors are ascertained, we can determine the relation between seating capacity and population in the tributary area and evaluate the economics involved.

Over the period of half a century, the motion picture industry has grown to one of the five largest industries in the United States. This achievement is partly because of the leadership of a pioneer generation which had the business acumen to foresee the possibilities inherent in the motion picture and which had the capacity to develop and industrialize it. For the last ten years, however, social and economic trends, new technological inventions, and developments within urban and rural areas have been endangering the privileged position of this industry.

What the direct effect of these trends and changes will be on the industry as a whole is difficult to forecast, since no over-all survey has been undertaken covering each of its fields or branches.

However, sufficient data and information are available to define the anticipated effects *on the motion picture theater* and to establish the conditions under which it may operate and serve a community most successfully.

Trend in Social Activities and the Motion Picture Theater

The importance of the trend in social activities as related to the motion picture theater is revealed by recent surveys conducted on the

* Presented April 8, 1949, at the SMPE Convention in New York.

North American continent and in five European countries. In one of these surveys the question was asked "Would you mind telling me which, if any, of the following you did last night?" The person interviewed gave his answer from the list of activities and the answers were compared, as shown in Table I.

TABLE I

SURVEY OF SOCIAL ACTIVITIES

	U.S.A. and Canada	Denmark	Holland	Sweden	Norway	France
	Percentage					
Read	19	23	17	21	21	21
Listened to radio	28	13	18	22	18	22
Entertained or was entertained	17	16	18	19	6	12
Played cards	10	6	6	2	4	1
Went to motion pictures or theater	7	4	7	4	5	7
Watched sports	4	...	1	...	...	...
Danced	2	...	1	...	1	1
Other	13	38	32	32	45	36
	100	100	100	100	100	100

This survey indicates that in the United States and Canada, as a form of commercial entertainment the radio attracts four times as many people as motion pictures. (See Fig. 1.) The high percentage of radio listeners in relation to those who go to motion pictures is chiefly because the former offers free entertainment. In the field of paid entertainment the closest competition is the sport show which attracts 4 per cent as compared with the 7 per cent attracted by the motion picture.

TREND IN SOCIAL HABITS AS RELATED TO THE MOTION PICTURE THEATER

The most recent indication of the impact which television is having on social habits is contained in a survey conducted by the Duane Jones Company among television-set owners in the metropolitan area of New York. A questionnaire was mailed out in mid-November to 4500 television-set owners, and the results are based on a 35 per cent response.

Of those answering the poll, 92.4 per cent said that they now listened less to the radio, *80.9 per cent see fewer motion pictures,* 58.9 per cent read books less, 48.5 per cent read magazines less, and 23.9 per cent read newspapers less.

On the other side of the ledger, 72.1 per cent reported that more children visited their homes on social visits and 76.8 per cent said that their adult entertainment had increased.

THE THEATER AND POPULATION

In order to evaluate these data with reference to anticipated theater attendance, we shall consider first the potentiality of the theater in relation to population figures.

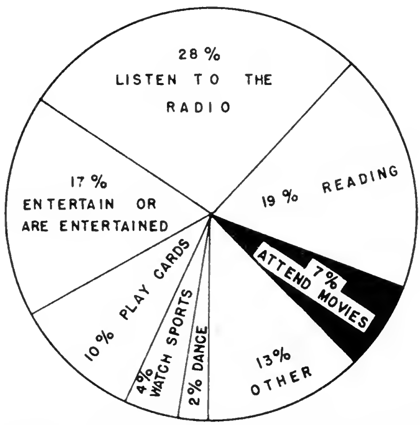

Fig. 1—Social activities in the United States and Canada.

In the large urban centers of Canada and the United States, there is a theater seat provided for every 7 to 8 people. In Canada with a population of approximately 12,300,000 there were 1477 theaters in 1946, having a total seating capacity of 758,640, a seat for every 17 persons. The total number of admissions was 215,000,000 or 293 per seat for the year. The average revenue per seat for the year was $72.00.

Had each theater played to a full house at each performance attendance could have numbered 605,000,000. Actually, therefore, only 37.6 per cent of the total seating capacity of the theater was utilized. It may be assumed that this figure will decrease because of the following trends:

1. Technological

The development of television, bringing visual entertainment within easy reach of the individual and large groups as well.

2. Social

The increasing interest in home entertainment, which radio and television provide free.

3. Economic

The decrease in effective family income, because of reduction of industrial employment opportunities for women and the change from inflation to deflation in our economy.

4. Physical

The increasing demand for up-to-date facilities and conveniences inside and outside the theater auditorium, because of competition with other forms of commercial entertainment and the increasing number of cars.

5. Urban Development

The decentralization of industries and the development of new residential areas on the fringe of established urban centers, which will make necessary new theater facilities at the expense of those already established in the regional area.

In view of these trends, the theater operator who intends to build a new theater faces the following problems:

(a) how to utilize more than 37 to 40 per cent of the potential seating capacity.

(b) and consequently, how to achieve a profitable yearly revenue per seat.

The answers to these problems cannot be provided simply by a mathematical formula, but only by considering a number of factors involved.

6. Determining Factors of Revenue per Seat

There are four major factors which directly affect the revenue per seat of a theater:

(a) The class of picture the theater offers. (This depends largely on the films available in the motion picture film market and the demand of the population from which the theater draws its attendance, as related to age groups, purchasing capacity, spending habits.)

(b) The location of the theater from the point of view of accessibility and the population density of the surrounding residential areas within a mile radius.

(c) The size and design of the theater, which ultimately governs the capital investment and the operating costs.

(d) The facilities provided by the theater inside and outside the auditorium.

7. *Importance of Location*

The importance of the location of the theater cannot be overemphasized. Literally, many millions of dollars are involved in the selection of proper locations for theaters. There is no doubt that good pictures can modify temporarily the handicap of an inappropriate site but they cannot completely overcome this disadvantage.

In order to analyze the specific locations that are more desirable than others, we shall distinguish the following areas, in which theater sites may be considered:

1. Large urban centers.
2. Fringe areas.
3. Suburban neighborhoods.
4. Small towns in the regional areas of large cities

LOCATIONS OF THEATERS IN LARGE URBAN CENTERS

The basic structure of a city is composed of several functional areas—central retail and business sections, wholesale areas, industrial areas, residential districts, and their neighborhood shopping centers. These areas are generally scattered segments of a series of concentric circles. At the center is the financial and office district, immediately surrounding this is the central shopping area. In one section of the latter there is always a scattering of theaters, generally next to the window display stores. The motion picture theater tries to attract the man, or especially the woman, on the street. To do this, it must be easily accessible to the window-shopping crowd.

The motion picture business has demonstrated clearly how proximity of competing houses aids business. In many cities, all the downtown motion picture houses are located on one street, and even within three or four adjoining blocks.

A survey and analysis of retail centers of 24 cities in 20 different states, covering 135 blocks, reveals an interesting pattern and relationship between theaters and stores.

According to this survey, theaters represent 10.7 per cent of all store units, while restaurants represent 9.2 per cent. The next types in order of importance are shoes, jewelry, and men's furnishings, each about 5 to 6 per cent, women's clothing stores, candy, drug, cigar stores, each about 2 to 3 per cent. Restaurants and snack bars are in nearly every block where there is a theater. Moreover there are almost as many restaurants in a block containing theaters as there are theaters.

With the exception of downtown areas, theaters show no strong tendency to be grouped in the same blocks. In 135 blocks containing theaters, two theaters per block were found in only 13 cases, and three theaters per block in three cases.

Generally speaking, in blocks containing theaters, the following store uses comprise one half of the total occupancies: theaters, restaurants, men's furnishings, shoes, jewelry, women's clothing, candy, drugs, and cigars.

An important share of the retail business of the city is, however, conducted outside the central area in retail subcenters extending along major streets and in neighborhood shopping nuclei. In such locations, the proximity of residential districts justifies the location of a theater.

POPULATION AND THEATERS—TORONTO

An interesting study covering the city of Toronto indicates the relationship of population to theaters situated outside the downtown business center. The survey was conducted within concentric zones one mile apart. (See Figs. 2 and 3.) The first zone is around the central shopping area and the last one, 6 miles distant, takes in the fringe of the metropolitan area. Table II shows the number of people and theaters at various distances from downtown Toronto and the population per theater seat.

This tabulation reveals that the number of theaters and their seating capacity increase as the population increases up to the zone which is 3 to 4 miles from the downtown area. (See Figs. 4, 5, and 6.) These figures then decrease to the limit of the urban area which is 6 miles from the center. Population per theater and per seat, however, increases from about 4745 to 11,650 and from 5.16 to 17.93, respectively. The figures also indicate that the supporting population required per seat increases with the distance of the zones from the center, increasing by approximately 2 to 3 persons per mile.

Another interesting feature of the survey is that there is a relation

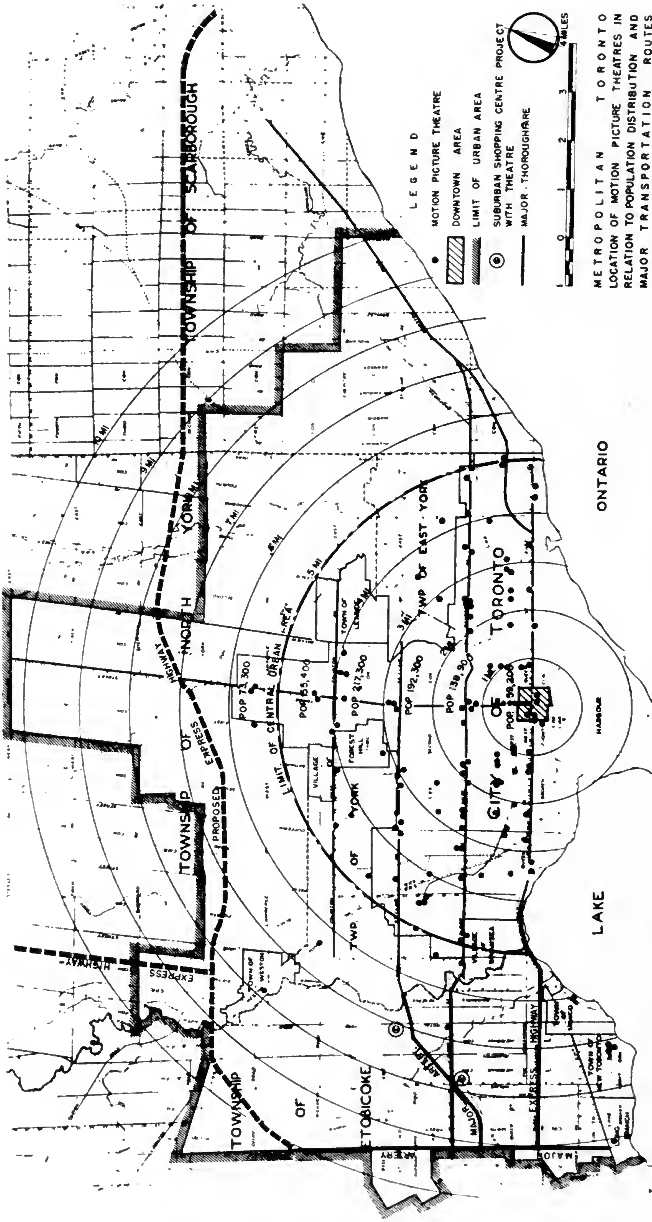

Fig. 2—Map of theater locations.

between the number of the supporting population required and the density of residential population per acre, the purchasing capacity, and the spending habits of the residents. In high-density areas with low-income groups, the supporting population per seat varies from 3.3 to 7. In low-density areas with high-income-class groups, it varies from 7 to 19.

The nucleus of retail business along thoroughfares attracts the establishment of theaters. In Toronto, along three major thoroughfares, on a stretch of 6 miles, there are 25, 17, and 16 theaters, respectively. Along secondary thoroughfares for the same distance, the maximum number is 8, and the minimum is 1. Both these major and

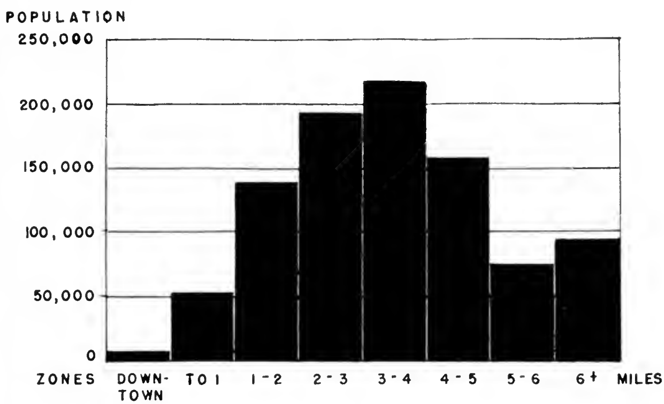

Fig. 3—Population on concentric one-mile zone.

secondary thoroughfares possess a large number of scattered shopping and convenience goods stores, and carry a heavy concentration of vehicular traffic.

LOCATIONS OF THEATERS IN FRINGE AREAS

The Toronto survey shows that between the 5- and 6-mile zone there is a population of 73,000 with 8 theaters, having a total seating capacity of 6000. The average seating capacity of these theaters is 750. The average number of people per theater is 9000 and per seat 12. The location of the theater is closely related to the local shopping area, which consists of a large number of grocery, fruit, and vegetable, drug stores, meat markets, and other convenience goods outlets, interspersed with a lesser number of men's and ladies' wear stores. Almost without exception these stores draw customers from within

TABLE II
RELATION BETWEEN THEATER LOCATION AND POPULATION PER SEAT
(Data—1945 population map—Town Planning Consultants Limited)

	Population	Theaters	Seats	Persons per Theater	Persons per Seat
1. Downtown area	7,000	9	13,583	660	0.52
2. Within 1-mile radius excluding the downtown area	52,200	11	10,115	4,745	5.16
3. Between 1- and 2-mile radius	138,900	19	16,566	7,310	8.41
4. Between 2- and 3-mile radius	192,300	28	21,420	6,868	8.97
5. Between 3- and 4-mile radius	217,300	26	21,042	8,358	10.33
6. Between 4- and 5-mile radius	155,400	19	15,851	8,179	9.80
7. Between 5- and 6-mile radius	73,200	8	6,092	9,275	12.00
8. Beyond 6-mile radius	93,200	8	5,198	11,650	17.93

Metropolitan Area Toronto

Total Population (1946 estimates, Dominion Bureau of Statistics)

Population	Theaters	Persons per Theater
959,308	128	7573

easy walking distance, that is, from the area within a $^3/_4$-mile radius. It is obvious that a new theater here depends exclusively on the number of people living in such an area.

LOCATION OF THEATERS IN SUBURBAN NEIGHBORHOODS

The suburban neighborhoods are the frontiers of future urban development, and therefore they are potential locations for new types of shopping centers and theater sites.

Both the United States and Canada have embarked on a vast housing program. In the coming decade, in all likelihood, millions of homes will be built. The recognized trend is toward the establishment of residential districts in which residents share the common services, social activities, and facilities provided in the vicinity of the

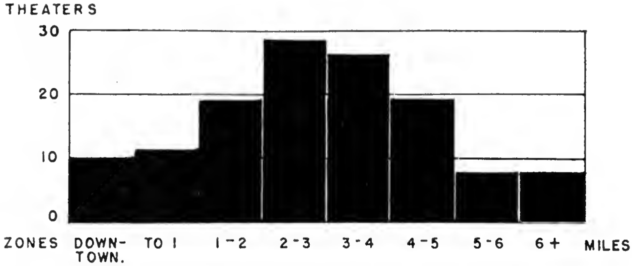

Fig. 4—Theaters in concentric one-mile zones.

dwelling. Such neighborhoods obviously depend on the larger urban centers for their basic employment, transportation, and cultural facilities. Their shopping centers should contain only the types and number of stores which can be well supported by their own population.

However, if the shopping center is near to highway approaches from other areas, it frequently will draw a sizable portion of business from outside its tributary and trading area. It may attract attendance from the urban center itself if large parking areas are provided, and thus reverse the magnetic attraction of some theaters situated in the central area.

The greater the increase of population in outlying areas, which is expected to result from the construction of urban freeways or limited-access highways providing access to the central city area, the greater will be the growth of outlying neighborhood business centers.

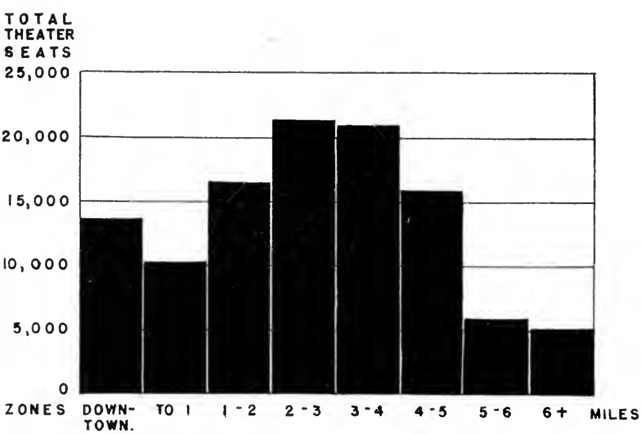

Fig. 5—Total theater seats in concentric one-mile zones.

In the Toronto metropolitan area, two large-scale neighborhood business developments with theaters are under preparation at present. In each case, the theaters planned will be twin buildings starting with an auditorium of 750 seats, which will be duplicated later as warranted by population increase. Parking facilities will be provided for over 500 cars, or one parking space for every $1^1/_2$ seats.

LOCATION OF THEATERS IN SMALL TOWNS

The small town is rapidly coming to the fore all over the country. It has been demonstrated that industry is tending to operate in a larger number of places rather than concentrating in already congested

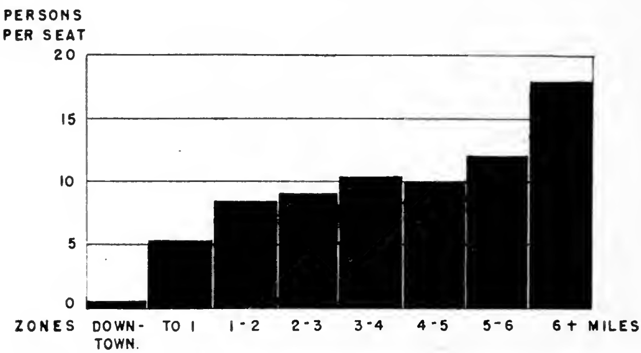

Fig. 6—Persons per theater seat in concentric one-mile zones.

areas. The small cities where industries are or may be located fall into two categories: those with a population between 10,000 and 25,000 (there are 662 such towns in the United States); and those with a population between 25,000 and 50,000 (there are 212 such cities in the United States).

Some of these are independent communities, depending on a metropolis in no major way. Another type is the suburban residential city closely related, physically and economically, to a large city. There are also those small communities which are dependent upon a single industry, and are closely affected by its fluctuations.

In all these communities new theaters with up-to-date facilities will be required as industrial and population growth will warrant it.

When locating a theater in these communities a careful study will be required of existing theater facilities and population per seat, population growth, age groups, purchasing power, and spending habits as well as the characteristics of the business centers.

CONCLUSIONS

In the early stages of the motion picture industry the location of the theater was chosen by pure common sense and intuition. The theater industry had no tradition, and had to find its own way by experimental and empirical methods. However, with the help of land economics, sociology, and physical planning, we are able to determine with scientific exactness, the characteristics of the dynamic organism of the city. We are also able to identify the reasons for constant flux of the retail structure in the urban areas in response to economic forces. As the theater is part of the urban retail structure, to a large degree, it succeeds or fails as its location within the city structure is favorable or unfavorable.

Today the selection of the location is more important than ever because of the new trends already mentioned.

The following are the basic steps in determining the suitability of a location or site:

1. To determine the size of the population from which the anticipated attendance will be drawn, within a radius of 1 to 2 miles.
2. To identify the social and economic groups of the area tributary to the theater and the living and spending habits within these groups; also to identify the age composition of the population and to determine the population density and population growth.
3. To study the retail pattern of the area, the accessibility of the site, traffic conditions, and transportation facilities.
4. To define future residential, industrial, or commercial developments and probable changes in the area with reference to planning projects (new housing, zoning, slum clearance, and highways).
5. To consider these findings in relation to existing theaters in the area, their seating capacity, and population per seat in the tributary area.
6. To evaluate all findings in relation to capital investment in land and building, anticipated operating costs, and revenue.

While we should remember that special conditions prevail in each community, this suggested technique will assist with certainty, in selecting a desirable location for a theater.

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New Portable High-Intensity Arc Spotlight*

By RUSSELL J. AYLING

Strong Electric Corporation, Toledo 2, Ohio

Summary—**The spotlight to be described includes many features which are the result of an extensive investigation of desirable characteristics in such devices. An integral transformer supplies low-voltage alternating current to the arc from any 115-volt, alternating-current outlet at a drain of only 10 amperes. A double-element variable-focus optical system allows the spot size to be continuously adjusted with negligible light loss.**

Introduction

For many years there has been a need in theatrical and allied fields for a lightweight portable spotlight of extremely high intensity. The operator either depended upon an incandescent or vertical arc-type spotlight for short projection distances, or the large theater-type spotlights which employ heavy rotating equipment and tremendous power consumption. The Strong "Trouper" designed for use in theaters, auditoriums, and night clubs is an answer to this need. (Fig. 1.)

Featuring an automatic carbon feed, the new "Trouper" produces a brilliant white, uniformly illuminated, and clear-cut spot, which supplies that extra sparkle to a performance, obtainable only with the use of high-intensity carbon arcs. With a color temperature of approximately 5700 degrees Kelvin, as measured with an Eastman color temperature meter, the brilliancy of spot greatly surpasses any incandescent or vertical low-intensity carbon-arc spotlight and actually will equal many of the large high-intensity types.

The "Trouper," with a net weight of 215 pounds, has been developed with the thought in mind of simplicity, portability, and ease of operation. It takes a new operator only a few moments to master efficiently the operation of this well-balanced spotlight.

The power requirements are extremely modest. Drawing 10 amperes from a 115-volt outlet, the power rating is only 1 kilowatt. The following description of the design and operation of the "Trouper" covers (1) base and power supply, (2) lamp and optical system

* Presented June 10, 1949, at the Central Section Regional Meeting, Toledo, Ohio.

mounting channel, (3) lamphouse, (4) lens optical system, (5) color boomerang, (6) optical system calculations, and (7) "Trouper" and television.

BASE AND POWER SUPPLY

The rigidly constructed base serves a dual purpose in supporting the lamp and optical system, and also housing the power supply. (Fig. 2.) The base is mounted on three rubber casters making it readily

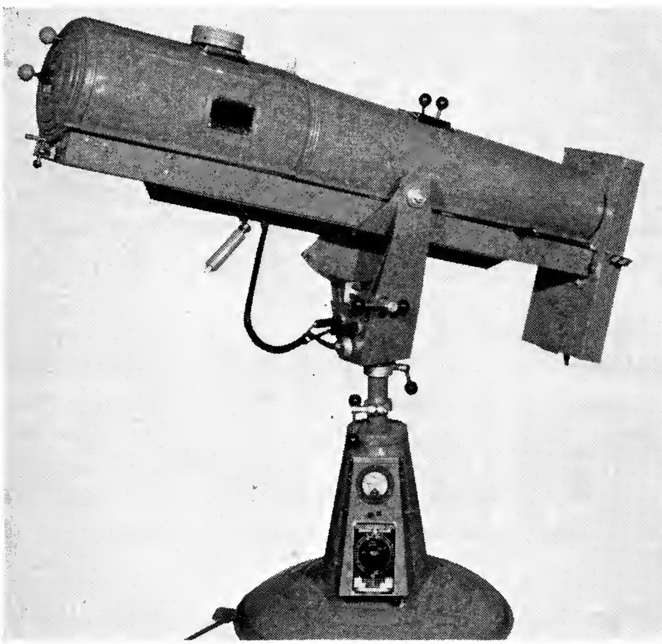


Fig. 1—"Trouper" spotlight.

portable. If it is desired to have a more rigid mounting for permanent installations, three jackscrews are provided and adjusted until the weight has been shifted from the casters to the screws.

The power supply is a compact, highly efficient, adjustable, transformer which reduces a 115-volt, 60-cycle, alternating-current supply to 21 volts at the arc. If desired, special transformers can be supplied for practically any voltage or frequency range. The transformer is mounted underneath the base, in an out-of-the-way location.

The standard 115-volt transformer is designed with a manual tap-changing system to allow for any commercial voltage variations between 95 to 135 volts. The conveniently located coarse tap adjustment has three leads mounted on a terminal block. The line-feed wire is connected to the terminal having the voltage marking most nearly equal to the local voltage condition. If a finer adjustment is desired, an eight-position dial switch efficiently serves the purpose. A quick twist of the switch in the desired direction will instantly change the power consumption without extinguishing the arc.

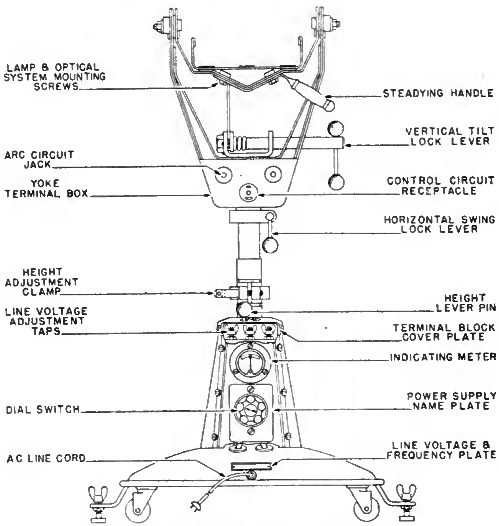


Fig. 2—Base and power supply.

An indicating voltmeter eliminates guesswork in adjusting the transformer for proper arc voltage. The meter dial is equipped with a green zone. When the needle is in the center of the green zone, the correct power is being supplied to the arc, and the correct gap will be maintained.

The top section of the base, called the yoke-and-cradle assembly, is connected to an adjustable, tubular column. This allows the optical centerline of the spotlight to vary in height from 46 to 58 inches. Practically any working condition can be mastered within this range.

A five-wire braided electrical cord, connected to the transformer is neatly concealed by running through the tubular column to the yoke terminal box. The three control wires are connected to a polarized twistlock receptacle, and the two heavier power wires are connected to individual electrical jacks.

A horizontal swing-lock lever, and a vertical tilt-lock lever mounted on the yoke, can be set to give the required amount of friction to suit the individual operator, when following a moving act. The spotlight can be swung through a full 360 degrees horizontal travel, tilted down to angles of 45 degrees or more, and tilted up to approximately 30 degrees.

LAMP AND OPTICAL SYSTEM MOUNTING CHANNEL

A heavy-gauge-steel U-shaped channel is employed to give a precision mounting platform for the lamp and optical system units. Being $4^1/_2$ feet in length this channel is rigidly reinforced to guard against any bending or twisting moments that might occur.

The lamp and optical system are mounted separately in this channel and each is held securely in optical alignment by three conveniently located screws. The channel is fastened to the base cradle by four easily inserted retaining screws. This makes the "Trouper" easily disassembled into two units for shipment.

LAMPHOUSE

The rigid lamphouse is designed to accommodate an alternating-current high-intensity carbon arc. (Fig. 3.) The correct carbon trim is two 6-mm $\times$ 7-inch National alternating-current high-intensity, copper-coated carbons which operate at 45 amperes and 21 volts.

The carbons, having a burning rate of 4.3 inches per hour, are fed automatically from a lead screw, which is rotated by a 20-revolution-per-hour synchronous drive motor. At this rate, a full trim of carbons will burn for $1^1/_3$ hours. This precision method of feeding results in a constant arc gap, and essentially no carbon drift. The carbons are held securely in the jaws by a special heat-resistant leaf spring. By use of a lifting cam the spring is decompressed rapidly for changing carbons. Knobs, for manual striking of the arc, and focus adjustment of the arc, extend through the rear of the lamp in a convenient location.

A silvered, glass reflector, elliptical in shape, efficiently collects the arc-crater light and directs it to a circular aperture. The crater is magnified $7^3/_8$ times its original size at this aperture. The physical dimensions of the reflector are $3^1/_4$-inch focal length, 24-inch working distance, and $10^1/_4$-inch diameter.

Horizontal and vertical reflector tilt adjustment handles, project through the rear of the lamp, and assure quick alignment of the projected carbon crater on the aperture hole. To keep the reflector free from copper deposits caused by carbon sputtering or falling molten copper, a special heat-treated glass deflection shield, $2^1/_2$ inches by 4 inches, is inserted between the arc and bottom portion of the reflector. The copper deposits will collect on this shield which can be replaced from time to time at very little cost. There is negligible light loss as a result of this glass. A special safety feature is a door-operated line switch to assure that all power to the arc is turned off when the lamphouse door is open. Another line switch (toggle-type) is conveniently located at the top rear section of the lamp.

The lamphouse, constructed entirely of sheet metal, has a large cubical content for the size of the arc, resulting in a cool operating

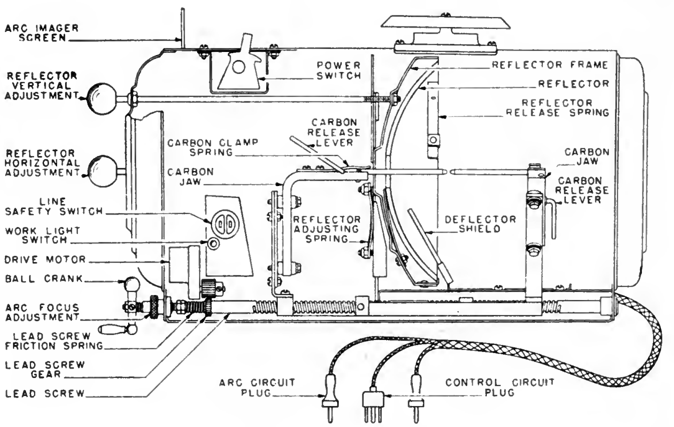


Fig. 3—Lamphouse.

lamp. The lamphouse door is equipped with a colored glass window for viewing the arc characteristics. An arcescope screen, located at the top rear of the lamp, projects a side pinhole image of the carbons for convenience to the operator in keeping a correct focus.

A five-wire braided cord, from the lamp, is plugged into the yoke terminal box, thereby completing the circuit to the power supply. This method of electrically connecting the lamp and base provides for quick disconnect when disassembling the "Trouper" into two units. Many times the operator must trim the lamp in semidarkness. A door-operated trimming light adds to his convenience.

Lens Optical System

The lens optical system is a new method of efficiently utilizing all light passing through the aperture. (Fig. 4.)

A two-element, variable-focal-length lens system, which continuously focuses on the aperture, is used to project the desired spot sizes. This system consists of a $2^1/_2$-inch focal length, 2-inch diameter double convex pyrex lens, and an 18-inch focal length, 7-inch diameter plano-convex objective lens. A handle mounted on the side of the large lens carriage controls the variation of projected spot size. This handle may also be utilized to vary the angularity of the spotlight to maintain the spot on a moving act.

A specially designed linkage is provided to control the relative movement between the two lenses. The linkage properly adjusts, automatically, the distance between the lenses as they are moved toward or from the light source. A clear-cut spot is created at any po-

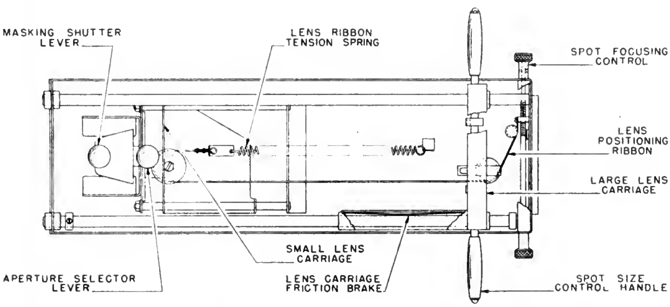


Fig. 4—Lens optical system.

sition. A spot-sharpness focusing control slightly changes the relative position of the lenses, to compensate for variation of projection distances.

The aperture plate, upon which the lens optical system is focused, has three positions of use, and is actuated by a conveniently located handle. In position 1, a $1^1/_4$-inch-diameter hole emits the light, and will allow a variation in spot size from a small spot to a stage flood. From minimum to maximum positions, the spot diameter will increase seven times. Position 2 is a $^3/_4$-inch-diameter hole, used only for a small head spot. Position 3 can be used as a dowser. A quick flip of the aperture handle and any one of these positions can be obtained instantaneously. As an example of spot-size variation for a 60-foot throw, the $1^1/_4$-inch-diameter aperture will handle spot sizes from $4^1/_2$ feet to 32 feet in diameter. With the $^3/_4$-inch aperture a $2^1/_2$-foot head spot can be obtained.

A masking shutter is provided for stripping a spot horizontally when desired. The shutter blades are adjustable to compensate for off-normal projection that might occur. In the closed position the shutter can also serve as a dowser. Both the aperture and masking shutter are constructed of 1/8-inch brass with a nickel plating to withstand the intense heat to which they are subjected.

The optical-system housing can be removed with very little effort, simply by loosening the three knurled screws holding the housing to the lamphouse, and the single knurled screw, securing the forward end. A lens-access hole is located conveniently to allow cleaning of the lenses without disassembling.

Color Boomerang

The boomerang is equipped with six color filter slides and a special track for inserting an ultraviolet (black-light-type) filter.

The operation of the individual color filter is accomplished by manually lifting the desired handle to the uppermost position. A permanent magnet located in the top of the boomerang holds the filter securely in position. The color is released by gently pushing the handle downward until it disengages from the magnet, and letting it fall in place. The color slides are easily removable for inserting new colors.

Optical-System Calculations

The basis for the optical system calculations is the lens formula[1]

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{V} \tag{1}$$

where
f = focal length of lens
u = object distance
V = image distance.

Substituting in (1) for the small lens we find that as u_1 is smaller than f_1, for this case, V_1 is a virtual image, so the sign becomes negative. Therefore,

$$\frac{1}{f_1} = \frac{1}{u_1} + \frac{1}{-V_1}$$

or

$$V_1 = \frac{f_1 u_1}{f_1 - u_1}. \tag{2}$$

To calculate the large lens position, we know that u_2 is the object-distance (Fig. 5). So from (1)

$$\frac{1}{f_2} = \frac{1}{u_2} + \frac{1}{V_2}$$

or

$$u_2 = \frac{V_2 f_2}{V_2 - f_2}. \tag{3}$$

Now we wish to find the distance d between the two lenses, so by observation (Fig. 5)

$$d = u_2 - V_1.$$

Substituting (2) and (3) we obtain

$$d = \frac{V_2 f_2}{V_2 - f_2} - \frac{f_1 u_1}{f_1 - u_1} \tag{4}$$

or

$$d + u_1 = \frac{V_2 f_2}{V_2 - f_2} - \frac{u_1^2}{f_1 - u_1}. \tag{5}$$

Therefore for any distance u_1 of the small lens, and a known projection distance V_2, we can readily calculate the position of the large lens to obtain a sharp, clear-cut spot.

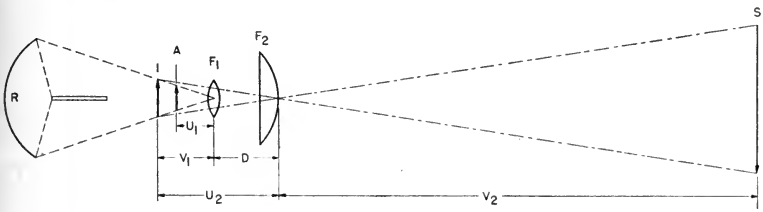


Fig. 5—Lens optical system.

F_1 = focal length of small lens.
U_1 = object distance for small lens.
V_1 = image distance for small lens.
F_2 = focal length of large lens.
U_2 = object distance for large lens.
A = aperture diameter.
D = distance between lenses.
S = diameter of projected spot.
I = virtual image.
R = reflector.
V_2 = image distance for large lens.

It is evident that the small lens creates a virtual image of the aperture. The large lens focuses on this virtual image and projects it to the desired location.

Table I shows the various distances of the large lens from the aperture as the small lens distance is varied. For these calculations the projected throw (V_2) is 60 feet.

TABLE I

u_1, Inches	$d + u_1$, Inches	u_1, Inches	$d + u_1$, Inches
0	18.47	1.50	16.22
0.25	18.44	1.75	14.39
0.50	18.34	2.00	10.47
0.75	18.15	2.125	6.43
1.00	17.80	2.160	4.75
1.25	17.22	2.1875	3.12

The projected spot size can also be calculated by the product of the magnification formula for each lens.[1]

$$\frac{S}{A} = \frac{V_2 V_1}{u_2 u_1} \tag{6}$$

where S = projected spot diameter
A = aperture diameter.

Substituting (2) and (3) we arrive at

$$S = A \frac{f_1}{f_2} \frac{(V_2 - f_2)}{(f_1 - u_1)}. \tag{7}$$

"TROUPER" AND TELEVISION

The more recent type of television camera tubes are the image orthicon[2] RCA-5769 and RCA-5655. They are recommended for outdoor pickup use, but are also suitable for studio use, where the illumination is greater than about 50 foot-candles.

The spectral response of these tubes has a high blue, good green, useful red, and practically no infrared sensitivity. Absence of infrared response permits portrayal of colors in more nearly their true gradation.

The "Trouper," with extremely high intensities and a color temperature in the blue region, is well suited as a light source for television pickup. In most studios it can be located 30 to 35 feet from the televised object, resulting in intensities up to about 2000 foot-candles, and an over-all illumination of 6000 lumens.

The "Trouper" is practically noiseless in operation, and under actual test operations, it has been found that no noise interference is picked up by the microphone.

REFERENCES

(1) J. Valasek, "Elements of Optics," McGraw-Hill Book Company, New York, New York, p. 67.

(2) RCA Tube Handbook News, "Image Orthicon Type 5769," Commercial Engineering, RCA, Harrison, New Jersey, issue 49B.

PROGRESS MEDAL AWARD

AT THE BANQUET held on October 12, 1949, during the 66th Semiannual Convention of the Society, Dr. Harvey Fletcher was presented with the 1948 Progress Medal Award, given for outstanding achievement in motion picture technology.

Dr. Fletcher was born September 11, 1884, at Provo, Utah. He received a B.S. degree from the Brigham Young University in 1907, and a Ph.D. degree from the University of Chicago in 1911, and numerous honorary degrees from other institutions of higher learning in the United States.

HARVEY FLETCHER

Dr. Fletcher was Professor of Physics at Brigham Young University from 1911 to 1916, when he left the university to join the Research Department of the Bell Telephone Laboratories. In 1933 he was appointed Director of Physical Research at the Bell Telephone Laboratories, a position which he still holds.

For a period of over thirty years, he has contributed immeasurably toward an understanding of the fundamental nature of speech and hearing. The results of his work appear in the design of microphones, equipment for electrical recording of speed and other sounds, and the development of loudspeakers which reproduce sound with high fidelity. His studies on hearing and the effect of sound intensity on aural frequency response were a substantial contribution to the motion picture art which led to recording techniques now used in the production of motion pictures. His development of facilities for transmitting music played by the Philadelphia Orchestra in the city of Philadelphia to Washington, D. C., by wire were a substantial early contribution to the somewhat later development of stereophonic recording. His work has done much to advance the art of transmission and recording of speech.

The Progress Medal was awarded to Dr. Fletcher

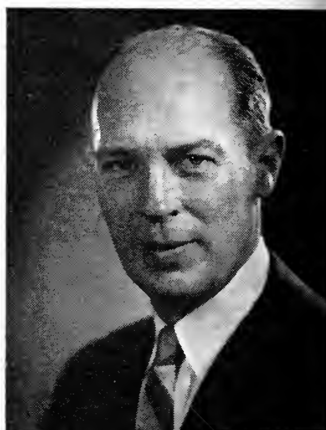
> "in recognition of his outstanding contributions to the art of motion picture sound recording and reproduction."

SMPE—SAMUEL L. WARNER MEMORIAL AWARD FOR 1949

EACH YEAR THE SOCIETY has the privilege of presenting the Samuel L. Warner Memorial Award to an engineer selected by the Society for outstanding technical work in the field of sound motion pictures. This award was established by the Warner brothers in memory of their brother Samuel L. Warner, who was a pioneer in the production of sound motion pictures.

This year the award was presented to Ralph M. Evans on October 12, 1949, for

> "his outstanding work in color motion picture films and related subjects."



RALPH M. EVANS

Mr. Evans, a Fellow of the Society, is superintendent in charge of the Color Control Department at the Eastman Kodak Company, where he has served in this capacity since the formation of the department in 1946. The function of the department is to maintain quality control on all color photographic processes at the Eastman Kodak Company and to carry on development work on these processes after their release to the public. Prior to the organization of the Color Control Department, Mr. Evans was in the Research Laboratories of the Eastman Kodak Company in charge of the development of color photographic processes. As part of this work he conducted a considerable amount of research on visual effects in photography, and this work is continuing under his direction.

Mr. Evans first came to Eastman Kodak in 1928. Later he was away from the Company for six years, employed by the Twentieth Century-Fox Film Corporation and DeLuxe Laboratories. This time was spent on color photography and control and development work in black-and-white motion picture photography.

He is past chairman of the Color Committee of the Society, and as the representative of this organization, he is on the Inter-Society Color Council. During the past two years he has served as chairman of the Inter-Society Color Council and is now a member of its Executive Committee. He is also a member of the Color Committee of the Illuminating Engineering Society.

Mr. Evans is well known for his illustrated lectures on color and color photography, which have been delivered in all parts of the country to scientific and technical societies.

Mr. Evans has written a comprehensive book* called "An Introduction to Color" which divides the subject of color into three sections—physics, psychophysics, and psychology. This is a new approach to the subject, and Mr. Evans' years of experience provide a background for this broad viewpoint.

He is a graduate of Massachusetts Institute of Technology where he majored in optics and photography and received the degree of Bachelor of Science in physics.

* Reviewed in the JOURNAL for February, 1949, page 236.

JOURNAL AWARDS—1949

THE JOURNAL AWARD for 1949 was presented to Mr. Fred G. Albin on October 12, 1949, for his paper "Sensitometric Aspect of Television Monitor-Tube Photography," published in the December, 1948, issue of the JOURNAL.

• • •

Fred G. Albin was born in Springfield, Ohio, on December 11, 1903. He received his education as electrical engineer from the University of California at Berkeley and California School of Technology at Pasadena.

In 1930 he became associated with United Artists and Goldwyn Studios in Hollywood as research engineer of sound recording, embracing the fields of acoustics, audio frequency, and photography. He gained renown for advancements in variable-density sound recording, contributing several articles to the JOURNAL of the SMPE.

In 1940 he became associated with the Radio Corporation of America as development engineer. During the war he developed high-powered radio-frequency generators for industrial applications. Toward the end of the war he developed large-screen television projectors of the instantaneous type; also the kinescope recording systems now extensively used by television broadcasters.

In his paper, which is an outstanding and well-detailed report of an engineering study, Mr. Albin reviews the practices of cathode-ray tube photography on motion picture film. He analyzes, from the standpoint of conventional photographic sensitometry, the photographic and electronic aspects of television film recording procedures that are currently in use.

FRED G. ALBIN

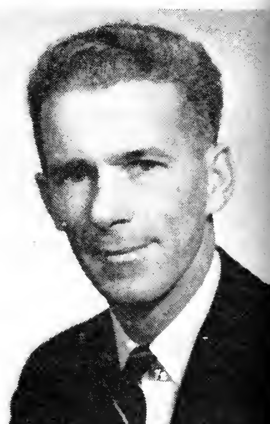
Picture reproducibility is a difficult problem, because the combined gammas of the several elements of a typical television system do not approach unity and therefore an original scene picked up by a television camera cannot be faithfully reproduced by a subsequent linear photographic process without resorting to some practical form of gamma correction.

The author shows that this problem can be solved through the use of nonlinear electrical circuits which are designed to produce an over-all television system gamma of approximately 1.5. Modern photographic techniques can then produce a resulting motion picture film record that "... equals conventional practice in motion picture professional photography."

• • •

Honorable Mention was awarded to Mr. Charles R. Fordyce for his paper, "Improved Safety Motion Picture Film Support," which appeared in the October, 1948, issue of the JOURNAL.

Mr. Fordyce presents with utmost clarity and in a very readable style the history of the recent development of a safety film support which is suitable for professional motion picture use as a base for either 35-mm negative or release positive film. His report follows this new film base through its several stages of labora-



C. R. FORDYCE

tory development into commercial "trade tests" that were designed to provide comparative performance data between the new safety film and conventional nitrate release positive film.

• • •

Mr. John A. Maurer received Honorable Mention for his paper, "Optical Sound-Track Printing," published in the May, 1948, issue of the JOURNAL.

Mr. Maurer reviews current commercial practices in the printing of motion picture sound track, explaining the nature of the more serious defects produced in the printed film, together with a study of contributing causes. By way of solution, he presents in remarkably understandable language, the detailed history of the development of a printer differing markedly from conventional types.

JOHN A. MAURER

Fellow Awards—1949

AT THE BANQUET held on October 12, 1949, President Sponable presented the Fellow Award to the fourteen members of the Society whose names are listed below:

JOSEPH E. AIKEN
Naval Photographic Center

GERALD M. BEST
Warner Brothers Pictures

DANIEL J. BLOOMBERG
Republic Studios

HERMAN H. DUERR
Ansco Corporation

ALLEN B. DUMONT
Allen B. DuMont Laboratories, Inc.

FERDINAND L. EICH
Paramount Pictures, Inc.

PHILO T. FARNSWORTH
Farnsworth Television and Radio Corporation

CHARLES R. FORDYCE
Eastman Kodak Company

LORIN D. GRIGNON
Twentieth Century-Fox Films

M. A. HANKINS
Mole-Richardson Company

GARLAND C. MISENER
Ansco Corporation

EDWARD S. SEELEY
Altec Service Corporation

JOHN E. VOLKMANN
RCA Victor Division

FRED WALLER
Vitarama and Cinerama Corporations

Book Reviews

Electron Tubes

Volume I—1935–1941; Volume II—1942–1948

Published (1949) by *RCA Review*, Princeton, N. J. Volume I—475 pages + x pages. 238 illustrations. $6^1/_4 \times 9$ inches. Price, $2.50; $2.70 outside of the United States. Volume II—454 pages + x pages. 241 illustrations. $6^1/_4 \times 9$ inches. Price, $2.50; $2.70 outside of the United States.

These two volumes contain 40 reprints of papers and 52 summaries of papers on the subject of vacuum-tube theory and practice. They were all written by RCA authors and have been collected in these volumes from the many scientific and technical journals in which they originally appeared between the years 1935 and 1948. The papers and summaries in each volume have been divided into four groups: general, transmitting, receiving, and special. Each volume also contains a bibliography of additional papers and articles by RCA authors on vacuum tubes and related topics which have appeared in journals and trade papers. The bibliography in Volume I has some 400 items published between 1919 and 1941 while that in Volume II has 170 published between 1942 and 1948.

Although the papers in these volumes have all been available for some time to those with access to a fairly complete library of scientific periodicals, motion picture engineers in general who are interested in the theory and application of electron tubes will be grateful to the Radio Corporation of America for bringing together from many widely scattered sources these contributions from RCA workers. Motion picture sound engineers will find many of these papers of particular interest and value if they are not already familiar with them.

L. F. Brown
Consulting Engineer
1236 Green Acre Ave.
Hollywood 46, Calif.

The Sound Track Book of the Theatre

Published (1949) by *The Sound Track*, 1001 W. Washington Blvd., Chicago 7, Illinois. Also available from Motiograph, Inc., 4431 W. Lake St., Chicago 24, Illinois, and from Motiograph dealers. 440 pages + 5-page index. 315 illustrations and diagrams, 6×9 inches. Price: $10.00.

The finest symposium of the theater to be published in years. This book covers the entire field of the theater and consists of reprints of the most important articles appearing in the magazine, *The Sound Track*.

Part One—Projection and Sound—covers minutely every part of the projector from intermittents and shutters to belts and bearings. Naturally the chapters lean heavily on Motiograph design and equipment but it is written with a wide enough scope so that the information is applicable to any type of projection equipment.

Book Reviews

Part Two—THEATRE MANAGEMENT—is of special interest to theater executives. As in Part One, all forms of management problems including programming, exploitation, accounting, acoustics, air conditioning, and theater design are thoroughly discussed by authorities in their particular field.

Part Three—RECENT THEATRE DEVELOPMENTS—brings information on three new projects that have recently come before the industry, namely, Drive-Ins, Television, and Stereophonic Sound.

Detailed plans, including approximate costs, are given for building and equipping a modern Drive-In Theater.

The article on Theater Television, while basic in form, covers the essentials of transmission and reception. Several misconceptions are cleared up and a practical system of theater television equipment is presented.

Excellent quality reproductions of photographs, diagrams, and cartoons on nearly every page brighten the book considerably.

This book should be of the greatest interest to every theater owner, executive, and projectionist and as a manual should be in every theater in the country.

WILLIAM K. AUGHENBAUGH
Crosley Broadcasting Corporation
Cincinnati, Ohio

SMPE Officers and Committees

The names of Society Officers and of Committee Chairmen and Members are published annually in the April issue of the JOURNAL. Changes and corrections to these listings are published in the September JOURNAL.

Current Literature

The editors present for convenient reference a list of articles dealing with subjects cognate to motion picture engineering published in a number of selected journals. Photostatic or microfilm copies of articles in magazines that are available may be obtained from The Library of Congress, Washington, D. C., or from the New York Public Library, New York, N. Y., at prevailing rates.

American Cinematographer

vol. 30, no. 7, July, 1949

India's Movie Industry (p. 236) C. DeVinna

Du Pont's New Color Film (p. 240) V. B. Sease

Translucent Photo Backgrounds Cut Production Costs (p. 240) P. Tannura

The Research Council Camera Crane (p. 242) F. E. Lyon

The Animars (p. 248) J. D. Hayes and K. Pestrecov

vol. 30, no. 8, August, 1949

The New Nord Camera (p. 282) D. Hoffman

Some Do's and Don't's for TV Film Photography (p. 283) C. Loring

Color Compensating Filters Simplified (p. 284) A. Rowan

Kinevox is Newest of Magnetic Film Recorders (p. 292)

New Hallen Recorder Announced (p. 299)

International Projectionist

vol. 24, no. 7, July, 1949

Distortion Factors in Sound Reproduction. Pt. II (p. 5) R. A. Mitchell

Cadmium-Mercury Vapor Lamps: Present Status (p. 8) H. B. Sellwood

British vs. American Projectors (p. 10) R. H. Cricks

vol. 24, no. 8, August, 1949

Lens and Film Factors Affecting Focus (p. 5) R. A. Mitchell

The Great Enigma: The Stereoscopic Perspective (p. 13) T. Nakken

British Kinematography

vol. 154, no. 1, July, 1949

The Kinema and Town Planning (p. 1) C. Williams

Make-up and the Motion Picture. I. Make-up in Relation to the Photographic Emulsion (p. 9) E. Taylor

Communications

vol. 29, no. 7, July, 1949

TV 16-mm Pulsed-Light Projector (p. 14) H. B. Fancher

vol. 29, no. 8, August, 19[illegible]

The Limitations of Sound Recording (p. 28) S. J. Begun

International Photographer

vol. 21, no. 7, July, 1949

New Triple Head Color Printer (p. 20) P. A. Roos and C. R. Hallowell, Jr.

Du Pont Synthetic Positive Color Film Being Demonstrated (p. 24)

vol. 21, no. 8, August, 1949

MGM's 25th Anniversary (p. 5)

New High-Speed Camera (p. 18)

Radio Engineering News

vol. 52, no. 1, July, 1949

Sound Mixer for TV Film Recording (p. 12)

RCA Review

vol. 10, no. 2, June, 1949

Method and Multiple Operation of Transmitter Tubes particularly Adapted for Television Transmission in the Ultra-High-Frequency Band (p. 161) G. H. Brown, W. C. Morrison, W. L. Behrend, and J. C. Reddeck

Development and Performance of Television Camera Tubes (p. 173) R. B. Janes, R. E. Johnson, and R. S. Moore

To the Editor

In the article by J. E. Bates and I. V. Runyan, which appeared in the July, 1949, issue of the JOURNAL, the regeneration of Ansco Color bleach solutions by the use of *liquid* bromine is disclosed (pp. 16–17). We believe it is only fair to your readers to inform them of the legal situation regarding the use of *liquid* bromine in bleach regeneration. The method is the subject of a patent application assignable to Pavelle Color Incorporated. (The term *liquid* bromine is stressed to distinguish from bromine water which had been tried by others and discarded because of bath dilution.) Before anyone spends time and money installing this process, he should know that its use may not be entirely free.

We have delayed publishing our data and experience on bleach regeneration pending patent-office action on our application, but will prepare a paper in the near future.

The article by A. H. Brunner, Jr., P. B. Means, Jr., and R. H. Zappert in the same issue contains a statement which we believe to be incorrect. They state on page 30 that the colorimetric method of Varden and Seary (*J. Soc. Mot. Pict. Eng.*, vol. 47, pp. 450–453; December, 1946) for ferrocyanide determination is not sufficiently accurate for bromine regeneration. For over three years we have controlled the regeneration of thousands of gallons of bleach by the colorimetric method. Even with the crude apparatus described in our article, it is easy to determine the ferrocyanide concentration within an accuracy of plus or minus 0.03 per cent. We have found this to be entirely adequate.

EUGENE G. SEARY
Chief Chemist
Pavelle Color, Incorporated
New York 19, N. Y.

European Advisory Committee

A Continental Division of the SMPE European Advisory Committee has been appointed by the President of the SMPE. The Division Chairman is L. Didiée, President of the AFITEC (Association Française des Igenieurs et Techniciens du Cinéma), and members are—

R. BOCQUEL	Television Engineer
G. MARESCHAL	Technical Manager of Société G.T.C.
and M. TERRUS (asst.)	Technical Manager, Eclair
J. CORDONNIER	Technical Adviser for Acoustics
and R. ALLA (asst.)	Technical Manager Cinéac (exhibitors)
M. YVONNET	Manager Sound Recording Dept., Eclair
and M. CERTES (asst.)	Manager Sound Recording Dept., Pathé-Cinéma Studios
S. FELDMAN	Technical Manager, Paris Studios Cinéma
and J. FOURRAGE (asst.)	Lighting Equipment, Eclair Studios
J. VIVIÉ	Permanent Secretary of the AFITEC

The purposes of the Continental Division and the British Division of our European Advisory Committee are to serve as liaison between the General Society and organizations interested in motion picture engineering. They also will report on foreign developments of interest to Society members and will aid the Papers Committee whenever likely JOURNAL material appears.

New Products

Further information concerning the material described below can be obtained by writing direct to the manufacturers. As in the case of technical papers, publication of these news items does not constitute endorsement of the manufacturer's statements nor of his products.

New Filament Lamp

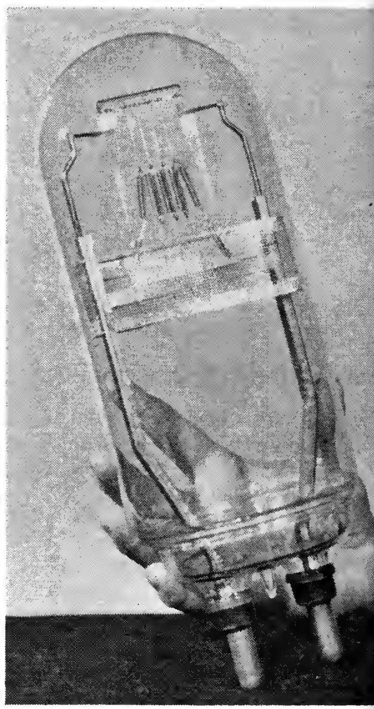
A 3000-watt incandescent lamp to compete with arc lamps for spotlighting stage shows has been developed by **General Electric's Lamp Department** at Nela Park, Ohio.

Producing an estimated 900,000 candle power in properly designed equipment, the new spotlight is intended primarily for lighting the stage from distances of 75 to 150 feet. It is seen by General Electric's illuminating engineers as suitable for outdoor theaters, sports arenas, auditoriums, itinerant spectacles, and other applications where the long-distance projection of an intense beam of light is required.

Because of its simplicity of operation in a well-constructed fixture, and because of its advantages over arc spotlights, the lamp is seen by lighting designers as permitting the application of professional stage-lighting techniques to retail store fashion shows and other demonstrations. It is expected to be used widely in television lighting.

The new lamp is tubular in shape, four inches in diameter and nearly a foot long. Of bipost construction, it is intended to be burned vertically in a base-up position. This causes blackening to occur outside of the pickup range of the reflector, thus contributing greatly to the prolonged efficiency of the lamp. It has a rated burning life of 100 hours.

The lamp's light output is not subject to variations common to arc lamps. Unlike arc lamps, the lamp can be dimmed as desired. The current required is half that of a 70-ampere, direct-current arc, thereby permitting more light for the same wiring capacity. At a throw of 100



feet, it gives an average of 90 foot-candles of light for a spot six feet in diameter, an amount equal to the illumination from a 70-ampere arc. At wider spreads, it can produce greater illumination than even higher current arcs.

New Products

Further information concerning the material described below can be obtained by writing direct to the manufacturers. As in the case of technical papers, publication of these news items does not constitute endorsement of the manufacturer's statements nor of his products.

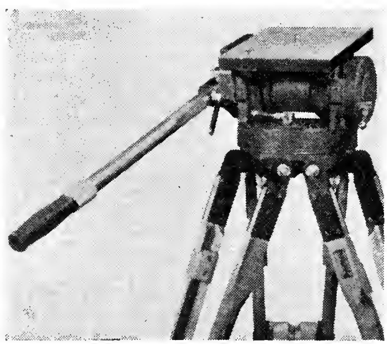
The lamp is used in a special fixture which forms an accurately controlled beam and provides flexibility in beam pattern. The first equipment to be built for the lamp is the Dyna-Beam Klieglight, manufactured by Kliegl Brothers of New York City. Since the 3000-watt lamp employs standard voltages, and may be used on either alternating- or direct-current circuits, arc-lamp generating equipment is eliminated, and with no carbon adjustments to make, one man can handle several units.

Balanced "TV" Tripod Head

The Camera Equipment Company, 1600 Broadway, New York 19, New York, has announced a new balanced "TV" tripod head. This pan and tilt head meets the strict requirements of televison technicians and is a distinctly new concept of pan and tilt action, whereby friction and gyro principles have been discarded.

Floating action is experienced with the balanced "TV" tripod head. Even in pans or tilts of slight degree, or pans of 360 degrees, extra smooth action is realized. The tilt is balanced to assist the television cameraman in the operation of his camera, which reduces to a minimum the amount of effort required to move the camera.

The balanced "TV" head relieves the operator from additional strain and eliminates the possibility of accidents. If, because of neglect on the part of the operator, the head is left unlocked with the camera mounted, it cannot fall forward or backward. The pan handle is adjustable for the operators' comfort, with no play between the pan-handle mounting



bracket and the head. To adjust the position a simple locking lever is released, adjustment made, and lever repositioned. The pan handle is an adjustable telescoping type.

The weight and manufacture of the camera to be used must be known to achieve proper tension and accomplish floating action. A special "TV" size tripod base with reinforced shoes can be supplied for the head which can also be mounted on all standard professional-type tripod bases, perambulators, pedestals, and dollies.

Statement of the Ownership, Management, Circulation, *Etc.*, Required by the Act of Congress of August 24, 1912, as Amended by the Acts of March 3, 1933, and July 2, 1946, of *Journal of the Society of Motion Picture Engineers*, published monthly at Easton, Pa., for October 1, 1949.

State of New York }
County of New York } ss.

Before me, a Notary Public in and for the State and county aforesaid, personally appeared Boyce Nemec, who, having been duly sworn according to law, deposes and says that he is the Executive Secretary of the *Journal of the Society of Motion Picture Engineers* and that the following is, to the best of his knowledge and belief, a true statement of the ownership, management (and if a daily, weekly, semiweekly, or triweekly newspaper, the circulation), *etc.*, of the aforesaid publication for the date shown in the above caption, required by the Act of August 24, 1912, as amended by the Acts of March 3, 1933, and July 2, 1946, embodied in section 537, Postal Laws and Regulations, printed on the reverse of this form, to wit:

1. That the names and addresses of the publisher, editor, managing editor, and business managers are:

Name of— *Post Office Address—*

Publisher, Society of Motion Picture Engineers, Inc., 342 Madison Ave., New York 17, N. Y.
Editor, Helen M. Stote, 342 Madison Ave., New York 17, N. Y.
Managing Editor, None.
Business Manager, Boyce Nemec, 342 Madison Ave., New York 17, N. Y.

2. That the owner is: (If owned by a corporation, its name and address must be stated and also immediately thereunder the names and addresses of stockholders owning or holding one per cent or more of total amount of stock. If not owned by a corporation, the names and addresses of the individual owners must be given. If owned by a firm, company, or other unincorporated concern, its name and address, as well as those of each individual member, must be given.)
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3. That the known bondholders, mortgagees, and other security holders owning or holding one per cent or more of total amount of bonds, mortgages, or other securities are: (If there are none, so state.)
None.

4. That the two paragraphs next above, giving the names of the owners, stockholders, and security holders, if any, contain not only the list of stockholders and security holders as they appear upon the books of the company but also, in cases where the stockholder or security holder appears upon the books of the company as trustee or in any other fiduciary relation, the name of the person or corporation for whom such trustee is acting, is given; also that the said two paragraphs contain statements embracing affiant's full knowledge and belief as to the circumstances and conditions under which stockholders and security holders who do not appear upon the books of the company as trustees, hold stock and securities in a capacity other than that of a bona fide owner; and this affiant has no reason to believe that any other person, association, or corporation has any interest direct or indirect in the said stock, bonds, or other securities than as so stated by him.

5. That the average number of copies of each issue of this publication sold or distributed, through the mails or otherwise, to paid subscribers during the twelve months preceding the date shown above is: (This information is required from daily, weekly, semiweekly, and triweekly newspapers only.)

BOYCE NEMEC, Exec. Secy., Business Manager.

Sworn to and subscribed before me this 19th day of September, 1949.

(Seal) Elisabeth J. Rubino
Notary Public, Clerk's No. 41-3390800,
Queens County.

(My commission expires March 30, 1951)

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Society of Motion Picture Engineers

342 Madison Avenue—New York 17, N. Y.—Tel. Mu 2-2185
Boyce Nemec . . . Executive Secretary

Motion Pictures in the Guided-Missile Program*

By H. M. COBB

Aberdeen Proving Ground, Aberdeen, Maryland

Summary—**Methods of obtaining ballistic data on long-range and guided missiles in the Army Ordnance Department's missile program at White Sands Proving Ground are described. The use of motion pictures for obtaining trajectory measurements and information on detailed flight performance of missiles launched at the White Sands range has produced a significant wealth of data for use of ballisticians and design engineers engaged in the development of long-range guided missiles.**

The use of motion pictures as a method of obtaining ballistic data on full-scale, free-flight missiles and guided missiles has been employed at the White Sands Proving Ground, New Mexico, since the summer of 1945. At that station, where the Army Ordnance Department, in collaboration with other departments of the Armed Services, conducts flight tests of high-altitude and long-range missiles, the Ballistic Research Laboratories have installed and operate several types of motion picture instruments by means of which a variety of experimental work is carried out in connection with the missile program.

Theoretical and experimental work on the development of observing methods and instrumentation is performed by the Ballistic Research Laboratories at Aberdeen Proving Ground. These methods and instruments are applied at the White Sands range for the purpose of obtaining basic data to be used by design engineers in the development of new weapons.

Other methods of obtaining ballistic data are used also since observing conditions, the different types of data required, accuracy requirements, time limits to be met, and the cost of the entire missile project make it impractical to depend upon a single method. Both ground- and missile-borne instruments of electronic as well as optical types

* Presented October 13, 1949, at the SMPE Convention in Hollywood.

are employed. Thus data obtained by one system may be checked against that obtained by a completely independent system, or the data from one system may be augmented by data from another system. Since we are here concerned primarily with motion picture

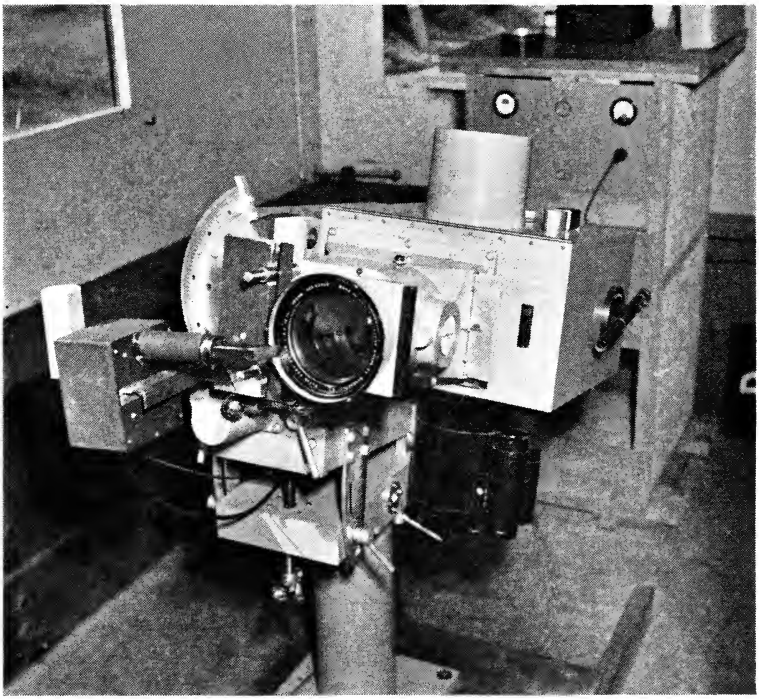

Fig. 1—Bowen-Knapp camera with timing device. Exposures are of $^1/_{10,000}$-second duration, may be taken at rates between 30 and 180 per second, the corresponding field sizes being $5^1/_4$ inches by 0.9 and 0.15 inch, respectively. The instrument may be equipped with either a 7- or 12-inch focal-length lens.

records a brief description of the instruments used and the variety of data obtained will illustrate the usefulness of the method in this field.

Near the launching position fixed motion picture cameras, especially designed for wide field, are used to observe take-off or launching performance of the missiles. By means of triangulation from a set of two or more of these stations located approximately one mile from the launching stand the position of the missile at a given time may be determined to an accuracy of about six inches up to an altitude of approximately 3000 feet. These cameras normally are operated at 30 frames per second with an exposure time of one ten-thousandth of a second. A high accuracy of the measurements and the details of missile performance observed during the critical launching phase have constituted a very significant wealth of data to the design engineers.

Trajectory data beyond the field of the fixed cameras are obtained

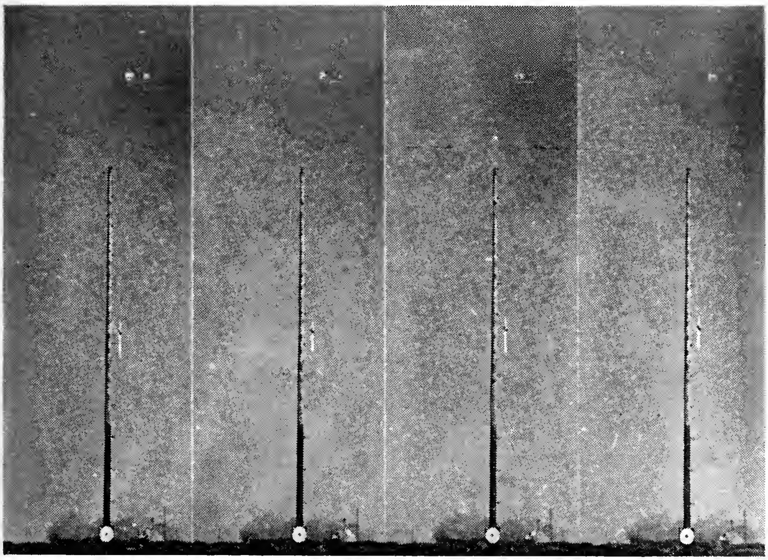

Fig. 2—Bowen-Knapp camera record of a V-2 shortly after launching.

by use of tracking phototheodolites which record on each frame the azimuth and elevation of the optical axis at the time of exposure as well as the picture of the missile. From the position of the missile image within the frame the tracking error is measured, hence the direction of the missile from the station may be obtained to an accuracy of approximately 20 seconds of arc. The shutters of all instruments are actuated synchronously from a central station. The instruments were originally built with optical systems of 12 and 24 inches focal length but recent modifications have included cassegrain systems up to 180 inches focal length.

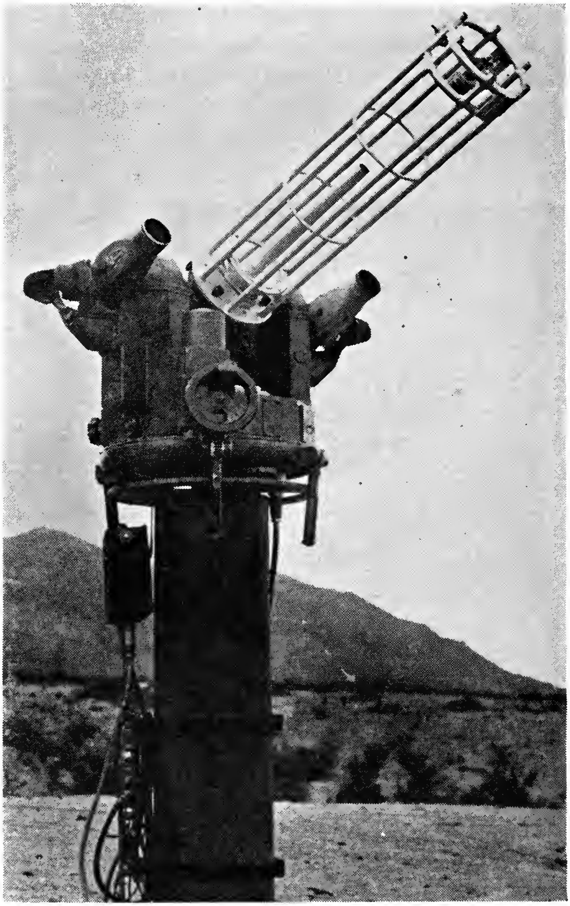

Fig. 3—Askania cinetheodolite, modified with cassegrain optical system of 15 feet focal length. Exposures may be made to a maximum rate of 4 per second, with simultaneous recording of azimuth and elevation of optical axis.

Although the phototheodolite observations do not meet the highest accuracy requirements they are capable of furnishing a trajectory in a comparatively short time. Under normal atmospheric conditions observations are obtained on a V-2 missile to an altitude of approximately 35 miles, beyond which other types of observations may be available or a vacuum trajectory may be computed.

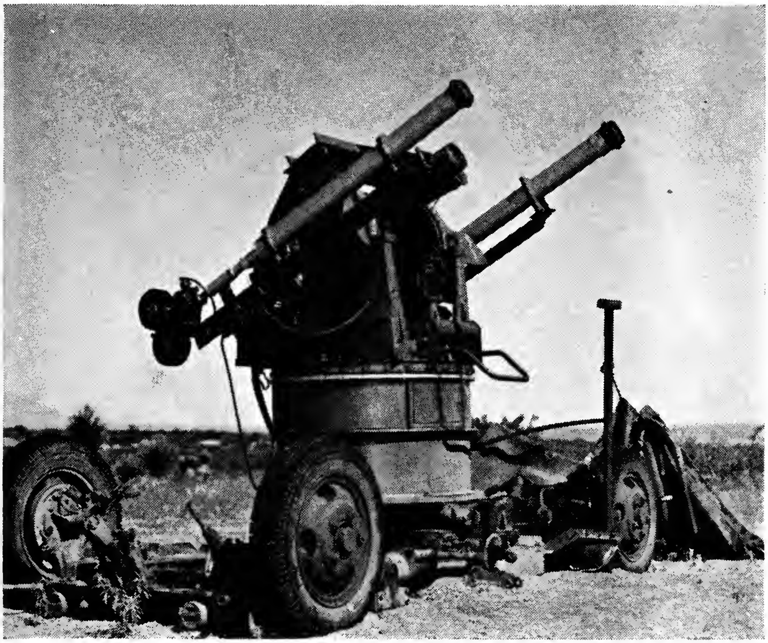

Fig. 4—Twin 4.5-inch tracking telescope on modified M-45 mount, showing recording and tracking instruments. The effective focal length may be varied from 15 to 35 feet, and 35-mm photographs taken at rates up to 20 exposures per second.

During the early stages of the high-altitude missile program it was recognized that long-focus instruments would be required for obtaining detailed information regarding flight performance at missile distances beyond the range of those described above. To meet this need the development of long-focus tracking instrumentation was started at the Ballistic Research Laboratories. The first instrument, built as an experimental model, consisted of a 4.5-inch refracting telescope of 60 inches focal length mounted in conjunction with an auxiliary lens near the prime focus to produce an effective focal length of approximately 240 inches. This optical system was mounted, with a standard motion picture camera, on an M-45 machine-gun turret which was in turn mounted on a standard 37-mm gun carriage.

The instrument was first tested at the White Sands Proving Ground in May, 1946, and indicated a promise of such valuable observations of missiles at great distances that development and construction of

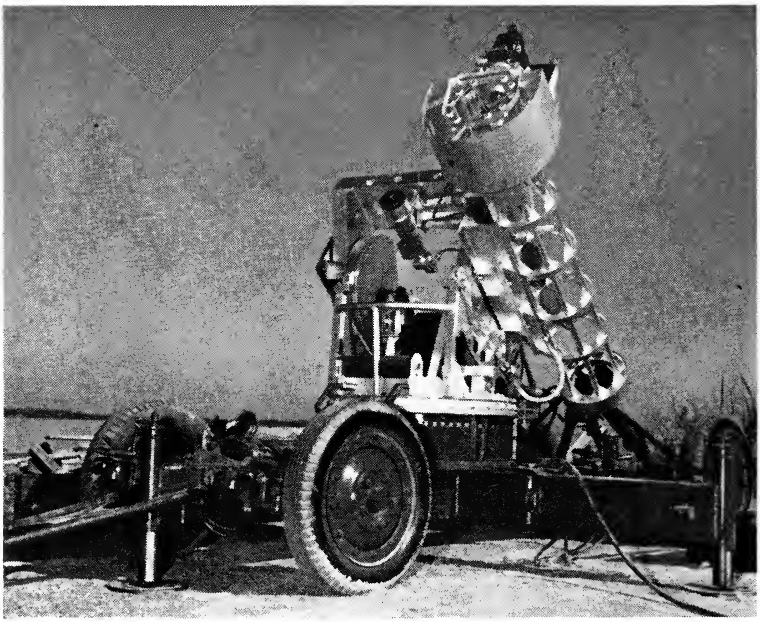

Fig. 5—10-inch tracking telescope on modified M-45 mount. The effective focal length may be varied between limits of about 18 and 40 feet.

larger instruments of the same general type were initiated. The next two instruments developed were mounted in essentially the same way as the first but consisted of 10-inch Newtonian reflectors with effective focal-length variable between approximately 20 and 40 feet. The successful application of these instruments led to the construction of a 16-inch Newtonian reflector on an M-2 90-mm gun mount, capable of operating with effective focal lengths between 40 and 80 feet.

Observations obtained by these instruments have given information, not only as to how the missiles performed but in a number of instances why they performed as they did. Functional failures, separation of booster rockets, and ejection of experimental apparatus

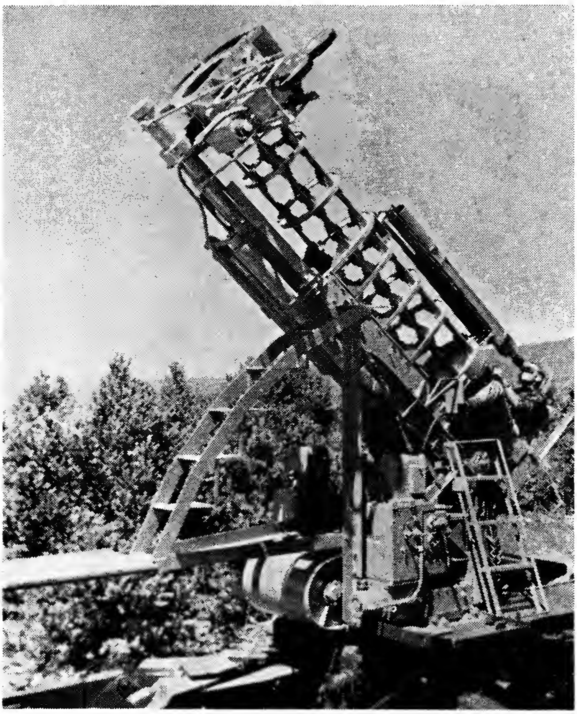

Fig. 6—16-inch tracking telescope on modified 90-mm mount, of effective focal length from 40 to 80 feet. The instrument is located 40 miles from the launching site, at an elevation of 8000 feet.

from the missiles may be observed. Photometric and spectrographic studies of the jet flame at high altitudes and at high velocities have furnished information regarding fuel-burning processes and heat distribution within the jet and have given an indication of aerodynamic flow patterns around the base of the missile. Orientation of the missile axis and rate of spin may be determined from these motion picture observations with a high degree of accuracy. Orientation of the axis of a V-2 at an altitude of 20 miles has been determined with a probable error of 0.6 degree.

Fig. 7—4.5-inch tracking telescope photograph of A-4 missile, at a distance of 8 miles, taken with a 20-foot focal length. Not reproduced portion of 35-mm frame contains azimuth, elevation, and time records.

These instruments already have shown their usefulness in the ballistic-measurements field and have pointed the direction in which future development should move. Studies of tracking systems, drive systems, control systems, recording methods, and problems of atmospheric transmission of light are being continued at the Ballistic Research Laboratories. Further development of long-focus motion

Fig. 8—Sample frames at 10-second intervals of tracking telescope record of A-4 missile during period of propulsion, showing changing jet structure. Corresponding slant ranges vary from 8 to 20 miles.

picture instruments necessarily will depend upon progress in the guided-missile program. New problems of observation will furnish the guide line in research on methods of measurement.

High-Speed Motion Picture Photography*

There are two methods of taking high-speed motion pictures widely used in the United States today. Furthermore there is work being conducted at present which will combine both of these methods into a third method.

The first general group are those motion pictures made by the use of a continuously moving film camera and an associated trigger circuit which fires a high-voltage gas-discharge tube at a selected frequency. This particular method has been developed by Dr. Harold E. Edgerton and his associates at the Massachusetts Institute of Technology.

The first work done in this field was to use a gas-discharge lamp to secure single exposures with a view camera. The gas-discharge tube consists of either a glass or a quartz tube which is filled with a rare inert gas such as xenon and possibly krypton added to it. There is an electrode on both ends of the tube and a third electrode outside of the tube. A high-voltage direct-current potential of approximately 2000 volts, though the voltage may be considerably higher, is kept across the first two-mentioned electrodes. The gap is great enough so that breakdown does not occur. This high direct-current potential is stored in a capacitor having a capacity of from 0.3 microfarad to 1300 microfarads. When an induced high voltage (from 10,000 to 15,000 volts) is applied to the third electrode on the grounded side of the capacitor ionization of the gas takes place which lowers its resistance and permits the stored charge in the capacitor to discharge. This discharge through the inert gas causes a very brilliant flash of short duration. The capacitor and the external resistance of the circuit are the controlling factors of the actual time of the flash. In the first work done along this line a raw spark in air was fired in the same manner and using a smaller capacitor but of the same or higher voltage. Flashes occurring in from $^1/_2$ to 2 microseconds were easily obtained. The gas tubes as now generally used work from 1 to 2000 microseconds.

* Presented April 6, 1949, at the SMPE Convention in New York.

The General Electric Company has developed a circuit which is similar to the Edgerton circuit but instead of using the gas tube as described above a high-pressure mercury-vapor lamp namely the H6 is used. With this particular lamp and its associated circuit, flashes of 1 to 2 microseconds' duration are obtained at a very high energy level.

With a continuously moving film camera and a commutator for firing the lamps in synchronism with the film movement the frequencies can be stepped up considerably so that up to 3000 pictures per second can be obtained from a given firing circuit. However, recently, electronic switching equipment has been developed so that six circuits may fire into a given tube to obtain pictures up to 20,000 per second. In the computation of the picture-taking speed and the film speed it is necessary to balance the exposure time or the duration of the flash so that it causes no blur on the film as the film is moving continuously. Therefore, the shorter the flash the better the result in terms of a produced photographic image. If the film is moving at 100 feet a second and a flash occurs in 1 microsecond the film will move 1.2 mils which is within the resolving power of the films used in high-speed motion picture photography. In taking pictures of this type, no shutter is used, hence under ordinary circumstances the room must be darkened sufficiently to prevent the film from being fogged by extraneous room light. This type of photography has been used very extensively in many types of industrial research in providing solutions to problems which have been troublesome to engineers for many years. There has been developed recently a unit which fires the lamp up to rates of 10,000 per second and furnishes sufficient illumination to light a field 12 inches square. The power supply needed for this is $2^1/_2$ kilowatts and the exposure time is 1 microsecond per flash. The larger units supplied with the General Radio Company circuit will provide sufficient illumination to light a comparatively large field. Higher picture-taking rates than these stated above can be used when the subject is in silhouette or photographed by the schlieren method. Methods of schlieren photography will be discussed later.

Another application of the gas-discharge-tube technique is to use the flashing lamp as a multiple-exposure device on a stationary piece of film. If the rate of firing is known, it is possible to compute acceleration and deceleration of various subjects under study by opening the shutter, starting the flashing lamp, having the test subject go through its operation once, and closing the shutter. In this way a multiple image is obtained, and knowing the subject distance and focal length of the lens, it is possible to compute rates of movement.

With the increasing use of the single-flash technique it has been necessary to develop shutters which would fire the gas-discharge lamp at the instant the shutter was fully opened. Older techniques required that a slow shutter or the open-flash method be used, but shutters have been developed recently by the major lens manufacturers which are synchronized with the flash and at shutter speeds as high as $^1/_{400}$ second. It has been learned, however, that using short focal length lenses may step this figure up to $^1/_{750}$ or $^1/_{1000}$ second.

The rotating-prism motion picture cameras are the most commonly used high-speed cameras today because of their portability. These cameras are light in weight, can run from either alternating or direct current and have lenses available of varying focal length. In the case of the Kodak high-speed camera, lenses of $2^1/_2$- and 4-inch focal length are available with other focal lenses available on special order. With the Western Electric Fastax camera, there are lenses available in focal lengths from 35 mm to 15 inches and development is proceeding on a 30-inch lens.

The Kodak high-speed camera used 16-mm film and operates through the range of 1000 to 3000 pictures per second. Variable speeds lower than 1000 frames a second can be obtained through the use of a continuously adjustable autotransformer such as a Variac. The optical image moves in synchronism with the film through the use of a rotating plane-parallel glass plate of precise thickness which is located between the lens and the film. Two frames are exposed for each rotation of this plate, and a speed of 90,000 revolutions per minute is attained at 3000 pictures a second. The exposure per frame is equal to the reciprocal of 5 times the camera speed. For example, at 1000 frames per second the exposure time per frame is $^1/_{15,000}$ of a second.

A 32-volt universal-type motor operates the camera. To limit acceleration strain, a mechanically coupled rheostat gradually reduces resistance until the preset terminal voltage is attained. At 3000 frames a second, the terminal input to the motor is equal to the full line voltage, usually about 115 volts.

An automatic switch within the camera is preset to cut off the current supply at the end of a run. This switch may be set for either a 50- or 100-foot length of film. A synchronizing switch can be set either to open or close an external circuit at any time during a run. This supplementary circuit permits the subject being photographed to start ahead of, simultaneously with, or after the camera has begun to operate. When the camera is operated on 60-cycle current, a built-in argon lamp flashing 120 times a second exposes this number of traces along the edge of the film. Accurate determination of the speed at any instant during a run can be made by counting the number of frames between two consecutive traces and multiplying by 120.

The Kodak high-speed camera uses a telescopic type of view finder wherein by looking through the eyepiece it is possible to compose and focus the image directly on a piece of matte-surface film which is inserted in the aperture.

In the case of the Fastax cameras, of which there are three, an 8-mm 10,000-picture-per-second camera, a 16-mm 5000-picture-per-second camera, and a 35-mm wide-angle 3500-picture-per-second camera, the film-loading situation is comparatively simple. The Fastax is loaded by placing the feed spool on the feed spindle, pulling about a 12-inch length of film off, and pulling the knob on the hold-down roller out, and then moving that assembly upward on its axis counterclockwise. The film is then placed on the sprocket with the perforations in engagement with the teeth. Care must be taken to be sure that the film is inserted between the timing lamp and the sprocket teeth properly and not in interference with the timing lamp. The free end is then placed into the take-up spool, the take-up spool placed on the take-up spindle, and the slack taken out of the film. The door is then closed and the camera is ready to be operated. The Fastax camera does not require a starting resistor for the two motors on the camera which are rated at 120 volts. One motor drives the sprocket and prism assembly while the other motor drives the take-up spindle. When starting, the take-up motor has a tendency to run a little faster than the driving motor and consequently the film is kept under tension and assistance is given the driving sprocket with this tension that exists. The acceleration is such that the motors cannot be started above 150 volts without ripping the film.

A 4-sided prism is used for the 16- and 35-mm Fastax cameras and an 8-sided prism for the 8-mm Fastax camera. In the case of the

8-mm cameras, those now in manufacture have a prism which is the same length as that of the 16-mm camera so that by substituting the aperture plate with one whose slits are twice as long as provided, a full-width 16-mm picture is obtained, with an 8-mm frame height. This will prove of advantage in making ballistic studies and detonation-rate studies as well as burning of fuel in cylinders. It will be necessary for the customer to provide his own aperture plate for this change.

In the case of the Fastax camera, where the film is mounted on a sprocket when operated, the lens is focused at the plane of the aerial image which is approximately $6^1/_2$ mils above the surface of the sprocket. There are four holes in the sprocket. By rotating the sprocket by hand until one of the holes is lined up with the rotating prism, when the prism faces are perpendicular to the optical axis, the image formed by the objective lens is picked up on a ground glass on the door of the camera. This image is projected on to the ground glass by first having passed through a right-angle prism, through a 32-mm microscope objective, through another prism, and on to the ground glass. There is a little trap door in the housing which should be at right angles to the door of the camera as pictures are being taken. If there is a bright light back of the camera and the trap is open, the sprocket holes are exposed on the film.

It is possible by using a $^3/_8$-inch punch to view the subject up until it is ready to be taken by punching a hole in the middle of the frame of the film. This hole is lined up with the hole in the sprocket and focusing is done normally. This hole should be punched about from 12 to 18 inches from the end of the film so that the camera can be loaded normally and be ready for use.

The Fastax camera is also equipped with a $^1/_4$-watt argon-lamp timer. The $^1/_4$-watt argon lamps can be actuated directly from 120-volt, 60-cycle alternating current which will lay down 120 pips per second, or it can be operated from an oscillator which will drive the lamp with a square-top wave. In order to increase the intensity of the lamp to provide an image which is stronger, the voltage may be increased to 135 to 150 root-mean-square volts. In the event that the $^1/_4$-watt argon lamps (AR-3) are broken, the replacement lamp should be burned on 60-cycle, 120-volt alternating current for 24 hours in order to age them, otherwise there may be a lack of stabilization between the firing voltages of the two electrodes. If a square-wave oscillator is used it is not necessary to do this since only one electrode is activated. In measuring the length between the pips from the beginning of one to the beginning of the next with the 60-cycle pulse the time interval will be $8^1/_3$ milliseconds. However, with an unaged lamp, it is necessary to measure from the beginning of one pulse to the beginning of the second pulse from the first one and consequently this measurement is $16^2/_3$ milliseconds.

The Potter Instrument Company of Long Island City has built an oscillator which will furnish 1000 pips per second for operating up to 14 high-speed-camera timing lamps simultaneously. This oscillator used a 100-kilocycle crystal control and the timing circuit is then derived from breaking the 100,000-cycle output of the crystal to 1000 through two decade reductions. This oscillator can be operated from either 60-cycle or 400-cycle, 120-volt circuits. The 400-cycle circuit permits using this equipment in aircraft.

It has been observed that the human eye and brain cannot assimilate many actions going on simultaneously upon a screen. Therefore, in taking high-speed pictures the primary rule of photographic composition is to make the picture as simple as possible by confining the subject under study to one of its component actions rather than the subject as a whole. If, for example, a calculating machine is being photographed, individual springs, cams, locking levers, and similar devices should be photographed separately rather than attempting to make a high-speed picture of the whole unit at once. Greater magnification is obtained when the single subject is photographed. If possible, there should be some color contrast so as to delineate the actions as they occur from static or stationary parts.

Then comes the problem of lighting this in the laboratory. Formerly, the lights used for high-speed photography were quite bulky; 750-watt, 2000-watt, and 5000-watt lamps in reflectors have been employed. As a general thing a spherical reflector was placed back of the lamp so that the image of the filament would be projected on the subject. There were other cases, however, in which reflector-type lamps were used such as the RSP-2 750-watt photospot, airplane landing lamps (for portable use in planes), and 150-watt show-window spots when burned at 220 volts after preheating. The older type lamps as mentioned above have been extremely effective for lighting small subjects or when banks of them were used for lighting subjects up to roughly 24 by 24 inches. Most high-speed-camera subjects fall within this field. When using the lamps mentioned above, particularly the 750-watt and 2000-watt setups, lamps were secured which were rated at 100 volts. When they were set up on the subject, two lamps burned in series so that each lamp burned at approximately 60 volts. In the case of the Fastax camera when the shadow density was observed through the ground glass with this setup and by stopping down the lens, an exposure would be correct for 5000 pictures per second at between *f*/5.6 and *f*/8 depending upon the color and brightness of the subject. This guessing method has not been too satisfactory. When they were ready for picture-taking the lamps would be turned on to full brightness and used in parallel rather than series. There is available on the market today a very convenient series-parallel switch for this purpose, as well as for a new lamp which will be mentioned shortly. It is manufactured by the Industrial Timer Corporation, Newark, New Jersey. This particular switch will accommodate four lamps and is known as their "HI-LO" switch.

There has been recently developed by the General Electric Company a "750R" high-speed photographic lamp. This particular lamp is designed to operate at about 18 inches from the subject and the candle power at that distance within 5 degrees of its axis is 75,000. Two of these lamps are adequate to make pictures of subjects up to 4 by 4 inches at *f*/5.6 at 5000 pictures per second. Using four of these lamps on the subject it is possible to take full-color Kodachrome pictures at 5000 pictures per second at *f*/2.

Mercury-arc lamps have not been satisfactory on alternating current because of their pulsing on and off. The Philips Company is using mercury arc for illuminating subjects powered with direct current so as to avoid flutter. Fluorescent lamps cannot be used because of their fluttering and comparatively low intensity. One should consider that between approximately 100,000 to 500,000 foot-candles are necessary to take pictures under ordinary circumstances of high speed with the lens reasonably well stopped down.

In order to eliminate many of the troubles that have been encountered, the Weston Electrical Instrument Company is announcing an exposure meter for high-speed photography which will measure either incandescent light or sunlight. Edgerton earlier announced a high-speed gas-discharge-tube exposure meter. There will be provided an index on the Weston meter for measuring values of light from 100 to 300,000 foot-candles. Three steps on the meter will be necessary in order to measure this range, and there will be attached to the meter an exposure scale for both Super XX film and Kodachrome film, Type A.

The high-speed cameras can be very satisfactorily used out of doors. Kodachromes have been obtained in New Mexico during the bright-light period of the day (10 A.M. to 2 P.M.) in the summertime at 1000 pictures per second at *f*/2. Furthermore black-and-white pictures have been successfully taken at speeds up to 4000 per second under reasonably brilliant lighting conditions out of doors. With special processing techniques, pictures have been taken under water in normal daylight at depths up to 10 feet at 4000 pictures per second (it is suggested that the subject be painted a light color for making such studies and that a reflective bottom, such as white sand, be present). Silhouette pictures can be taken at speeds up to 14,000 per second in daylight.

In taking a picture of incandescent subjects it is often necessary to use neutral-density filters to cut down the light produced by the incandescent subject. A neutral density of 1.0 for example has a transmission of 10 per cent light, neutral-density filter of 2.0, 1 per cent, a neutral density of 3, $^{1}/_{10}$ of 1 per cent, and so forth. In taking pictures of photoflash lamps burning it is necessary to use a neutral density of 3.0 to 4.0. Trial and error are about the best means of determining the exposures to be used for incandescent subjects.

It has been found that the reciprocity loss on Kodachrome is considerably greater than on Super XX film and, therefore, the exposure factor between the two changes considerably. Instead of being 12 to 1 as it is in normal daylight, the figure becomes from 32 to 64 times. There is a peculiar effect, however, that has not been explained and that is when a picture is taken on Kodachrome with a Fastax camera there is no noticeable difference between the beginning of the film and the end of the film on projection. In exposure it is noticeable if the two ends are placed one along side of the other.

There are a number of films which can be used with high-speed cameras. For the 16-mm high-speed cameras, Kodak Super X, Super XX, and Kodachrome, Type A, reversal films are available as well as Kodak Super XX Negative, Linagraph Ortho, Linagraph Pan, and Super XX and Super X Blue Base Reversal Films. For the 8-mm Fastax, only Kodak Super XX, Super X, and Kodachrome, Type A, reversal films are available. For the 35-mm Fastax camera, Linagraph Ortho, Linagraph Pan, and Kodak Super XX negative films are available. These are all Eastman Kodak Company products and should be ordered from your local photographic dealer. It is essential that all orders for 16-mm film to be used in high-speed cameras specify, "Spooled for High-Speed Cameras." Film orders for the 8-Mm Fastax camera should specify, "Spooled for 8-Mm Fastax Camera." This assures the user that he will receive fresh film of highest emulsion speed and that it will be correctly perforated and spooled on aluminum spools without core clips. The use of other than aluminum spools will impair the dynamic balance of the camera, and should a core clip become detached at the end of a run, it would seriously damage the camera mechanism.

The Linagraph Ortho and the Linagraph Pan are used in high-speed cameras when modified for use as an oscilloscope camera. Methods of high-speed oscillography will be discussed later.

In making schlieren pictures several methods can be used. The first method is to use an incandescent lamp and image the filament of the lamp at the objective lens. The subject will pass between the lamp and the objective. In order to focus the lamp at the lens a spherical mirror can be placed back of the lamp. By adjusting the relationship between the mirror and the lamp it is easily possible to secure the image of the filament at the lens. The objective lens is then focused at the subject plane and not at the light source.

A second method is to replace the spherical mirror with one or two condensing lenses in order to image the light source at the objective lens.

A third method which has just recently been developed by Edgerton and his associates has been to link the flashing lamp with the Kodak and Fastax high-speed cameras. The flashing lamp which they have developed for this purpose will be ideal for schlieren pictures, for the actual time of flash is 1 microsecond and it can be operated up to frequencies of 10 kilocycles. In this case the incandescent lamp is replaced by the new flashing lamp and there is a triggering device in the high-speed camera which allows the lamp to be fired when the picture frame is on line with the optical axis of the complete system. This type of light source is particularly adaptable for making schlieren pictures for the effective time of exposure is reduced considerably. The two first-mentioned systems would not resolve velocities of shock waves comparable with that of the method just mentioned.

The third method can also be used to illuminate high-speed photographic subjects from the front. This lamp will adequately light a field size 12 $\times$ 12 feet. There are several advantages in using this method for the time of exposure is reduced to about 1 microsecond. Furthermore, the high-speed motion picture camera, either Kodak or Fastax, provides the necessary shutter action so that the unit can be used under fully lighted conditions. Prismatic aberrations caused by the angle of rotation in a rotating prism are eliminated, only those aberrations existing which are caused by the glass block itself remaining. These new lighting units which can be synchronized quite easily with the Fastax or Kodak camera are available from Edgerton, Germeshausen, and Grier, Cambridge, Massachusetts.

Both the Kodak and Fastax cameras can be used as ultrahigh-speed oscilloscopic recording cameras and frequencies up to one million cycles can be recorded as a continuous-wave trace and considerably above this if only the envelopes are required. In the case of the Fastax camera, the prism assembly is removed from the camera for this procedure. This can be done by removing the aperture plate and the four screws which hold the split plates. The prism shaft is then pulled out very carefully and the split plates removed as soon as they are clear. The prism shaft can then be completely removed. It is suggested that split-plate assembly be replaced by a single plate with four holes drilled in it so that film chips will not get down into the main drive assembly. It will be necessary to refocus the camera and use the visual focusing only on the ground glass and disregard the lens-focusing scale. In reassembling the camera the prism faces should be lined up so that the picture will be framed correctly and not out either $^1/_5$, $^2/_5$, $^3/_5$, or $^4/_5$ of a frame because of mismatching gear teeth.

The Eastman Kodak Company does not recommend that owners of the Kodak high-speed camera attempt to modify their cameras for oscillographic work. It is recommended that such modification be made at the factory in Rochester.

A P11 coating is used on the cathode-ray tube and additional intensifying voltages supplied. In the case of a 5-inch tube it is best to use voltages in the neighborhood of 6000 in order to get 350 kilocycles. A 2-inch-tube oscilloscope which is designed for this particular unit when operating at 2000 volts will supply the necessary frequencies up to a million. Very fine relay chatter, blast fronts, velocities of projectiles, and many other subjects can easily be studied by this new method.

There is a control unit now being made for the Fastax camera known as the J410 or "Goose." This unit is manufactured by the

Industrial Timer Corporation, Newark, New Jersey, and has built into it a timing circuit which allows the Fastax Camera to be increased in speed over 40 per cent. The camera is started off at 130 volts and 70 milliseconds later voltages up to 280 can be applied to the motors. The running time of the film is reduced to 0.8 of a second. There is a timer associated with the camera circuit which allows the camera to be set at operating times up to 6 seconds. Associated with the control unit is an event timer which allows the event to be either started or stopped at any predetermined time up to 6 seconds either ahead of, simultaneously with, or after the camera has started. This unit increases the flexibility of the camera tremendously and is now currently available.

The Eastman and Fastax cameras have mounting holes provided in their bases for attaching the cameras to standard motion picture tripods. The cameras are heavy enough to require a reasonably heavy tripod and the Mitchell, Bell, Howell, and Akeley tripods as well as others of that type are satisfactory. For laboratory usage a drill-press stand with a tilt-top table can be used quit satisfactorily.

Many times it is necessary to reduce the heat of the lamps on the subject which is being photographed, therefore, either of two schemes can be used. Aklo heat-absorbing glass can be put between the light and the subject or a water cell can be used in the same position. The Aklo heat-absorbing glass is obtainable either from the Corning Glass Works or from the Libbey-Owens-Ford Glass Company. Water cells which are made from glass, rubber seals, and metal housings are rather expensive to design and to seal properly. There is a small flask available which can be used quite advantageously and that is a Pyrex Kolle culture flask. The diameter of this flask is 135 mm and the outside distance between the flat walls is 35 mm. This flask is portable and can be easily filled just prior to use.

With the above brief description on how to use the high-speed camera the committee has attempted to bring the users up to date on the latest developments in the field of high-speed photography in order to make it more generally useful.

High-Speed Motion Pictures by Multiple-Aperture Focal-Plane Scanners*

By FORDYCE E. TUTTLE

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Summary—Heretofore, in all high-speed photography instantaneous time covered one complete frame, the continuity of instantaneous frames forming the time axis. This is fundamental even with image dissecting methods which reduce frame length by lateral displacement of frame elements, a trick done to shorten physically the time axis and allow the higher speeds mechanically inherent in less length of film. A new method of obtaining high-speed pictures is described whereby instantaneous time covers multiple small portions of a single frame, the total area of these small portions being sufficient to provide detail and the single frame being large enough to permit unmagnified observation. This is accomplished by multiple-aperture focal-plane scanners.

Practically every worker in the field of high-speed motion picture photography has had to make some compromise on picture definition to obtain high rates of picture taking. As soon as we exceeded the speeds at which we could afford to stop the film mechanically to receive an image, we all found ourselves in some kind of trouble.

Those who chose to make the image travel with the film by moving image reflectors or refractors had to be content with approximations. A rather poor image, progressively astigmatized and progressively distorted, could be made to move in the same direction as the film. Periodically during the picture-taking cycle this image might move faster than the film, and periodically it might move slower than the film. We had to be satisfied if we could achieve an average image velocity that equaled the average film velocity.

Those who chose stroboscopic illuminating devices attempted to make the individual picture exposure time so short that they did not care whether the film was moving or not. To obtain more light, they could even allow their pictures to blür quite a bit before they produced images as bad as the image travel systems. Any self-luminous or continuously illuminated objects in their scenes, of course, smeared out beyond recognition.

* Presented April 6, 1949, at the SMPE Convention in New York.

Those who chose to rely on the image dissection system made no attempt to achieve definition in the direction of film travel except by the use of multiple-picture elements. There is no pretense of moving the image with the film, nor is streaking avoided by chopping the light. By restriction of the height of individual elements, it is possible to stop the smear every time it becomes too bad.

All of us have found picture unsteadiness a problem. Imperfect picture definition and imperfect picture registration have, therefore, always made the collection of motion data for first-, second-, and third-derivative analysis difficult.

The device described here is not in any sense a cure-all for these troubles. It is our hope, however, that in some form it might prove itself to be useful.

A chronological history of the development work to date will aid this discussion.

Several years ago Richard Engelken, a well-known consulting engineer of New York City, undertook a display-device assignment. He conducted several experiments that led him to some interesting conclusions. Unfortunately, he died before he completed his studies, and only recently have we been able to try out some of his suggestions.

Very abbreviated and somewhat rephrased, his comments were as follows:

1. With a fine-grain emulsion we are satisfied with definition in a picture enlarged as much as thirty diameters (a microfilm standard).

2. Let us put that same fine-grain emulsion on a plate thirty diameters larger than the frame size which we say gives us a satisfactory picture.

3. On this plate, then, without trying to get something for nothing, we should be entitled to store information sufficient in quantity to show thirty times thirty or nine hundred pictures, each with definition no better or no worse than that of single smaller pictures.

4. Now let us not make our nine hundred pictures all condensed small images which have to be enlarged for viewing, but let us space out the silver grains which are used to display a single picture in some orderly extended array so that each picture will be spread over the thirty-diameter plate.

5. This spacing of dots will be exceedingly coarse for the fine-grain emulsion used, so coarse in fact that in the neighborhood of each picture element there will be room for dots to be used for the eight-hundred and ninety-nine other pictures.

To follow these suggestions, we must, of course, provide ourselves with some means for positively selecting those silver grains which we need to portray a single picture, and make sure that when we take the

Fig. 1—Composite picture of a landscape, a beach scene, and a young child.

image, only those grains are used. When later we wish to show the picture, we must not allow the observer to see any image elements belonging to some other picture.

A well-made focal plane sieve might do this. Small holes, widely spaced in an opaque member placed in contact with the emulsion, would allow only the parts of the picture that get through the holes

Fig. 2—A landscape.

to expose the film. If later each hole (or the sieve as a unit) could be displaced an amount equal to the diameter of a hole, a second picture could be taken on the unexposed parts of the film. In fact, every time we move the holes to a new nonoverlapping position, we can take a new picture until we have filled the film with images. Neither the film nor the sieve can be allowed any dimensional change between

Fig. 3—A beach scene.

the time of exposing and the time of viewing the pictures, if a very disturbing scrambling is to be avoided.

It seemed too ambitious at the start to attempt making an extremely accurate sieve and an extremely accurate mechanical system for two-dimensional scanning. It was, however, decided to attempt to make a line screen with dimensions selected to permit thirty images. One-dimensional scanning by this grid filled the thirty-

Fig. 4—A young child.

diameter film with images. Shrinkage difficulties were minimized by having both the grid and the film on glass plates.

Demonstration of the ability of such a grid to separate images is simple. Fig. 1 contains the pictures of a landscape, a beach scene, and a young child. With unaided viewing, it presents a scrambled appearance. However, when we place the same plate behind a grid that is similar to the one through which it was multiply exposed, we can see fairly good representations of the component subjects. These are shown in Figs. 2, 3, and 4.

The dimensions of the grid and plate may be of interest. The overall size is 10 × 12 inches. One-thousandth-inch transparent lines are separated by opaque areas so the lines are on 0.030-inch centers. Very few people are able to believe from visual judgment that the transparent lines are as narrow as they are.

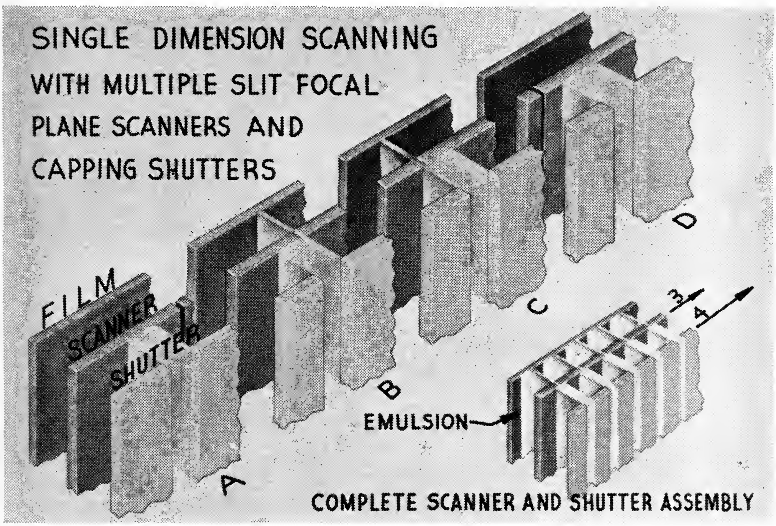

Fig. 5

The casual observer, when he is close enough to see the line structure, is inclined to guess the white lines are wider than the black lines. The effect of this physiological phenomenon is to make the picture seem quite continuous, although twenty-nine thirtieths of it is missing.

In order for us to make use of the grid device for motion pictures, we need only to place the grid in a focal plane position behind a lens. If we move the grid continuously in front of a stationary film plate, we shall impress on the plate a series of images portraying the motion of whatever is occurring in the object plane of the lens. Since for each one-thousandth-inch movement of the grid we are entitled to have a new position picture of the object, it is obvious that we shall not have to move the grid very fast to achieve high-speed motion pictures. One inch per second will give the equivalent of one thousand pictures per second. In spite of the fact that our individual picture size is 10 × 12 inches, we need to move the grid only 0.030 inch to take thirty pictures, instead of the thirty feet we would have to move the film to take thirty one-foot high pictures in more orthodox ways. Because the film plate is stationary, the image steadiness, of course, is excellent.

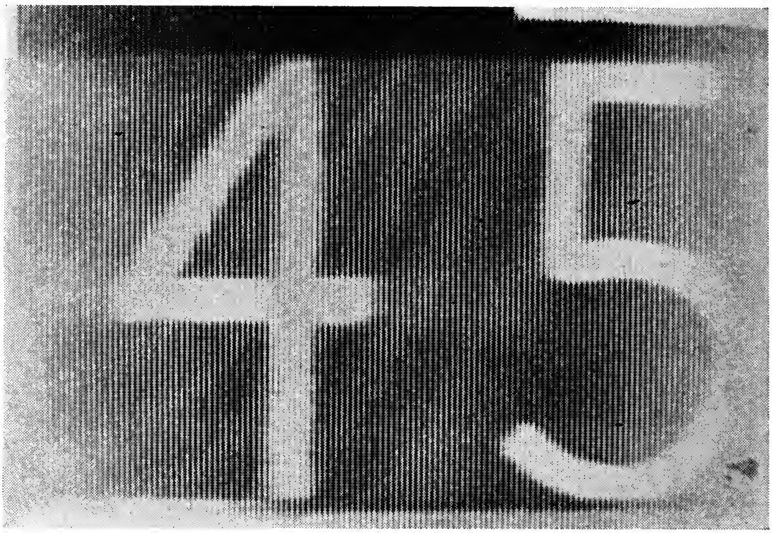

Fig. 6—16-mm frame showing high-speed numbers.

A 4- × 5-inch camera was built to try out the high-speed use of the moving-grid system. The grid in this camera was spring driven and moved a total of 0.090 inch. During the first one third of this motion, no exposure is produced because of the action of a multiple-aperture capping shutter. Exposure occurs for the next 0.030 inch, and the last third of the motion is used to decelerate the mechanism with the slits capped. Fig. 5 shows the performance of the grid and capping-shutter system. Picture speeds of 16,000 per second have been achieved with the particular spring drive used.

A motion picture film has been made from the grid playback of pictures taken with this camera. Unfortunately, we have not had opportunity to photograph any very romantic subjects, and the pictures illustrated are those of white numbers painted on a black belt moving across the object field. Fig. 6 shows a reproduction of one frame from the 16-mm motion pictures we have taken of the viewing grid being motor-driven across the exposed developed plate. The numbers are quite identifiable even in cases where the images are moving as fast as 250 miles per hour on the plate.

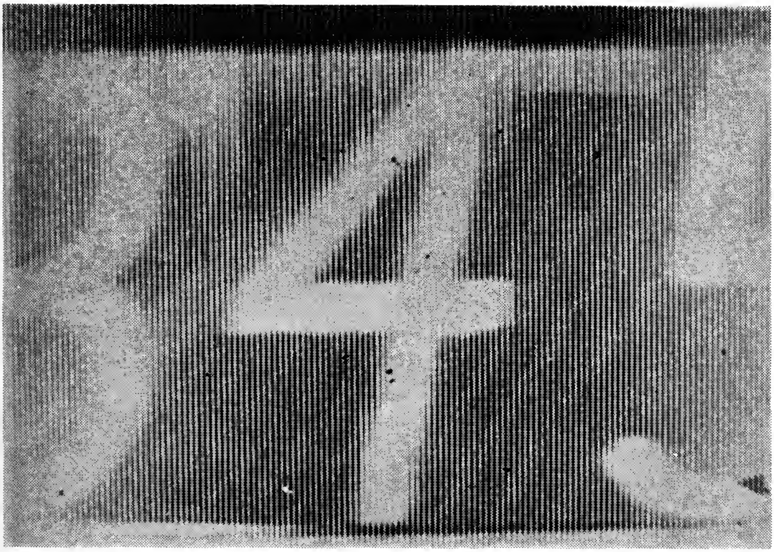

Fig. 7

In Fig. 7 we have stopped the translation of the grid in a mid-point of image travel. The number aspect you see is the result of a small amount of rotation of the grid analyzer. This rotation allows you to see an early time picture of the tops of the numbers and a late time picture of the bottoms of the numbers. The numbers slant from left to right. As the analyzing grid becomes parallel to the taking grid position, the numbers straighten up as in Fig. 6 because the top of the numbers was taken at the same time as the bottom of the numbers. Finally, as the rotation of the grid is reversed, the numbers lean from right to left as in Fig. 8 because you are seeing the late time picture of the tops of the numbers and an early time picture of the bottoms of the numbers. In Fig. 9 the capping shutter was removed from the camera so that parts of three sequences of pictures are seen. Although the belt of numbers was moving at a fixed speed, the multiple images appear to be traveling at different speeds. This effect is the result of acceleration and deceleration in the grid movement.

Some very interesting and useful stereoscopic observations can be made from a plate contact exposed behind a grid and viewed through an analyzing grid, which is held out of contact with the image plate. Let us have in the scene five different belts with numbers painted on them. One belt is stationary. Two are moving rather fast, one at

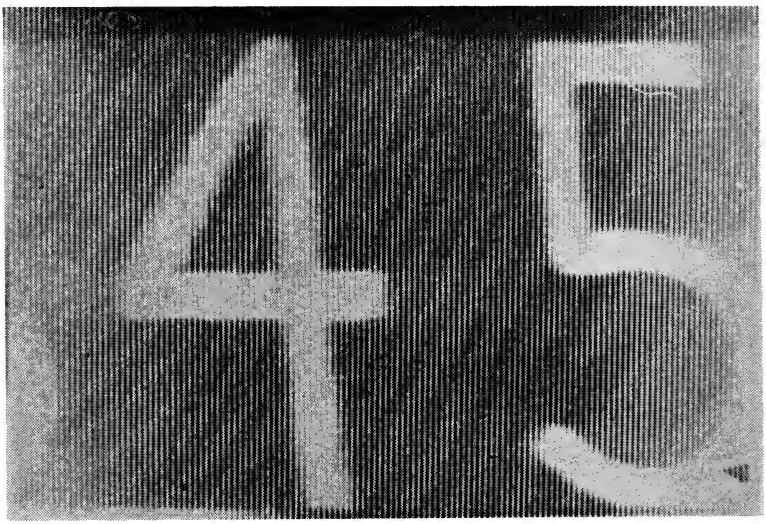

Fig. 8

a constant velocity and the other at the same average velocity but being accelerated. The two others are moving very fast, one again at a constant velocity and the other at the same average velocity but being decelerated.

If we view this scene through the separated grid in its parallel alignment position, the stationary belt will appear to be in the plane of the screen. The two rather fast moving belts will appear coplanar but displaced from the screen plane. The two very fast moving belts will be in a different plane further displaced from the screen plane.

If now we rotate the viewing grid, the stationary numbers will still appear erect and in the screen plane. The numbers on the belts moving at constant rates will lean over in their own planes, very much like the numbers shown in Figs. 7 and 8. The numbers on the fastest moving belt will, of course, lean more than those on the slower moving belt. The numbers on the belts that are being accelerated and decelerated do very interesting things. Rotating the grid in one direction will make the numbers lean, of course, but the planes of the numbers also tilt, the accelerated numbers tilting their tops toward the screen plane and the decelerated numbers tilting their bottoms toward the screen plane.

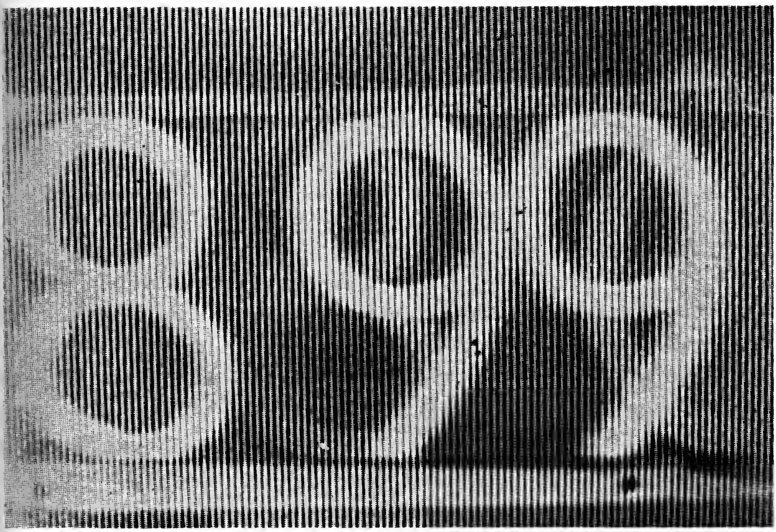

Fig. 9—Multiple images recorded without the capping shutter.

Without painstaking measurement of the position of fuzzy unsteady pictures, good indications are thus given as to the sign and magnitude of the function photographed and its first and second time derivatives.

Further study should be given to the acuity of stereo interpretation of data, and a great deal of work should be put on the use of multiple-sequence photography of the type shown in Fig. 9. It is hoped to describe in a later paper these subjects as well as a camera with a two-dimensional scanning system capable of taking at least a thousand pictures at a rate of at least a million pictures per second.

Improvements in High-Speed Motion Pictures by Multiple-Aperture Focal-Plane Scanners*

By FORDYCE E. TUTTLE

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Summary—It is shown how, with the multiple-aperture scanning method of high-speed photography, the absolute number of entirely new position pictures of a moving object is more a function of how many grains of emulsion are uncovered in the total aperture travel than a function of the number of aperture widths uncovered. This results in many more frames per event than had been assumed heretofore. A second camera of this type is described in which two-dimensional scanning gives composite pictures with a dot structure. This is accomplished by means of a rotating disk. This camera is capable of taking high-speed pictures at the rate of at least 1,000,000 per second.

At the April, 1949, meeting of the Society of Motion Picture Engineers in New York a new method of obtaining high-speed pictures was described† whereby instantaneous time covers multiple small portions of a single large frame, the total area of these small portions being sufficient to provide detail and the single frame being large enough to permit unmagnified observation. This is accomplished by multiple-aperture focal-plane scanners. It is now proposed to discuss further certain details of this new approach for the investigation of high-speed phenomena and to describe a camera of considerably more flexibility than that shown in April.

Absolute Number of Time Positions

Our first attempt to investigate the high-speed aspects of multiple apertures moving in a focal plane was described as a spring-driven camera with a one-dimensional scanning grid. The dimensions of the grid were given as one-thousandth-inch transparent lines separated by opaque areas so that the lines are on 0.030-inch centers. Continuous translation of this grid served to uncover new emulsion as time

* Presented October 12, 1949, at the SMPE Convention in Hollywood.
† This issue, pp. 451–461.

passed to record composite position pictures of a moving subject. Since the process is continuous, the question of how many position pictures are recorded in this manner before double exposure takes place becomes an important one, and one for which the answer is not immediately obvious. As a starting point, one might say that for every one-thousandth-inch movement of the grid, an entirely new picture could be recorded. On that basis and the grid dimensions given we could profess to be able to record thirty composite-position pictures on one plate before double exposure results. If that were the case, during playback for observation it would be necessary to index the analyzing grid one thousandth of an inch to observe a new position picture of a moving object, a total indexing of thirty thousandths of an inch thus passing the thirty position pictures across the screen for observation. Even with this assumption one can visualize the large number of pictures per second possible by this method, a linear grid velocity of only approximately one-half mile per hour giving ten-thousand position pictures per second.

That the above assumption fortunately is pessimistic, and that a great many more position pictures of the moving object are actually present after 0.030 inch of grid translation, can readily be demonstrated. With some thought it becomes apparent that the absolute number of pictures of, say, the leading edge of a moving object is more a function of how many grains of emulsion are uncovered per 0.030 inch of travel than a function of the number of slit widths uncovered. The total number of "frames" for a grid-type camera would be determined by the accuracy of one's analysis of the exposed plate. Concrete basis for this claim is the fact that when an exposed high-speed composite-picture plate is examined with an analyzing grid, subject motion can be observed when the grid is moved less than the transparent line width or less than one thousandth of an inch. These minute subject advances can be seen readily in the table viewer. However, they can be better shown to a larger audience by a 16-mm demonstration film.

The first section of this film shows the smoothness of subject motion when a plate carrying composite motion picture frames is examined through a continuously moving grid. The motion pictures were taken continuously of the picture area as the grid scans the photographic plate. About two hundred 16-mm frames were exposed during the 0.030-inch excursion. The film demonstrated that the subject motion is extremely smooth and the picture detail is nearly equal to that of conventional 16-mm motion pictures even though twenty-nine thirtieths of every picture is missing.

The second part of the film shows that actually at least one hundred subject positions can be counted. This second part of the film was prepared as follows: We arranged to index mechanically an analyzing grid in small-step increments across a composite-picture plate. We could detect visually subject motion with each minute advance. As previously stated, it was found that the grid advance for which motion was apparent could be much less than one transparent slit width. We recorded multiple frames on conventional 16-mm film for each of one hundred 0.0003-inch grid advances. In the film, the subject appeared to jump from one separate position image to another. The subject motion in this case was slow motion but the same theory would apply regardless of the subject velocity. (A 16-mm film demonstration was then made to show the effects outlined.)

The previous statement, that the real number of position pictures which exist on a composite plate is a function of emulsion resolution, can now be accepted readily. The actual number of jumps which one could record as shown on the film may only be limited by one's ability to index the scanning grid mechanically in extremely small steps. From the foregoing we now see that the performance of our previously described, single-dimension scanning camera was considerably better than claimed. It had been stated from the preliminary slit-width subject-position assumption that we had taken motion pictures at the rate of 16,000 per second. Since we have now demonstrated that one hundred or more position pictures are available for a grid movement of 0.030 inch, the 16,000 per second previously claimed was actually at least 48,000 frames per second. This more accurate picture rate of 48,000 frames per second adds considerable supporting evidence for a statement in our previous paper, namely, that we had stopped subject motion with the camera when its image speed on the film was 250 miles per hour. In a reverse sense, that statement also lends considerable weight to our argument here that we must have had a good many more than 16,000 frames per second recorded. Such image velocities would most assuredly have produced blurred images if pictures were taken at the 16,000 rate in the normal sense. It is impressive that 48,000 pictures per second can be taken with power supplied by only a small simple coiled spring, and it is a relief not to have to work under the handicaps of high-speed problems.

TWO-DIMENSIONAL SCANNING CAMERA

In our first paper on this subject,† the basic theory proposed a composite picture made up of widely displaced silver deposits with unexposed areas between them much larger than the deposit size. The spacing of the coherent elements for one picture would be so coarse as to provide room in the neighborhood of each for elements to be used for 899 other pictures. Such a system would require a well-made focal-plane sieve for positively selecting those elements which constitute related parts of a single picture both for exposure and for viewing. Once again if each hole (the sieve as a unit) could be translated to a new nonoverlapping position, unexposed emulsion would be uncovered for the recording of an entirely new picture. This theory requires two-dimensional scanning, a picture now being made up of dot elements rather than linear strips as before. A two-dimensional scanning system could be made by using two of the one-dimensional form described in our first paper and operating at right angles to one another. This, however, would be much too complex especially in view of the high speeds we wish to attain. A much simpler approach is to use a disk carrying a configuration of holes, the disk rotating in a camera focal plane to record the composite subject motion frames as the event progresses. Such a disk begins to approach the theoretical sieve which we proposed in our initial paper.

A two-dimensional version of the high-speed multiple-aperture scanning camera will now be described which is capable of taking 900 pictures at a rate up to several million per second. These figures are based upon the assumption that the number of frames is a function of aperture diameters uncovered. This we have now shown to be on the low side factorily. However, since we have not done any absolute frame-number work for this device similar to that already described for the one-dimensional case, this basis will suffice for our preliminary introductions. Basically this camera consists of a focal-plane sieve in the form of a disk which rotates very nearly in contact with the emulsion of a photographic plate on which the images are recorded. The camera contains a capping shutter which operates in much the same fashion as that described for the one-dimensional case. Fig. 1 shows the configuration of holes on the disk and the action of the capping shutter. On any given radius there is a series of holes one unit of length in diameter, each thirty units of length apart. On another radius sufficient distance away such that its outermost hole can be

† This issue, pp. 451–461.

thirty units of length along the periphery from the outermost on the previous one, there is an identical radial series of holes. However, on this radius each hole along the radius is one unit closer to the center than its contemporary on the radius just ahead of it. This process or spiraling-in of holes is continued for additional equispaced radii until the radius is reached on which the outermost hole is at a distance one unit of length from the center greater than the second hole on the initial radius considered. Since the separation between the outermost hole and the next one in on any radius is thirty units, this requires thirty radii, each with its series one unit closer to the center than its

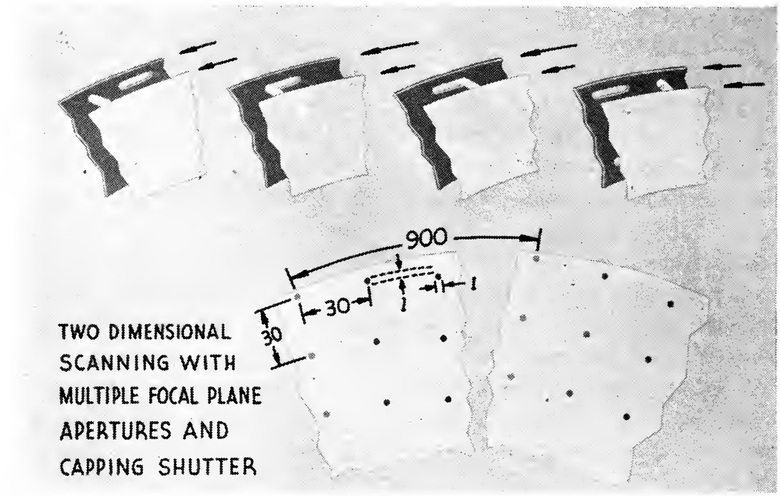

Fig. 1

predecessor. Since each radial series is separated from its neighbor by thirty units on the periphery, the linear distance involved is 900 units. At this point the configuration is repeated and continued until the complete disk is covered. Any hole of unit diameter travels 900 units before it uncovers emulsion which has already been exposed. In other words, based upon the frame slit-width function, 900 separate frames are available. At the moment we are using a disk in which the hole diameters are one-half thousandth of an inch and the separations involved are therefore fifteen thousandths. Such a configuration, when used to scan a 4 × 5 plate, produces a pattern for each frame 240 dots high and 300 wide. The manner of producing such a sieve will be the subject of a future paper.

A disk 21 inches in diameter carrying this configuration of holes need only be rotated at 500 revolutions per minute to attain a picture-taking rate of one million per second. This is the basic picture-taking speed of the camera. However, change gears are provided to achieve both slower and faster rates of picture taking. A capping shutter disk is rotated in assembly with the one already described. This disk is identical in all respects to the first except that the holes are now slots two and one-half thousandths long and one-half thousandth wide. The two disks rotate in assembly until the shutter disk is given an added rotational kick by a coil spring. This indexing of the

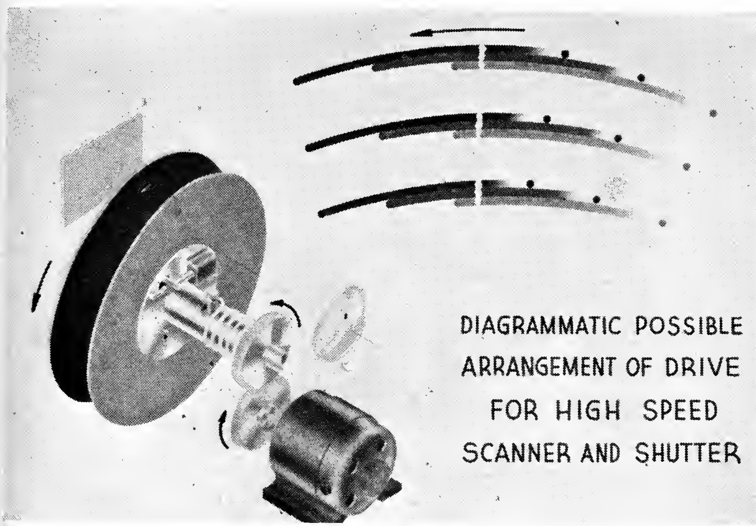

Fig. 2

disks with respect to one another is triggered by the event to be photographed. The interaction during indexing between the two is shown at the top of Fig. 1 where the arrows represent velocity vectors. Exposure takes place as the holes and slots pass through registering position, the length of the slot and its velocity relative to the hole being correct to expose all of the emulsion available to a given hole during its translation. The camera construction is such that it may also be used as a viewer for examination of the composite photographic plate.

Fig. 2 shows the mechanical arrangement for the new high-speed camera. At the top of the figure is shown how a particular scanning hole can proceed for the allowed 900 units of length before arriving at emulsion area previously exposed. The exposing and capping shutter disks are driven in fixed coupled relation by spur gears from an ordinary motor. About the shaft and rigidly attached to it is a torsion spring which is always trying to index the capping shutter disk counterclockwise with respect to the hole disk by means of a pin working through a slot in the outer shaft and attached to an inner one which

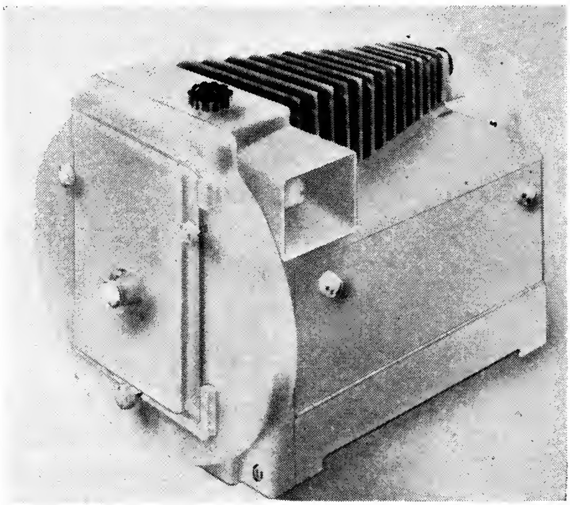

Fig. 3—Two-dimensional scanning high-speed camera.

carries the shutter disk. Relative movement between the two disks is prevented by a pin attached to the shutter disk and which rests against a solenoid arm mounted on the exposing disk. Retraction of this arm by an electrical impuse allows the pin to drop into the notch thus permitting a small relative movement between the two and causing the exposure. Other than the lens used and a means for holding the photographic plate, this is all there is to the complete camera. Fig. 3 is a rendering of the exterior appearance of the camera.

We plan to present the results obtained with this camera as the context of a further paper on this subject.

Twenty-Lens High-Speed Camera*

By CHARLES W. WYCKOFF

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Summary—A brief description of the Jenkins camera is presented with illustrations of the optical principles. In co-operation with the Taylor Model Basin, the optical system was redesigned in an attempt to overcome faults encountered with the Jenkins camera. Lenses were mounted on the rim of the lens wheel instead of the flange. This eliminated one fault but introduced others. These faults were all minimized to the extent that the resolving power of the camera is better than that of the film. The 20-lens camera covers a 35-mm sound aperture and holds up to 200 feet of film. It has been operated up to 2350 pictures per second at an *f*/9 effective aperture.

As far back as 1910, one of the founders of the Society of Motion Picture Engineers, Charles Francis Jenkins, described a non-intermittent type of motion picture camera which he had invented. It was more than just a motion picture camera, it was in fact, a high-speed motion picture camera capable of recording at a rate of approximately 3000 pictures per second. This astounding speed was truly a great triumph especially since the only film available lacked both strength and quality.

Jenkins achieved these speeds by abolishing the standard practice of intermittent motion of the film and using in its stead continuous travel. To prevent the image from smearing as the film was moved past the picture gate he devised a unique system of image tracking. His tracking system consisted of moving a photographic objective along with the film; essentially, the camera consisted of several cameras operating one after the other. As each camera moved into position, it recorded an image and then moved away allowing the next camera to commence recording.

To achieve the seemingly complicated action, Jenkins used a lightweight disk or wheel mounted on the shaft of an electric motor, Fig. 1A. A series of matched focal-length lenses were mounted near the rim of the wheel with their optical axes parallel to the wheel axis. As the lens wheel was rotated, each lens in turn would sweep past the

* Presented April 6, 1949, at the SMPE Convention in New York.

picture gate. By means of a gear drive from the lens wheel shaft, the film was also made to move past the gate in synchronism with the motion of the lenses. As each lens was brought into position, it would commence recording an image on the film.

A study of Fig. 1B, will show that the image-tracking action

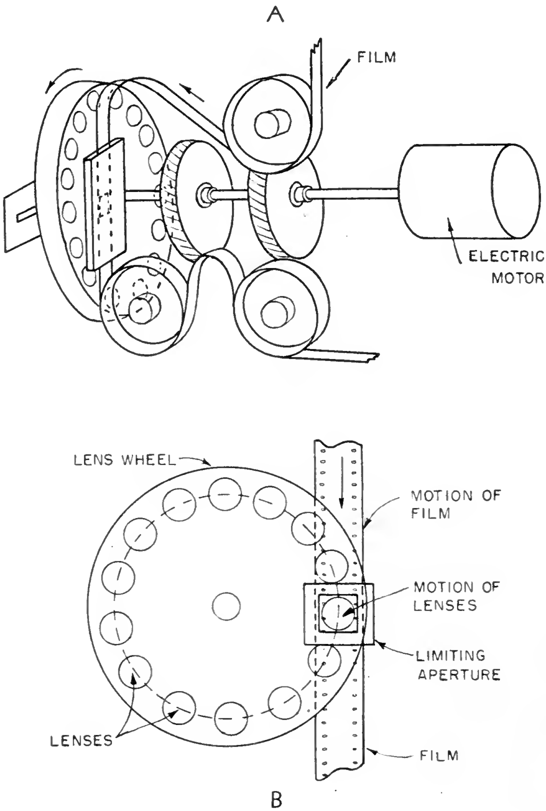


Fig. 1—Schematic of Jenkins camera.

of the film is not perfect. The film travels along a straight line whereas the optical axes of the lenses travel along an arc. Thus the image of a point will tend to be a vertical crescent rather than a point. This can be clearly seen in Fig. 2, which is a single frame from a high-speed motion picture made with this camera. Notice how the small self-luminous fragments are all crescent-shaped. This effect can be

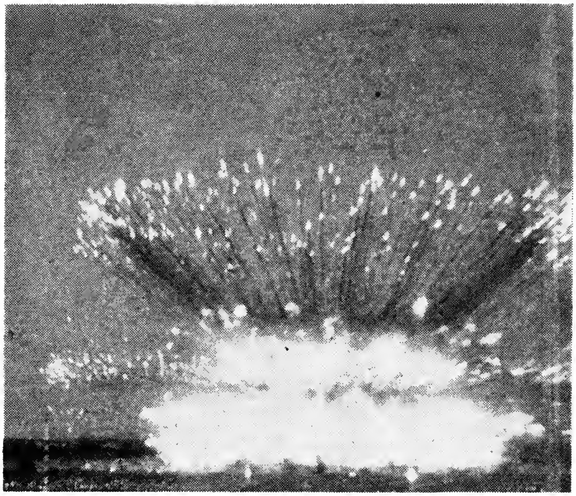


Fig. 2—Typical Jenkins camera record.

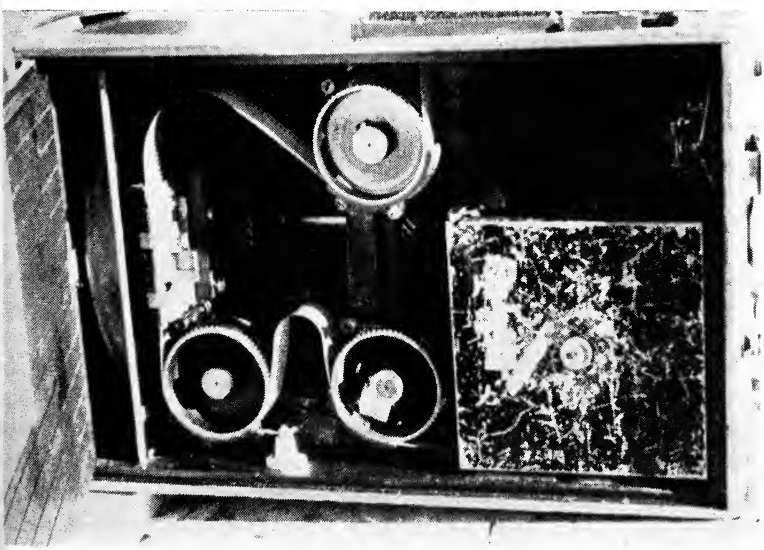


Fig. 3—Interior of Jenkins camera.

minimized by increasing the radius of the lens wheel. It is also necessary to place a limiting aperture or slit in front of the optical system, thereby reducing the distance over which the image is tracked on the film. As the radius of the lens wheel increases, the arc becomes more nearly a straight line. The radius chosen by Jenkins was on the order of 6 inches and the number of lenses was 48. Fig. 3 shows one of Jenkins' latest cameras which was constructed about 1914.

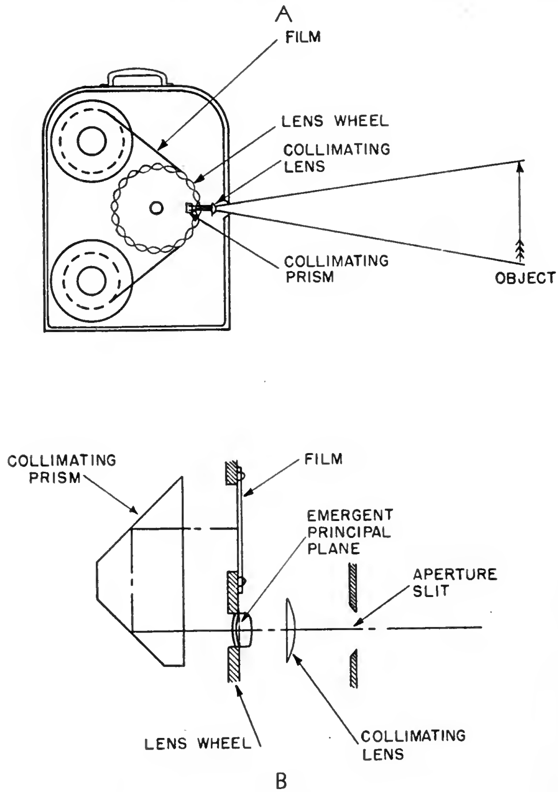


Fig. 4—Schematic of 20-lens camera.

The author used the camera a great many times in the early part of the war. In co-operation with Taylor Model Basin of the United States Navy, an attempt was made to correct the distortion inherent in this type of camera. This necessitated a complete redesign of the camera and optical system. The first step was to rotate the optical axes of the lenses in a plane 90 degrees to the wheel axis used by

Jenkins. Instead of being on the flange of the wheel they were placed on the rim. Fig. 4A is a schematic drawing of the optical system. The film travels beside the lenses over the same wheel. Light passes through the lens which is directly behind the main aperture and is reflected by a prism onto the film as shown in Fig. 4B. A glass prism autocollimator is used instead of mirrors so that a 2-inch focal-length lens may be used. The physical dimensions are too great to allow a 2-inch lens to be used without compensation. The

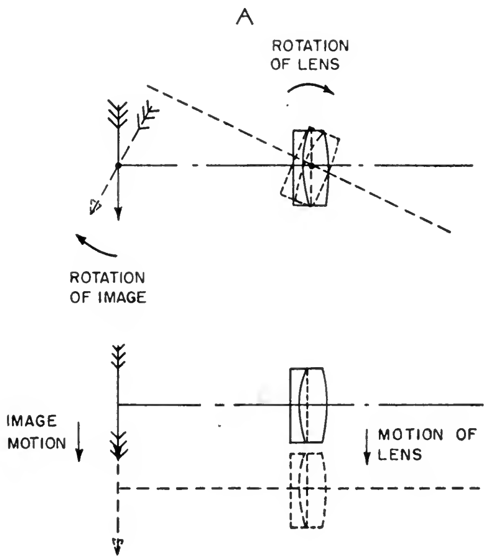


Fig. 5—Limits of image rotation.

glass of the prism produces this compensation by effectively shortening the optical path of each lens. Focusing is accomplished by placing a collimating lens of the correct local length in front of the lens wheel.

At first glance this seems like a simple straightforward answer to the problem of eliminating the crescent-shaped distortion prevalent in the Jenkins design. Indeed it does eliminate this distortion, but at the same time it introduces several other types of distortion into the system. First of all, the image and the lens will travel at the same speed only if the lens is focused at infinity and with the condition that the emergent principal plane of the lens rotates about the same radius as the film. Under any other conditions the film will move either faster or slower than the image, producing improper tracking or distortion smearing.

A second distortion is caused by the cylindrical section of the film plane. It is therefore difficult to have a critically sharp image over the entire film. A third distortion called "rotation of image" is

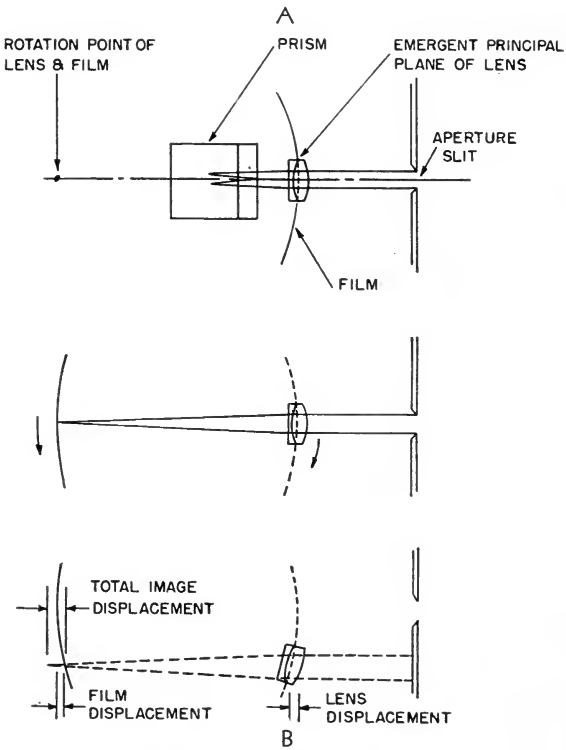


Fig. 6—Depth-of-focus limits.

shown in Fig. 5A, the extreme case of such rotation. In this diagram the lens is rotated about an axis passing through the optical axis and the emergent principal plane of the lens. As the lens is rotated, so must the film be rotated if the image is to remain sharp. If the lens is rotated about a point infinitely distant from the emergent principal plane but still on the optical axis there will be no image rotation. This is shown in Fig. 5B. To satisfy the conditions of image rotation the lens and film should be rotated so that the emergent principal plane of the lens and the film are always parallel. Instead, as seen in Fig. 6A, the lens and film approach one another because both are moving on an arc with the same radius. A larger radius will minimize this condition until with an infinite radius the displacement becomes zero. In Fig. 6B, the prism is

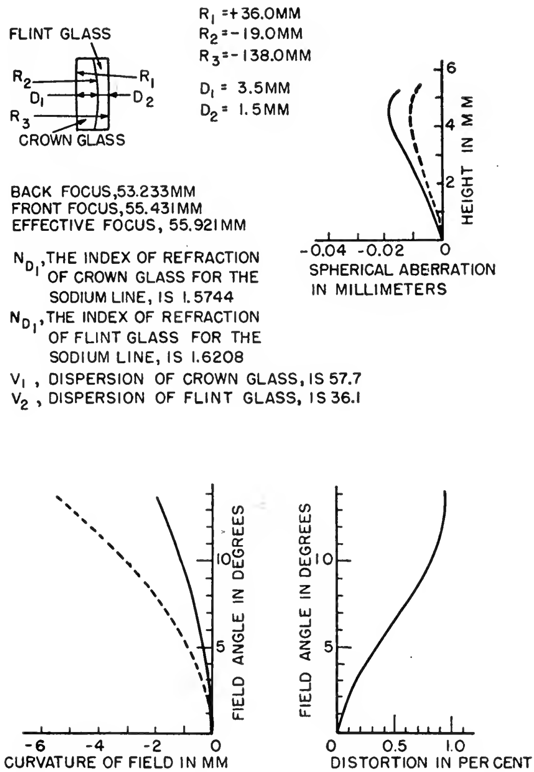


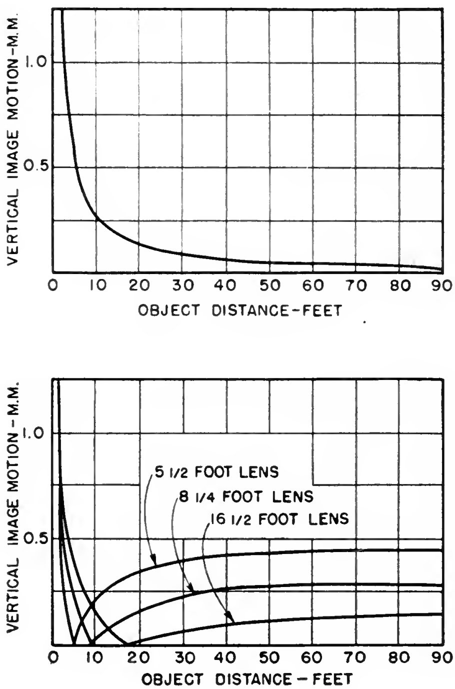
Fig. 7—Lens characteristics.

removed for simplicity and the film is placed behind the objective instead of alongside it. In the 20-lens camera the radius and limiting aperture are such that this displacement never exceeds three tenths of a millimeter. The depth of focus of the objectives is sufficient to tolerate this much displacement and still resolve 60 lines per millimeter.

These distortions just mentioned have not been completely eliminated in this camera. They have, however, been kept to a low enough value so that the resolution of the film becomes the limiting factor of the camera.

The lenses selected for this model camera are not by any means an optimum choice. They were chosen because they were a standard Navy item, readily available, and had characteristics adequate to test the usefulness of this type of optical system. These characteristics,

A



B

Fig. 8—Image motion for different object distances.

shown in Fig. 7, are all suitable for the camera with the exception of the curvature of field. The field angle in this camera is approximately 13 degrees and at this angle the curvature of the field is great enough to cause a blur in the corners of each picture.

A serious disadvantage of the 20-lens camera is lack of an adequate system for focusing. It was previously stated that for perfect image tracking the rotating lenses must be focused at infinity. Fig. 8A illustrates the amount of motion an imaged point will produce as the object distance increases. As the object distance is increased the amount of blur decreases. It is obvious from this figure that if the camera is to record a scene with a quality superior to the resolution of the film, the object must be at infinity. The lenses are therefore adjusted for infinity. To record an object at distances less than infinity, it is necessary to use collimating lenses. For the pilot-model camera, three such collimators were selected. These had focal lengths of $5^{1}/_{2}$, $8^{1}/_{4}$, and $16^{1}/_{2}$ feet, respectively. Thus, if an object is placed at $5^{1}/_{2}$ feet from the camera with the first collimating lens,

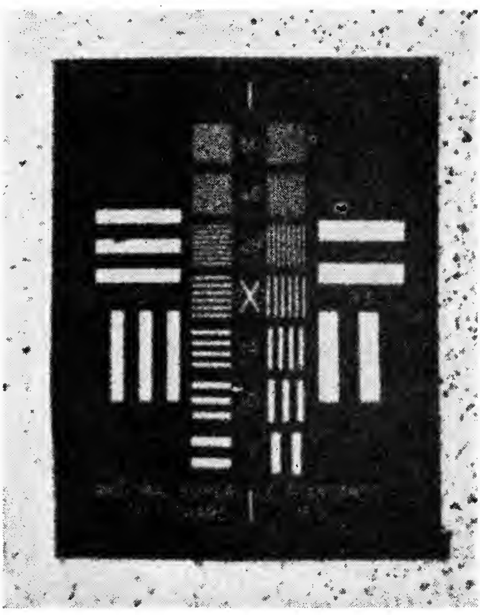


Fig. 9—Resolution chart as recorded by 20-lens camera.

the object will be essentially at infinity. Fig. 8B illustrates the image blur as a function of object distance for each of the three collimating lenses. It should be noted that at the object distance corresponding to the focal length of each collimating lens the amount of blur is zero.

The optical resolution of this camera is then limited not by improper image tracking but rather by (1) image rotation, (2) curvature of field, and (3) the use of a slit instead of a circular aperture. Image rotation can be kept below the value of film resolution by a large-diameter lens wheel which also reduces film-plane curvature. A rectangular or slit aperture undoubtedly reduces the resolving power of a lens. However, this is still better than the resolution of high-speed film. Fig. 9 is a frame from a motion picture of a National Bureau of Standards Resolution Chart. The chart was photographed at approximately 25 times the focal length. It will be noticed that the resolution recorded is probably the resolution of the film or somewhere around 45 lines per millimeter.

The only existing model of the 20-lens high-speed motion picture camera is the one which was constructed by the Navy, Fig. 10. It holds up to 200 feet of standard 35-mm film and has attained a

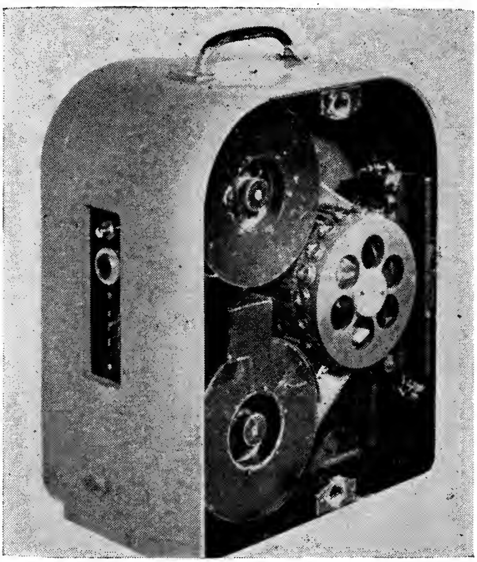


Fig. 10—Interior of 20-lens camera.

speed of 2350 pictures per second. With a more powerful drive motor it might be possible to double this speed. The effective aperture is *f*/9 and the exposure time is adjustable between approximately 10 and 60 per cent of the time interval between pictures. The size of the image is that of the standard Academy sound aperture.

A more detailed description of this camera is presented in Navy Department David Taylor Model Basin Report R-345. This report entitled, "A Twenty-Lens High Speed Motion Picture Camera," may be obtained by writing to the David Taylor Model Basin in Washington, D. C.

Half-Million Stationary Images per Second With Refocused Revolving Beams*

By C. D. MILLER

Battelle Memorial Institute, Columbus 1, Ohio

Summary—**A motion picture camera is described, developed in the laboratories of the National Advisory Committee for Aeronautics, which has made photographs of combustion phenomena in an engine cylinder at 500,000 frames per second. Illustrations and references are included. Sample photographs are reproduced.**

The time involved in the normal nonknocking combustion process in an engine cylinder varies about inversely as engine speed, other things being equal. Even with a speed of only 500 revolutions per minute the normal combustion process in a single cycle of engine operation is completed in less than 10^{-2} second. And with knocking combustion things happen much faster.

Recent studies in laboratories of the National Advisory Committee for Aeronautics[1] have shown that knocking combustion in an engine often involves detonation waves traveling more than a mile a second. In an engine of 5-inch bore such a wave would move entirely across the cylinder in less than 10^{-4} second. As this wave usually traverses only part of the chamber, it must be "seen" in an interval of only 2×10^{-5} to 4×10^{-5} second, if at all. If we want this wave to occupy an interval of, say, one second on the projection screen, at 16 frames per second, we must photograph at 4×10^5 to 8×10^5 frames per second.

In response to the demonstrated need in the study of knock, two different types of high-speed camera have been developed. The first[2] has been operated over a period of years at 40,000 frames per second in the NACA laboratories, and a slightly modified form of that camera now under construction at Battelle Memorial Institute is expected to operate at rates up to 100,000 frames per second.

* Presented April 6, 1949, at the SMPE Convention in New York.

The second type of camera, (Fig. 1) which will be discussed here, was invented in 1939 and has been described in a United States Patent filed[3] December 28, 1940, and in an NACA note.[4] First photographs of combustion were taken with this camera at 10^5 frames per second in 1942. The detonation wave involved in engine knock was photographed at 2×10^5 frames per second in 1944. This series of photographs was published[5] in 1946 and again[1] in 1947. Another motion picture of engine knock taken with this camera at 5×10^5

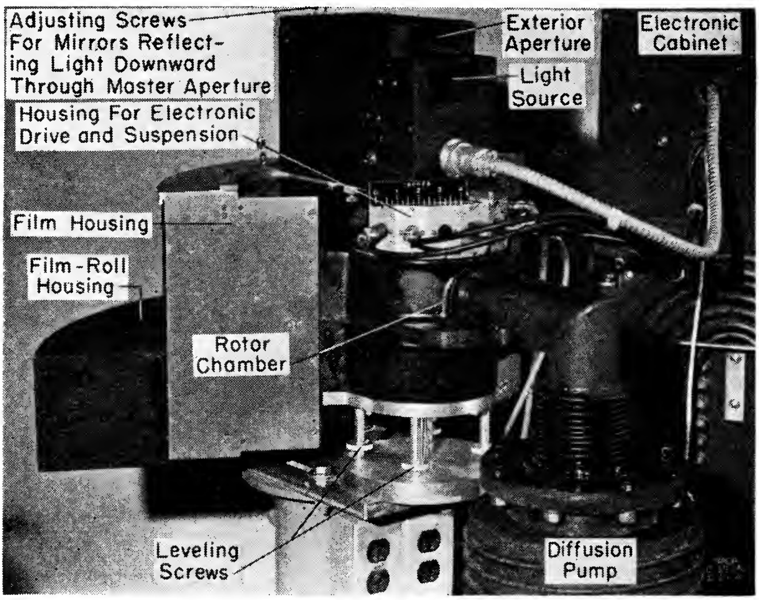


Fig. 1—Photograph of camera.

frames per second was exhibited[6] in 1948. It is anticipated that the camera will eventually be operated at 10^6 frames per second.

ELEMENTARY PRINCIPLE OF OPERATION

The elementary principle of operation is illustrated in Fig. 2 in a form designed to expose a series of only two frames. It is remarkable that this simple and obvious shutter mechanism apparently remained undiscovered[3] until 1939. Besides its use in the camera described here, this principle has been used in the Bowen camera,[7] which was, however, elaborated differently than described in the section of this paper on Camera Details.

In the device as shown in Fig. 2, an objective lens forms a stationary primary image on a rotating mirror. The revolving reflected beam from the rotating mirror sweeps across the stationary refocusing lenses, which are arranged to focus secondary images at two different positions on the stationary film. As the primary image is stationary, and is located at the center of rotation of the reflected beam, the secondary images are also stationary in spite of the rotation of the beam. Each secondary image is exposed, however, only during the

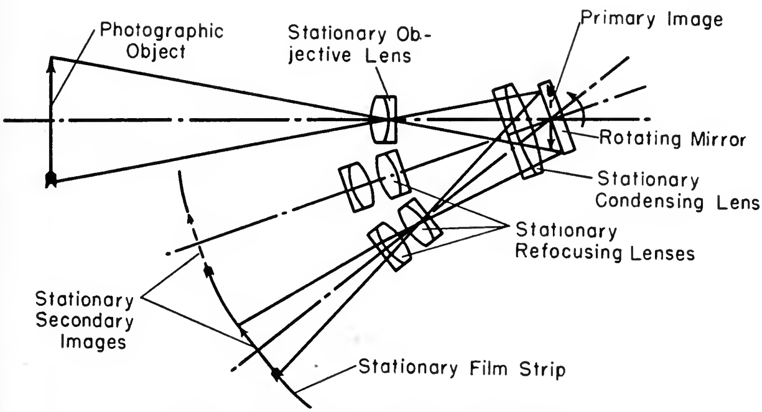


Fig. 2—Elementary principle of operation.

time the reflected beam is sweeping across the refocusing lens corresponding to that image. The arrangement is equivalent to two "still" cameras with high-speed shutters timed to open at slightly different times.

The stationary condensing lens shown in Fig. 2 is placed so close to the secondary image that it has little effect on the image. Its function is to condense the reflected beam into the smallest possible area on the surfaces of the refocusing lenses.

CAMERA DETAILS

In designing a camera suitable for studies of engine knock, some modifications were made on the elementary form shown in Fig. 2. The first such change was to eliminate the condensing lens and to grind the rotating mirror with a concave curvature, allowing the mirror to perform the function of condensing the reflected beam. This change permitted operation of the mirror through a greater angle of rotation than would have been possible with use of the stationary condensing lens.

Figs. 3 and 4 illustrate the camera design used with considerable

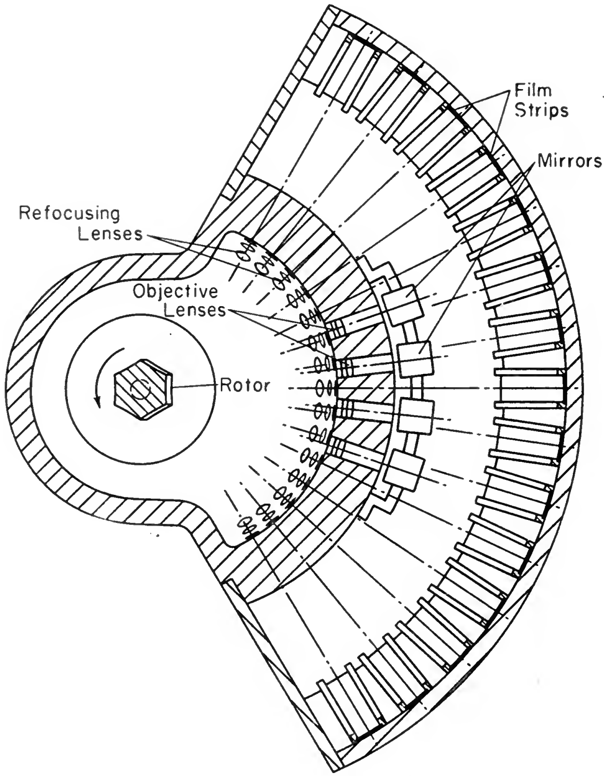


Fig. 3—Central horizontal section through camera.

simplification of mechanical details. Fig. 3 is a central horizontal section through the camera and Fig. 4 is a central vertical section.

Ninety refocusing lenses and four objective lenses are arranged in a spherical wall. The refocusing lenses are arranged on six levels, with 15 lenses on each level. The four objective lenses are on a central level, and are seen in section in Fig. 3. The apertures of refocusing lenses on three levels may be seen in Fig. 3 below the plane of the section; the other three levels are above that plane and do not appear. In Fig. 4, apertures of two of the objective lenses are visible; the other two are above the plane of the section. Six of the refocusing lenses appear in cross section in Fig. 4, one for each level. Apertures of some of the refocusing lenses appear in this view on each of the six levels, but nearly half of the refocusing lenses on each level are above the plane of the section and are not seen.

The hexagonal steel rotor, shown alone in Fig. 5, has six highly polished concave surfaces, each of which reflects the light beams through the refocusing lenses on one of the six levels.

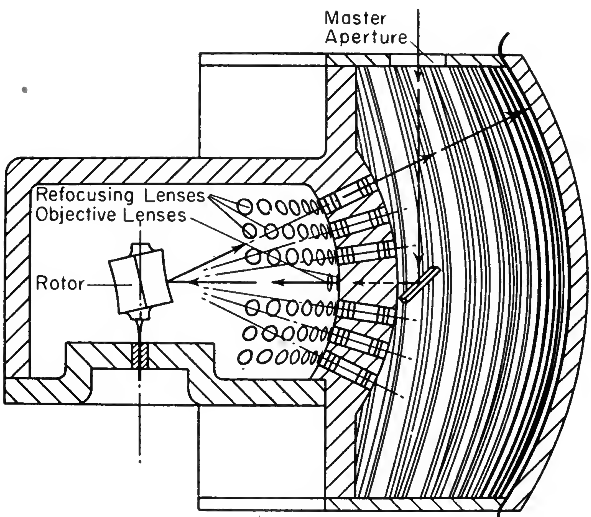


Fig. 4—Central vertical section through camera.

Fifteen stationary vertical film strips are fitted to the shape of a sphere, concentric with and approximately twice as great in radius as the spherical wall in which the lenses are mounted. Each film strip accommodates one refocusing lens on each of the six levels. Each film strip is part of a 100-foot roll, $^7/_8$ inch wide, arranged by mechanical details, not shown, in such a way that the exposed film can be pulled out and cut off after each shot, leaving the camera loaded for the next shot.

Light from the photographic object enters the camera through the master aperture seen in Fig. 4 and is reflected by four plane mirrors through the four objective lenses. The two objective lenses forming the upper (lower) two images as seen on the rotor in Fig. 5 have three times the angular spacing between them as have any two adjacent refocusing lenses on a given level. Consequently, secondary images formed by light from these two objective lenses are exposed on the film strips simultaneously. When the line of intersection of two rotor faces cuts across one of the upper (lower) images on the rotor, part of this image is refocused on one film strip and part on another. At all such times, however, the other upper (lower) image is falling full on one of the rotor faces and is consequently refocused entirely on one film strip. It is therefore possible to secure a continuous, uniformly timed series of whole images on the film for a complete turn of the rotor.

Four objective lenses were provided instead of two in order to double the picture-taking frequency and the number of frames exposed in a single series. The objective lenses forming the upper images in Fig. 5 are offset from those forming the lower images by $1^1/_2$ times the angular spacing between two adjacent refocusing lenses. Consequently, images corresponding to one of these pairs of objective lenses are formed on the film while the reflected beams corresponding to the other pair are falling on the spherical wall between two adjacent refocusing lenses. One of the pairs of objective lenses is thus responsible for a uniformly timed series of exposures, 102 in number, during a single turn of the rotor, and these exposures are interspersed with a similar series exposed by the other pair. The two sets can be combined to give 204 successive exposures.

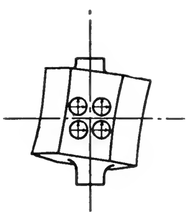


Fig. 5—Camera rotor with positions of four stationary primary images.

At many times during a turn of the rotor, two whole images are formed on different film strips at the same time. In such cases, the better image is used and the other discarded. In general, this procedure results in use of more images on the central film strips than the outer ones.

Re-exposure of images on continued turns of the rotor is avoided by timing the light flash for the duration of only one turn. Gas-filled flash tubes receive the early part of the discharge from a condenser whose capacity is sufficient to produce nearly uniform light intensity for the period of one rotor turn. At the end of one turn, an electronic delay system short-circuits the flash tubes through a grid-controlled arc tube.

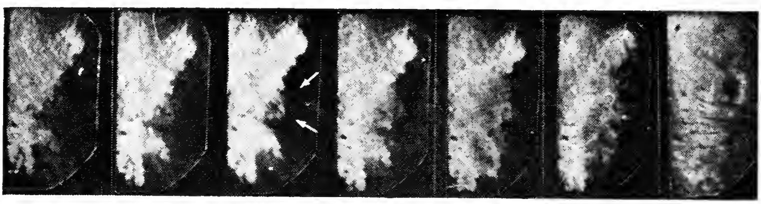
MOTIVE POWER AND ROTOR DYNAMICS

During early operation of the camera, motive power was supplied by an air turbine constructed at the University of Virginia.[8] The 5-ounce camera rotor was supported by the upper end of the same piano-wire shaft, 0.039 inch in diameter, that served the turbine itself. Two babbitt journal bearings were used, one below the turbine rotor, the other between the turbine rotor and the camera rotor. The upper bearing served to seal the evacuated rotor chamber from the atmospheric pressure existing within the air turbine.

The camera rotor, as seen in Fig. 4, has the appearance of being mounted to spin about an axis that makes a considerable angle with its own natural axis. At first sight many engineers therefore assume that the rotor cannot be balanced properly. The rotor is approximately a right prism of hexagonal cross section, with the prism axis intersecting the axis of spin at about 15 degrees. It is well known, however, that the inertial characteristics of any spinning body may be represented by those of an equivalent ellipsoid. It is also well known that the fundamental requirement for static and dynamic balance is that the body must be mounted to spin about one of the principal axes of the equivalent ellipsoid. Moreover, the equivalent ellipsoid for any right prism of regular polygonal cross section is a spheroid whose major or minor axis coincides with the prism axis. By pure coincidence the prismatic camera rotor, designed on the basis of optical considerations alone, has almost exactly the correct length to make its equivalent spheroid a true sphere. It may, consequently, be mounted and balanced to spin about any axis that passes through its center of gravity without changing its appearance appreciably.

The balancing of such a body, however, proved exceedingly difficult. The difficulty lay in the facts that the near-spherical body involves extremely high critical speeds, that the true axis of balance of the near-spherical body may make a large angle with the axis of spin even though the unbalance at speeds below 500 revolutions per second is barely detectable, and that shaft failure at the critical speed is certain if the angle between the true axis of balance and the axis of spin exceeds the greatest angular deflection that can be tolerated by the shaft.

After numerous shaft failures at a critical speed of about 1200 revolutions per second, a better understanding of the problem was gradually obtained and it was finally possible to spin the rotor with assurance of safety at 5500 revolutions per second, corresponding to 1.122×10^6 frames per second. It was not possible to operate the camera at such speed, however, because no solution was found to the problem of spattering oil from the journal bearing onto the camera lenses. Oil spattering was aggravated by the necessary evacuation of the rotor chamber. After some motion pictures of engine knock were obtained at 2×10^5 frames per second, the air-turbine drive was finally abandoned. Work was then started on an electromagnetic drive and suspension, modeled after an earlier development at the University of Virginia,[9] but with some novel features. The photographs recently exhibited, taken at 5×10^5 frames per second, were obtained with the electromagnetic drive and suspension.



1 2 3 4 5 6 7

Fig. 6—Selected frames from motion picture of engine knock.

Examples of Photographs Made with Camera

Fig. 6 presents selected frames from a shot of engine knock obtained at 2×10^5 frames per second. These photographs have been discussed at length elsewhere.[1, 5] The first frame of the series was exposed 25×10^{-6} second before knock started to develop, and the second frame only 5×10^{-6} second before the start of knock. Little change took place between the exposures of these two pictures because the combustion that precedes knock is too slow to produce much change in so short a time.

Approximately the right-hand half of the piston top is seen in each frame of Fig. 6, looking downward through a glass window mounted in the cylinder head. The spark plug was at the left side of the chamber, far outside the field of view. Before the exposures of the first two frames the flame traveled all the way across the combustion chamber from left to right. In each of these frames, the black cloud at the right represents the ignited and still-burning gas. The whitish mottled region in the left of each frame, on the other hand, represents the completely burned gases.

The third frame of Fig. 6 was taken only 5×10^{-6} second later than the second frame. The detonation wave known as knock started in this third frame, apparently in the burning gases, and caused the whitening of the part of the burning zone indicated by the arrows.

The fourth and fifth frames of the series were taken 5×10^{-6} and 15×10^{-6} second after the start of knock. Progress of the detonation wave in these frames is indicated by the dark-gray (not black) cloud in the central part of the picture. The wave traveled both upward and downward, as well as toward the left, at nearly 7000 feet per second during exposure of these frames.

The sixth and seventh frames were exposed 35×10^{-6} and 60×10^{-6} second after the start of knock. In the seventh picture the knock reaction has caused a fairly complete disintegration of the black combustion zone. In the sixth picture particles of free carbon, released by the knock reaction, are seen as small black spots. In the seventh frame these particles of free carbon have been smeared out into long filaments, because of the effect of their physical inertia as the expanding gases rushed by at high speed.

CONCLUSIONS

The quality of photographs obtained at rates up to 5×10^5 frames per second has been such as to provide valuable new information on engine knock. Some sacrifice in definition has been made, however, in order to obtain an extended sequence. It is believed that the camera can be redesigned to obtain even a longer sequence, at the same speeds, without such sacrifice in definition.

The camera is inherently limited to use at low relative apertures, $f/11$ in this case, but the aperture is adequate for shadow or schlieren photography. The aperture is also adequate for direct photography of many explosion and detonation phenomena without artificial illumination. It is believed that the camera should find wide application in the study of explosion and detonation phenomena, shock waves, ballistics, rapid stress changes in mechanical parts as observed by photoelasticity, and even the action of very small high-speed mechanisms.

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Very-High-Speed Drum-Type Camera*

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Summary—**A drum-type camera designed to take pictures at any rate up to 200,000 frames per second is described. A total of 1300 frames of the 16-mm frame size are recorded on a single piece of film from which they can be printed directly for projection and analysis.**

The principles of this camera and the results obtained from an improvised model have been described in a paper by Baird[1] in 1946. Since then an engineered prototype has been built and operated up to 125,000 frames per second.

Optical System

Fig. 1 contains front, side, and top views of a simplified camera which illustrate the basic elements of which it is comprised and its mode of operation.

In the top view the lenses $L_1L_2 \ldots L_5$ lie in a line behind the edge of the rotating disk S whose circumference contains a number of equidistant slots. Any slot passing in front of the lenses exposes them in the order 1, 2, 3, 4, 5; and with the slots so spaced that when one has finished exposing L_5 the next is beginning to expose L_1, the lenses are exposed repeatedly in the named order.

In the side view it can be seen that any one of the lenses L forms an image of an object in its field at a short distance behind it. This image, together with the other four which occur in the same plane, is projected by the second lens M via the reflecting face of the revolving prism P onto the film wound on the outside of the film drum F.

The prism P causes the images to travel with a velocity equal to that of the film thereby preventing relative motion between the two and the consequent blurring of the photographic images.

The pattern in which the individual pictures fall on the film is shown at "D"; each passage of a slot in front of the five lenses produces five pictures in a row lying crosswise on the film. From "D"

* Presented April 6, 1949, at the SMPE Convention in New York.

it can be seen that a row of five frames is laid down in the time required to move the film only one frame height. It is evident that for a given frame height and a given film velocity, the camera can take pictures at five times the rate possible when the film has the width of only one frame instead of five.

A closer inspection of the top view will reveal that the prism P is actually cut into five prisms all mounted side by side on one shaft in the form of a "stack." In the stack there are as many prisms as

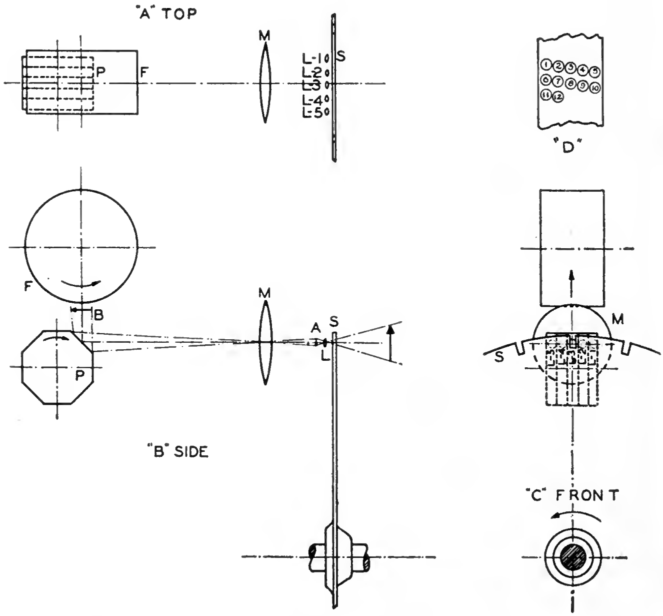

Fig. 1—Schematic views illustrating the operating principles of the camera.

there are of the small lenses L and each one of the prisms receives light from one of the small lenses. Adjacent prisms are rotated with respect to one another about the shaft of the prism assembly by an angular amount corresponding to the time required for a slot to travel between adjacent lenses.

In effect there are five cameras side by side, each with its own objective lens and prism to compensate for film movement; but all cameras place their images on the same piece of film, all use the same projection lens, and all are exposed by a common shuttering device.

For the sake of simplicity, the camera just described contained only five lenses; the actual camera, whose description follows, contains ten lenses.

Fig. 2 is a perspective view of the basic elements of the camera in their correct geometric relationship. Light going in a downward direction enters any one of the array of ten small lenses (*51*) which lie

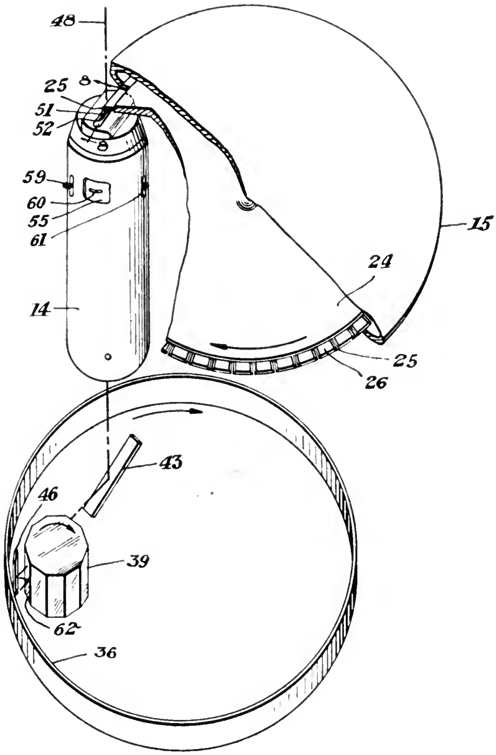

Fig. 2—A perspective view of the basic elements of the camera in their correct geometric relationship.

in a horizontal row below the edge of the slotted disk (*24*). The aerial images they form are projected by the enlarging lenses contained in the tube (*14*) via the mirrors (*43*) and (*46*) to the surfaces of the composite prism (*39*), from which they are reflected onto the film lying (emulsion side inwards) against the inside wall of the film drum (*36*). The slotted disk, the prism assembly, and the film drum are synchronized and rotated about their vertical axes by precise gearing.

The ten small lenses are ordinary achromats, each with a clear aperture of 0.055 inch and a focal length of 0.5 inch. When placed side by side the ten occupy a distance of only 1 inch. The slot widths, the clear apertures of the lenses, and the lens spacings are such that the total exposure time of each lens is equal to the reciprocal of the picture rate.

In the optical tube (*14*) there is a photographic shutter (*59*) which can be adjusted to stay open during a single revolution of the film drum thus preventing the reimposition of images on film area that has already been exposed.

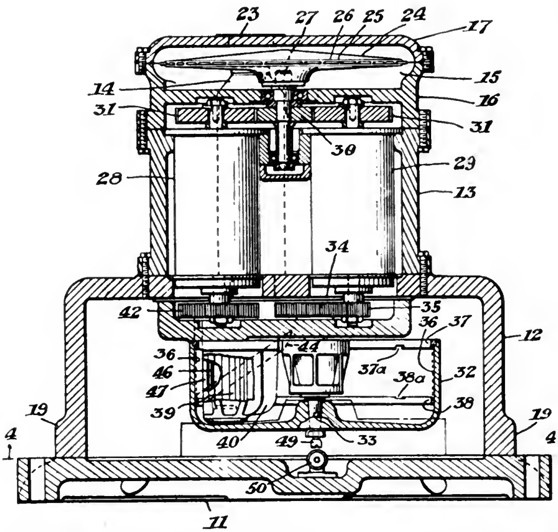

Fig. 3—A cross-sectioned view showing the engineering details of the camera.

The previously mentioned enlarging lenses consist of a Ross "Xpres" 4-inch wide-angle lens and a Cooke-process anastigmat placed end to end. This pair of lenses enlarges the primary images by three times.

Two grooved rings hold the piece of film against the inside of the film drum. The film is 39 inches long by 3 inches wide and holds a total of 1300 frames.

Fig. 3 is a sectional view illustrating the mechanical details of the machine. The upper chamber contains the slotted disk (*24*) mounted on a shaft which turns on two precision ball bearings. Also mounted on the shaft is the gear (*30*) which meshes with the two gears (*31*), each mounted on the shafts of the identical electric motors (*28*) and (*29*). In a similar fashion gears attached to the lower ends of the motor shafts drive the film drum and the prism assembly; the sectioned film drum can be clearly seen in the bottom chamber, but the prism assembly, somewhat behind the plane of sectioning, is partially obscured by the details of the drawing.

The slotted disk and the film drum are made from forged blanks of high-strength Duraluminum. The gears are made from nickel alloy and tool steel; their teeth are cut on 15-degree helices and have a normal pitch of 32 teeth per inch of diameter. Each elementary prism in the 10-prism "stack" is of stainless steel and has 20 faces polished to a high degree of optical flatness. The electric motors are rated to deliver 16 horsepower each at 18,000 revolutions per minute; they are of the 3-phase, 2-pole type and are driven by a variable-speed alternator. The speed of the machine is measured from the frequency of the electromotive force induced in the coil (*50*) by the revolving permanent magnet (*49*) attached to the lower end of the film-drum shaft.

The picture rate for which the camera was designed, namely 200,000 frames per second, requires that the prism assembly rotate at 60,000 revolutions per minute, the slotted disk at 30,000 revolutions per minute, and the film drum at 9000 revolutions per minute.

METHOD OF TAKING PICTURES

Since the picture-taking rate is high enough to expose the whole length of the film in $^1/_{100}$ second or less, ordinary magnesium wire flashbulbs, whose effective flash duration is of the same order, can be used to illuminate the subject. These bulbs are mounted in parabolic reflectors in numbers depending on the picture rate and the reflectance of the subject. To take a sequence of pictures the camera is accelerated up to the required speed and when that speed is reached a timing device trips the camera shutter, the flashbulbs, and the event at the proper instants.

PICTURES TAKEN BY THE CAMERA

Fig. 4 shows an enlarged portion of a length of film as it comes from the camera. It contains a sequence of pictures of a revolving disk on which a series of parallel lines and an arrow indicating the direction of rotation have been drawn. From the increments of rotation between successive frames it can be seen that time is increasing from left

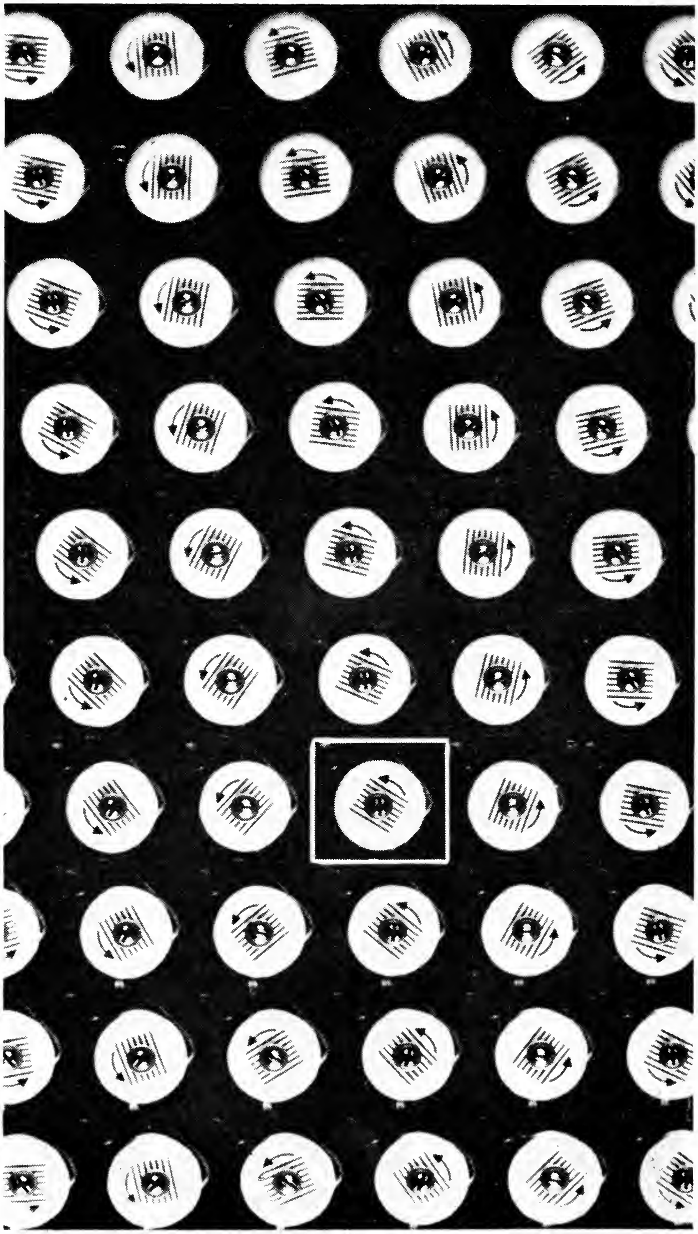

Fig. 4—A reproduction of a portion of the film strip as it comes from the camera. The white rectangle has been inked in on the negative to show the size of an individual frame. The pictures were taken at a rate of 39,000 per second. The subject is a rotating disk mounted on a shaft of an air turbine.

to right and from bottom to top. It can be seen also that the pictures produced by the individual small lenses are of uniform quality.

From these pictures it is possible to infer approximately the least fraction of a frame height that can be resolved: under the best conditions this is $^1/_{250}$ of a frame height. The film used is Kodak Super XX Aero. The total field of view of the camera is 11 degrees and the aperture of the system is $f/30$.

Fig. 5 contains pictures of a 0.22-caliber bullet striking a piece of plate glass taken at a rate of 100,000 frames per second. Time increases from left to right. In the first frame the bullet is about to touch the glass, in the third it is halfway into the glass, and in the fourth, fractures may be seen spreading from the area of impact.

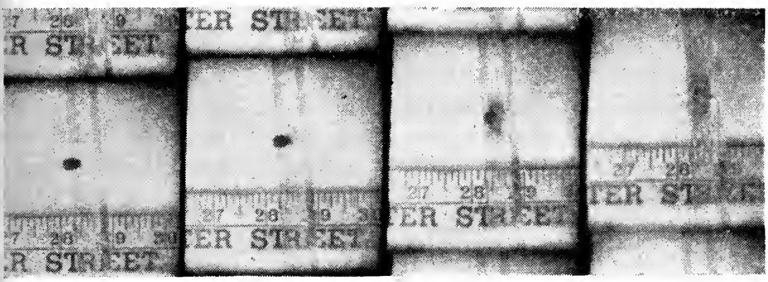

Fig. 5—A bullet striking a piece of plate glass. The plate glass is shown edge-on. A ruler in the background divided in inches gives the scale. The picture rate is 100,000 per second.

CONCLUSIONS

The speed range in which the camera operates enables it to be used in investigations of ballistic and shock-wave phenomena. It takes distortion-free pictures with excellent definition of either self-luminous or nonluminous events. The use of a 16-mm frame size enables the frames to be printed and to be projected with convenience. The camera can be moved around the laboratory floor to any required position. Further, the ability to record over 1200 frames in a sequence in combination with the above features makes the camera a versatile laboratory instrument and might uniquely suit it to certain types of investigations of shock-wave and ballistic phenomena.

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Design of Rotating Prisms for High-Speed Cameras*

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Summary—Principles of design of rotating prisms for high-speed cameras are discussed. A new approach is used in the principles and prisms of higher resolution can be obtained by following this unique approach.

There are a number of different types of high-speed motion picture cameras being made at present, but the most commonly used type is the rotating-prism camera. In this camera the image from the lens is projected through a rotating prism, which is so designed that its rotation causes the image to move in the same direction as the film and at the same speed. The rotating-prism-type camera is simple in construction and is readily portable, easily used, and adaptable to service under a wide variety of working conditions.

As the name implies the prism is the novel feature of all rotating-prism cameras, and it is the purpose of this paper to discuss the design principles of such prisms from the standpoint of good photography.

Doubtless it has been observed by all that a submerged object viewed obliquely appears to be in a position other than is actually the case. This is the light passing from one medium to another of greater density refracted toward the perpendicular to the interface between the two media. When the direction of propagation is from the more dense to the less dense medium, the reverse is true. If the receiving and emitting interfaces are parallel, the direction of propagation of light leaving the prism will be parallel to that entering but will be offset as indicated in Fig. 1. The amount of offset (ss' in the figure) depends upon the magnitude of the refraction effect and the thickness of the prism. This is expressed mathematically as

$$ss' = T \frac{\sin d}{\cos r}. \qquad (1)$$

* Presented October 28, 1948, at the SMPE Convention in Washington.

Recalling that by definition the index of refraction n is

$$n = \frac{\sin i}{\sin r} \tag{2}$$

and that from Fig. 1

$$d = i - r \tag{3}$$

equation (1) can be written

$$ss' = T\left[\sin i - \frac{\sin 2i}{2(n^2 - \sin^2 i)^{1/2}}\right] \tag{4}$$

and the velocity of displacement

$$\frac{d\,(ss')}{dt} = kT\left[\frac{\cos i - 4\,(n^2 - \sin^2 i)\cos 2i - \sin^2 2i}{4(n^2 - \sin^2 i)}\right]. \tag{5}$$

In (5) k is equal to di/dt, the rotational velocity of the prism which is constant.

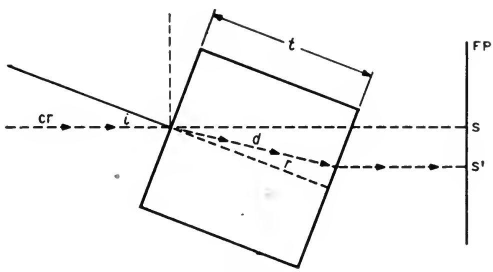

Fig. 1

It follows from (4) that the larger the value of n the smaller the value of T will be for a given image displacement. A minimum value of T is, of course, desirable for optical reasons and for reducing stresses. From (5) it follows that the velocity of the image is more nearly constant, the larger the value of n and the smaller the value of i. Expressed in other words, these deductions mean that the larger the value of n and the smaller the angle of rotation of the prism used in laying down the image, the less blurring will occur caused by dispersion and to variation between the displacements of the film and the image during the period of exposure. Since these are desirable features it follows that maximum values of n and minimum values of T and i are desirable design objectives for prisms of rotating prism cameras. In a paper published by Kudar,[1] prism design was studied from the standpoint of aberrations and it is interesting to note that the design features found to be desirable from that standpoint are identical with those above for good design of cameras.

In order to show how the above design objectives are achieved, it will be desirable first to consider the matter of maximum angle of incidence i to be used. In this connection, reference is made to Fig. 2, a plot of velocities of displacement computed from (5) for various values of incidence angle i. It is to be noted that the velocity of the image is maximum at 0 angle and decreases rapidly as the angle increases. By proper choice of gearing for driving the prism the image can be kept in step with the film within approximately 2 per cent for angles from 0 to 10 degrees and hence a maximum angle of incidence of 10 degrees is a logical value. The angle can be limited to this value by choice of apertures before and in back of the prism. In this connection it is of interest to note that the cone of light from an $f/2$ lens having a 2-inch focal length subtends an angle of approximately 30 degrees when the object is at infinity. If no ray in the cone is to strike the prism at an angle of incidence of more than 10 degrees at any time in the rotation of the prism the useful angle subtended by the lens is only about 10 degrees.

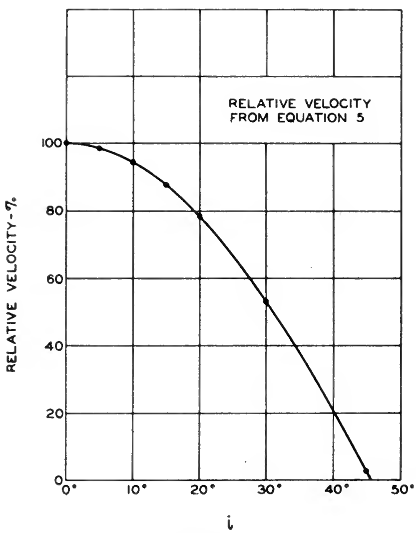

Fig. 2

Having selected the prism glass for maximum index of refraction and having chosen the maximum angle of incidence the next and final step in the prism design is to determine its thickness. This involves the use of (4). It is first necessary, however, to establish the value of ss'.

It is obvious from Fig. 1 that ss' is the distance a specific point of the image moves during the exposure of the corresponding point on the film. It is equally obvious that exposure of the entire scene to the film (within one picture frame) does not occur simultaneously but proceeds lengthwise on the film as the prism rotates. Having established the maximum angle of incidence ($i = 10$ degrees in the above case), it is evident that the time of exposure of any one point on the film is the time required for the prism to rotate through an angle of $2i$ (i.e., -10 degrees to $+10$ degrees in the above case). In a four-sided prism four pictures are exposed per revolution and, therefore, the film travels four picture frames per revolution of the prism and hence

$$ss' = \frac{4L \times 2i}{360} \tag{6}$$

where L is the length of film per picture frame.

With the value of ss' established and with values of i and n previously evaluated, (4) can be solved for the prism thickness to complete the story of the fundamental design of the prism. Fig. 3 shows the calculation for T versus i for varying indexes of refraction for a four-sided prism for a 16-mm camera.

In addition to a suitable prism there are of course a number of other technical features that must be incorporated in the camera design if satisfactory results are to be obtained. One of these has to do with the lengthening of the back focus by the prism.

Consider a diverging cone of light from the lens toward the film, and the prism immersed therein. All rays in the cone not normal to the prism face travel a longer path to reach the film plane than do the normal rays. For a ray on the optical axis this increase in back focus is expressed quantitatively by the equation

$$F = \left[\frac{n - 1}{n}\right]T. \tag{7}$$

For rays not on the optical axis the increase is

$$F = \left[\frac{n - 1}{n \cos r}\right]T \tag{8}$$

where r is the angle of refraction. In certain cases the back-focus effect is sufficient to cause a fuzzy picture at the edges unless corrected for by proper design in the lens and in the film sprocket.

Another point of interest in camera design is the matter of lens aperture. As previously indicated only a portion of light from a wide-aperture lens is used in a rotating-prism camera. Not only is a large-aperture lens therefore uneconomical but it introduces distortion and aberrations to reduce the resolving power of the image as shown by Kudar. If an exposure can be made at $f/5.6$, an $f/5.6$ lens should be used in preference to an $f/2.0$ lens stopped down to $f/5.6$. Of course, increasing the focal length of the lens accomplishes the same effect as reducing the aperture. The final objective in this direction is obtained when using a nearly parallel beam of light through the prism. This can be accomplished by a double-lens system where the objective lens forms an aerial image ahead of a second lens; the second lens focusing this image at the film plane. The second lens should be

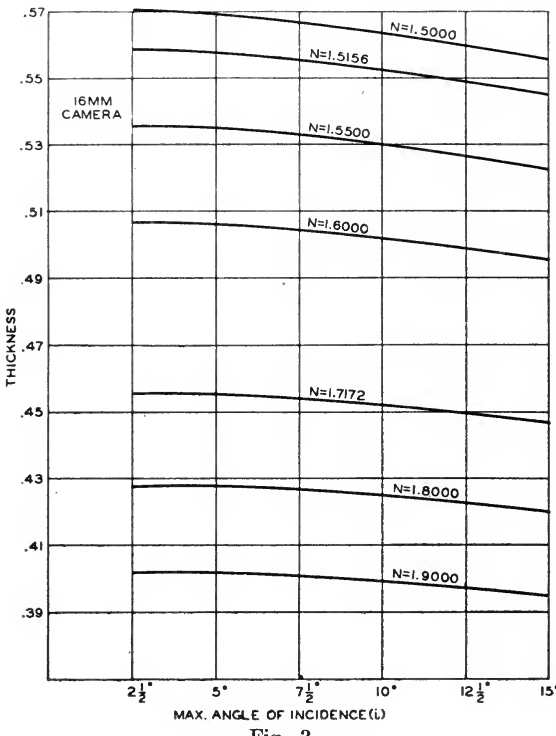

Fig. 3

focused so as to project the aerial image at a 1:1 magnification. In such a system it is comparatively easy to introduce a reticle at the plane of the aerial image if such is desired.

The rotating prism acts as a shutter as well as an image-compensating device. In acting as a shutter, as was explained earlier, the time of exposure is dependent on the maximum angle of incidence. If the prism does not run true, a jumpy picture would be obtained and therefore, the housing of the prism shaft must be of sufficient strength to withstand the centrifugal forces that are present when the prism is rotating and the prism must be mounted in such a way and with small tolerances that the effects of vibration are eliminated. This calls for bearings of extreme precision as well as precision-cut driving gears.

In order to obtain satisfactory results with any rotating-prism camera, it is necessary that the prism faces as well as the lens be kept clean.

The data as presented above indicate that high-quality, high-speed rotating-prism cameras are possible which will approximate the quality obtained with an intermittent-type motion picture camera. The use of prism glasses of high index of refraction and low dispersion with minimum thickness and minimum angle of incidence, in conjunction with suitably designed components such as lenses, sprockets, bearings, and so forth, produce these results.

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Recent British Equipment and Technique for High-Speed Cinematography*

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Summary—New British cameras for high-speed cinematography are described, among which are included those designed by Marley[1] and by Brailsford and Shrubb.[2] The principles of a new Kerr-cell electro-optical shutter which can be used for cinematography are outlined, together with details of its performance. New light sources for high-speed cinematography include mercury-vapor lamps run at high current densities, and foil-filled flashbulbs fired in rapid succession. Several applications of high-speed cinematography are described showing how the solutions to engineering problems have been obtained when the parts concerned are in rapid motion, especially when the amplitudes of the movements are too small to resolve easily in a normal record. The vibration characteristics of the anvil of an 8-ton drop-forging hammer were determined by the use of a special optical system attached to the anvil. Because of the widespread disturbance caused by the hammer blow, an artificially fixed point in space for reference purposes was arranged by means of a long-period damped pendulum system bearing a fiducial indicator. The surface characteristics of white-hot steel bars were studied during high-speed rolling by means of high-speed cinematography using ultraviolet light.

During the past two or three years, the use of standard ultrahigh-speed cameras for investigational work in Britain has increased, and details have been published of a certain number of highly specialized high-speed cameras. None of these has been aimed at exceptionally high picture frequencies, largely because experience has shown that even in ballistics work, a frequency of 100,000 frames per second is ample, while most ordinary industrial problems can be successfully investigated at frequencies of 3000 pictures per second or less.

In general, these cameras incorporate optical means of compensating for the movement of the film, which is in continuous motion, and the subject is illuminated continuously. Alternatively, the subject is illuminated by a series of flashes of short duration from a gas-discharge lamp, the flash frequency of which is controlled by a commutator coupled to the film-driving mechanism of the camera. A further refinement consists in using a combination of synchronized multiple-flash illumination and optical compensation for film movement.

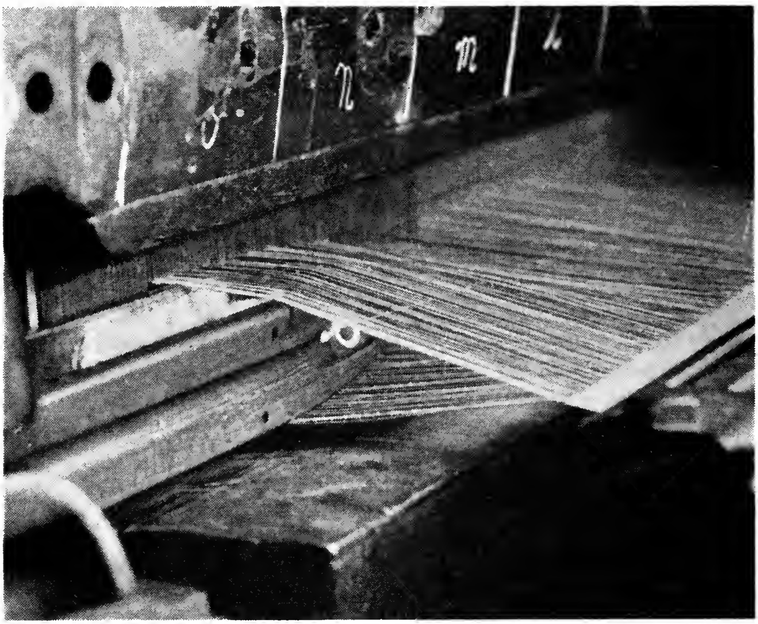
* Presented April 6, 1949, at the SMPE Convention in New York.

I. Cameras

Senior[3] has described a camera using multiple-flash illumination which has been used for studying underwater explosions. This consists of a flashing light source operated by a commutator coupled to a camera capable of transmitting 100 feet of 35-mm film continuously at the rate of about 90 feet per second. The highest picture frequency obtainable is around 1500 per second, but each individual exposure is extremely short, and hence frame-by-frame analysis of the record is relatively easy. For photographing small charges, a mirror is used, placed at 45 degrees under the surface of the water, but for most work the camera and lighting equipment were enclosed in a watertight compartment and completely submerged. The work carried out with this camera is particularly interesting, and has included examination of the explosion bubble and of the "split" of the water caused by the impact of the explosion, the influence of explosions near structures including bulkheads of vessels, a photoelastic study of the shock waves traveling through solid bodies, and stereophotography, using two cameras coupled together. It is claimed that stereo work is particularly easy, as the same flash can be used for the two cameras, and there is thus no difficulty in maintaining picture synchronism. The flash is triggered from one of the cameras, but the film is run through both at the same speed.

Another interesting camera is that designed by Henry[4] for the study of textile fibers during spinning and weaving. This consists of a drum camera, illumination being provided by a series of sparks in air or, alternatively, flashes from a gas-discharge tube. The equipment is capable of taking a series of 120 pictures at a frequency of 1500 per second, and can record an object moving at the rate of 10 meters (32.81 feet) per second, the accuracy of its position at any instant being determinable to within 0.5 mm. Field sizes up to 2 feet in diameter have been covered. Henry designed the equipment to be made easily in his own workshop at a low cost and succeeded in producing it for under 200 pounds (approximately 800 dollars). It has given excellent results, an example of which is shown in Fig. 1, in solving problems in the textile field, for which it was designed.

Brailsford and Shrubb[2] have designed a camera for the photography of metallic arc welding, which consists of a drum camera capable of taking 25 inches of 35-mm film (Fig. 2). The optical system for compensating for the film movement consists of a square glass prism rotated between the back of a conventional folding pocket camera and the drum carrying the film. One big advantage of the drum camera using a short length of film is that it avoids film wastage in photographing an operation which takes only a very small time to complete. Frequencies up to 2500 pictures per second have been attained, the drum and the glass block being geared together to provide correct compensation. A $3^1/_2$- by $2^1/_2$-inch Zeiss camera with a 10.5-centimeter $f/3.5$ lens was used, in conjunction with a drum about 8 inches in diameter. A special parallel-sided prism of crown glass was



British Cotton Industry Research Association

Fig. 1—Single-frame enlargement showing a shuttle emerging from the "shed" of a loom. Photographed with P. S. H. Henry's camera at 1500 frames per second.

made and mounted so that four pictures could be taken for each revolution of the prism. The image is cast on to a narrow slit running across the film on the drum at right angles to the direction of its motion. By this means, optical correction is improved, because it is limited to a small angle of rotation of the prism. With a slit one sixteenth of an inch wide, an exposure time as short as 45 microseconds can be obtained at a frequency of 2500 pictures per second. The film drum is made of solid mild steel, the web being lightened by drilling holes in it. The whole box containing the film drum can be detached from the camera for taking to the darkroom. The film is held on to the drum by a phosphor-bronze clip, which was found satisfactory for speeds of revolution up to 3000 per minute. For the photography of arcs, the camera lens was protected by means of a sheet of plate glass so that, if it became sputtered, it could be cleaned or renewed.

The camera which problably exhibits the greatest novelty is that designed by Marley.[1] It was primarily intended for the study of explosive detonations. For this reason, such a camera must be suitable for recording rapid changes in a subject of high luminosity for a very short period of time. The picture frequency must be very high,

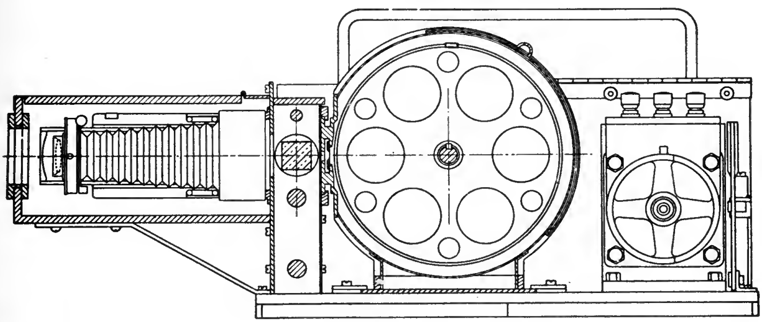


Fig. 2—Diagram of Brailsford and Shrubb camera which operates at a rate up to 2500 frames per second.

of the order 100,000 per second; and the exposure time for each picture, of the order of a few microseconds.

The camera (Figs. 3 and 4), consists of a series of 59 lenses, arranged round the periphery of a disk about 12 inches in diameter. A second fixed disk contains a series of slots, each one-thirty-second of an inch wide, forming diaphragms for the lenses, which are 3.5 inches in focal length and thus stopped down to an aperture of about $f/27$. An annular ring containing a similar series of slots can be moved through a small angle to form a shutter to expose all the lenses instantaneously. It is actuated by three springs and its opening can be synchronized with the detonation by an electromagnetically operated release gear.

The only continuously moving part of the camera is a disk of Hiduminium light alloy containing 16 slots mounted on the shaft of an electric motor and rotated continuously at a high speed.

The spring-actuated shutter uncovers the lenses for about 5 milliseconds, during which interval 59 pictures are taken. For a speed of rotation of the disk of about 6000 revolutions per minute, a picture frequency of approximately 100,000 is obtained, the exposure time for each picture being of the order of 5 to 10 microseconds.

The light transmitted by each lens is reflected, by a small surface-aluminized mirror placed at its rear, onto a strip of 35-mm perforated film two meters long, held round the inner periphery of a drum. Film is drawn from a lighttight cassette and can be returned to it for removal from the camera for processing.

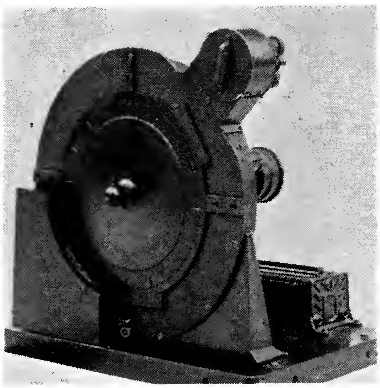


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Fig. 3—Marley high-speed camera for taking photographs of highly luminous subjects, such as explosions, at speeds up to 100,000 frames per second.

A group of eight photographs selected from a series made with the Marley camera at the rate of 76,000 frames per second of the detonation of a 2-pound charge of the explosive, tetryl, is shown in Fig. 5.

Froome[5] has published details of an interesting Kerr-cell system designed for repeat series exposures on a single plate, but adaptable for use with a drum camera or any camera using continuously moving film. The equipment consists of a standard type of Kerr cell, filled with very pure nitrobenzene, across which a potential of about 1000 volts is maintained. This produces further electrolytic purification which, in turn, produces an enhanced Kerr effect. The cell is controlled by a circuit which can be operated to give any exposure time between 0.1 and 6 microseconds at intervals from 4×10^{-7} to 70 microseconds. The number of exposures in a sequence can also be controlled. For a Kerr cell with plates 1 centimeter long, the electric field required for maximum effect is about 33 kilovolts per centimeter.

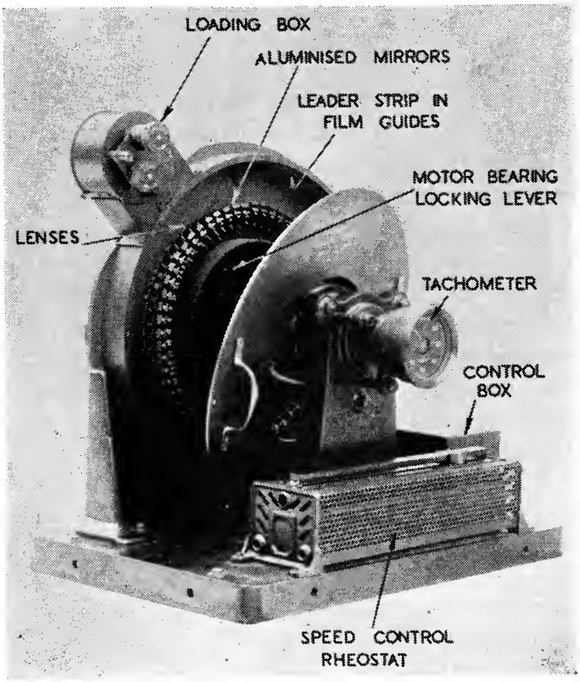

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Fig. 4—Rear view of Marley high-speed camera with back plate removed.

In the case of the equipment built by Froome, plates spaced by 3 mm were used, as he employed the equipment behind a microscope eyepiece from which the angle of the cone of light was small. To produce a larger aperture, a multiple-plate cell connected like a condenser would be needed, but this would have the effect of increasing the shortest exposure time possible. For exposures of not less than 1 microsecond, such a cell could be used behind a lens of 1-centimeter diameter, or slightly more.

II. NEW LIGHT SOURCES

New light sources have been described for use with the conventional types of mechanical high-speed cameras. The older method of using high-efficiency tungsten-filament lamps is being replaced steadily by the use of specially modified discharge tubes of various types. Beeson[6] has published information on an overrun high-pressure mercury-cadmium vapor lamp. This lamp can be run at a relatively low current for prolonged periods, when it gives a light output equivalent to about 2 kilowatts of tungsten-filament illumination. It can be overrun for short periods, the duration of which depends upon the degree of overload, and it then produces an extremely high intensity of illumination. For example, when run for one second at 120 amperes, it provides sufficient light to illuminate a subject 3 feet square and give adequate exposure on 16-mm Kodachrome film at $f/2.7$, using a Kodak high-speed camera, Type III, running at the rate of 3000 pictures per second. The color rendering, though not perfect, is sufficiently good for most practical purposes. Beeson[6] has also produced special illumination equipment consisting of 48 flashbulbs mounted on a rotating disk and triggered by means of a commutator so that each bulb is fired in turn as it passes through the reflector. The bulbs are fired at such a rate that substantially uniform illumination of the subject is obtained over the one second or so required to pass 100 feet of 16-mm film through the Kodak high-speed camera running at the rate of 3000 pictures per second. This equipment has been successfully used with the Kodak high-speed camera in several cases where an extremely high intensity of lighting is needed without undue heating of the subject.

Aldington[7] has published information on the gas arc, which consists of a continuously operated high current-density arc discharge in a rare gas, usually xenon. This lamp gives very high illumination for extended periods, but it has to be water-cooled.

III. TIME BASES

While both conventional high-speed cameras and specially designed cameras such as those described above have been used extensively for direct photography, there is a growing feeling that straightforward cinematography is not adequate for the examination of many problems. In the first place, more accurate time bases have had to be introduced than had previously been used. The inclusion of a specially

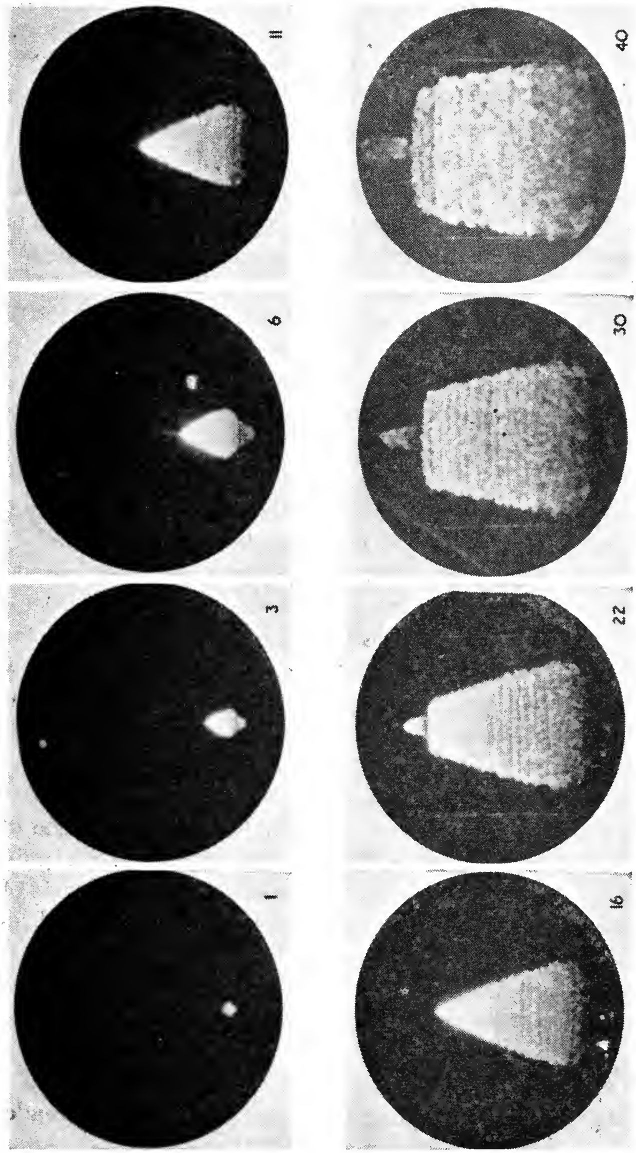

Fig. 5—Photographs taken with Marley high-speed camera at rate of 76,000 frames per second showing stages of detonation of a 2-pound charge of the explosive, Tetryl. Frame interval was 13.1 microseconds; selected frames only are shown.

designed clock or flashing lamp in the picture has not proved satisfactory for most types of work carried out at frequencies higher than 500 pictures per second. For this reason, several specially designed time bases have been employed. One of these described by Eyles[8] was designed in the Kodak Research Laboratory, at Harrow, England, for use with the Kodak high-speed camera, and has been manufactured by a firm of instrument makers and fitted to practically all of these cameras used in Great Britain. This time base consists essentially of an optical system for projecting the image of a condenser, illuminated by a small tungsten-filament light source, on to the edge of the film between the picture and the perforations. The beam of light is interrupted by shutter blades on an electrically maintained 500-cycle tuning fork. The beam is interrupted twice in each cycle and 1000 flashes of light per second therefore fall upon the film, to produce timing marks in the form of a series of short lines. At high camera speeds, these are sufficiently far apart to enable the resulting trace to be interpreted easily, but at lower speeds, to prevent overlapping, a second shutter is provided for controlling the width of the beam and which can be set from outside the time base by means of a dial calibrated in picture frequencies. The whole time base is made up as a flat unit which is bolted on to the base of the camera and rests on the tripod head. The only modification to the camera, apart from fitting the bolts, is the cutting of a hole immediately below the lower sprocket through which the optical system can project an image on to the film. The unit is energized from the same supply as that used to operate the camera.

Several other experimental time bases have been used, most of which depend upon a flashing source of light held close to the film inside the camera, the frequency of flash being controlled by a tuning-fork system outside. One of the most compact devices consists of a tiny plastic case containing a small spark gap and lens which throws an image of the spark on to the edge of the film. This is bolted to the inside of the camera cover plate, through which two leads run to an induction coil and a tuning fork controlling the frequency of sparking.

IV. UNUSUAL APPLICATIONS OF HIGH-SPEED CAMERAS

Extensive use of high-speed cinematographic equipment has made it clear that there are many thousands of applications for this technique in industrial and scientific investigations. Many of the applications on record are very similar to those reported in the United States.

There is, however, one point which does not seem to have been made in the literature on high-speed photography so far. It is that the use of the technique is frequently limited by the fineness of detail which has to be recorded. Engineers requiring to make use of high-speed photography often do not realize the fact that although the object to be photographed is plainly visible to the camera it does not necessarily mean that the movement in which they are interested will be easily discernible from the photographs produced. The amplitude of movement of the subject may be so small that the high-speed camera has great difficulty in resolving it. With modern equipment, the visual resolving power of the optical system expressed in lines per millimeter appears quite high, but the photographic resolving power is reduced by low contrast in the final photograph, which is accentuated by underexposure, and further degraded by imperfect compensation for film movement, and movement of the subject itself during the exposure. Thus, relatively small movements may be difficult even to detect, let alone accurately measure, unless they can be amplified in some way or examined against some fixed point.

The vibration of a mechanical sieve, which appeared to have quite a large amplitude, was extremely difficult to measure from a high-speed film record made of part of the sieve itself. The problem eventually was solved by embedding a bright steel ball in the surface of the sieve and illuminating it with a bright source of light, thus producing a point source of light. By running the high-speed camera at a relatively slow rate, this drew out a trace which could be seen on the screen and variations in its shape, which were quite marked, gave the required information on the changes in the form of vibration of the sieve, which could not be detected at all from a film taken of the sieve directly, and without resort to this optical trick.

Another example concerned the examination of the joints in railroad lines, and the movement of the fishplates which are used to secure the rail ends together. As a locomotive wheel passes over such a joint, there is a movement which appears to the eye to have considerable amplitude. Nevertheless, a direct record taken with a high-speed camera showed nothing which could be measured accurately. This problem was solved simply by placing a dial gauge, calibrated in thousandths of an inch, between the underside of the top flange of the rail and a large mass of concrete which was laid under the track. The readings of this dial gauge could be ascertained easily from a film taken of it as the wheel passed over the joint, and the movements of the rail, thus mechanically amplified, were plotted against time as recorded by the camera time base. This method has now been used successfully for a large number of applications to industrial problems.

A more elaborate optical-mechanical arrangement has been described by Eyles[9] and was used in the course of the examination of the movement of the anvil of a large drop-forging hammer. The hammer itself weighed 8 tons and, after operation for some time, it was found

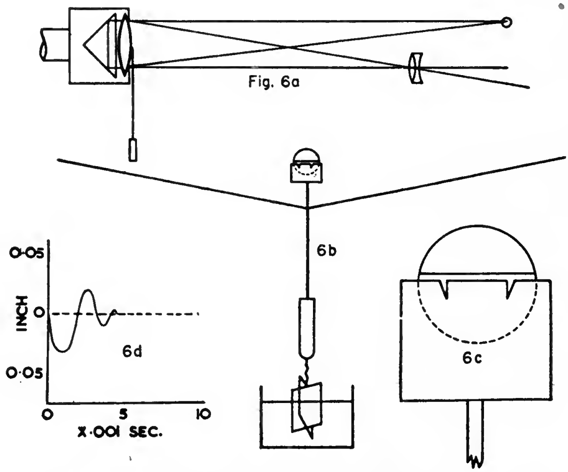

Fig. 6—Optical-mechanical arrangement for examination of movement of anvil in large drop-forging hammer.

a. Convex lens attached to a reflecting prism fastened to anvil to give a uniformly bright disk of light that can be photographed.

b. Method of damping shutter blade with a dash-pot so that top edge of blade is just below bottom edge of mask on illuminated disk.

c. Enlarged section of b.

d. Curve showing amplitude and duration of the vibration of the anvil.

that the foundations of the anvil showed signs of deterioration. The noise, flame, and smoke produced when the hammer was dropped were such that visual observation of the movement of the anvil was difficult, and various observers estimated it at between one hundredth of an inch and a quarter of an inch at each blow. Direct photography of the anvil was out of the question, owing to the small degree of movement and the shock transmitted through the surrounding ground. It was therefore decided to photograph a point on the anvil in relation to a fixed point in space just in front of it. A convex lens attached to a reflecting prism was fastened to the anvil, which, by means of suitable illumination, presented to the camera lens a uniform disk of light of high brightness (Fig. 6a). This was then masked so that only the bottom semidisk was visible. A shutter blade was hung in front of this, suspended on a long piece of elastic which stretched right across the shop, a weight being attached below the point of suspension of the shutter. This provided a pendulum of very long period which was virtually insensitive to the sudden movement of the anvil, and thus provided a fixed point in space with respect to which measurement of the movement of the anvil could be made. A dashpot below the weight assisted in keeping the shutter blade stable by damping its movement, and enabled it to be set so that, from the camera viewpoint, its top edge was just below the bottom edge of the mask on the illuminated disk (Fig. 6b, 6c). The camera thus saw a narrow horizontal slit of light which varied in width according to the form of vibration of the anvil under the shock of the hammer blow. In this way, the amplitude and duration of the vibration of the anvil were determined successfully (Fig. 6d).

In some cases, the use of ultraviolet and infrared illumination has been found of value in ultrahigh-speed photography. For example, in connection with the photography of the rolling of red-hot steel bars, in order to show the surface texture as the bars emerged from the rollers, it was found that this could not be observed in high-speed films taken in a straightforward manner, because the intrinsic brightness of the red-hot surface of the bar prevented any rendering of texture by external lighting. It was realized, however, that hot metal does not emit any appreciable quantity of ultraviolet radiation and thus the bars were successfully photographed by means of ultraviolet lighting using a Wratten Filter No. 18A over the camera lens to cut out all visible light. Ordinary high-speed panchromatic film is sufficiently sensitive in the region just below the visible to enable a good record to be made and, in this region also, the ordinary glass lenses are sufficiently transparent to the near ultraviolet. Thus, the use of special materials and of quartz lenses was avoided. Infrared illumination has also been used for the study of behavior at the electrodes of mercury-vapor arcs which normally are difficult to examine, owing to the high brightness of the arc itself closely adjacent to the electrode. The radiation of infrared light is, however, rather higher from the electrode itself than from the arc, thus enabling a satisfactory record to be obtained through the appropriate filter absorbing all visible light and transmitting only the near infrared.

NOTE: Figs. 3, 4, and 5 in this paper are published by permission of the Director of Road Research in Great Britain.

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Bowen Ribbon-Frame Camera*

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Summary.—A brief background is given of the Bowen ribbon-frame camera, as developed for the study of rockets and guided missiles under free-flight conditions. The main constructional features are discussed as well as the orienting system used on the rocket range. Timing and camera-phasing devices are mentioned which make the film record assessable to an accuracy of 20 microseconds on the CZR Bowen camera, a model recently developed to meet the increasingly stringent angular and timing accuracies needed in the testing of high-velocity missiles.

INTRODUCTION

When the California Institute of Technology was involved in the testing of rockets in 1941, it became apparent that a number of special cameras would be necessary for metric photography. Ira S. Bowen, the present director of the Mount Palomar Observatory, was then obtaining and developing photographic equipment for the Goldstone rocket range. One of his primary efforts was the construction of a camera which would give a record from which rocket positions, velocities, and accelerations could be accurately assessed.

The photographic assessment problem, in determining rocket velocities and accelerations, depends on three factors: (1) the accuracy with which a rocket position can be determined on film; (2) the accuracy with which the elapsed time between two frames can be determined; and (3) the length of film representing a given displacement increment over which the two readings are taken. In plotting results, rocket position on each frame plotted versus the time of each frame gives a trajectory. The difference between two points on the trajectory divided by the time increment between the points gives a velocity point, and two points on the velocity curve, divided by their temporal separation give an acceleration point. Unfortunately, the inaccuracies in the trajectory are magnified when the velocity is determined and again increased when the acceleration is desired. In other words, in taking the first and second derivatives of a trajectory obtained by film assessment, the trajectory error causes increasingly greater velocity and acceleration errors.

* Presented October 13, 1949, at the SMPE Convention in Hollywood.

A camera was needed then, which would have an accurately known frame speed, and in addition, since the percentage error in measuring a large distance is less than the percentage error in measuring a small distance, it was necessary to have the rocket image move as far as possible between frames. This necessitated the use of a long focal-length lens to produce as much image motion as consistent with de-

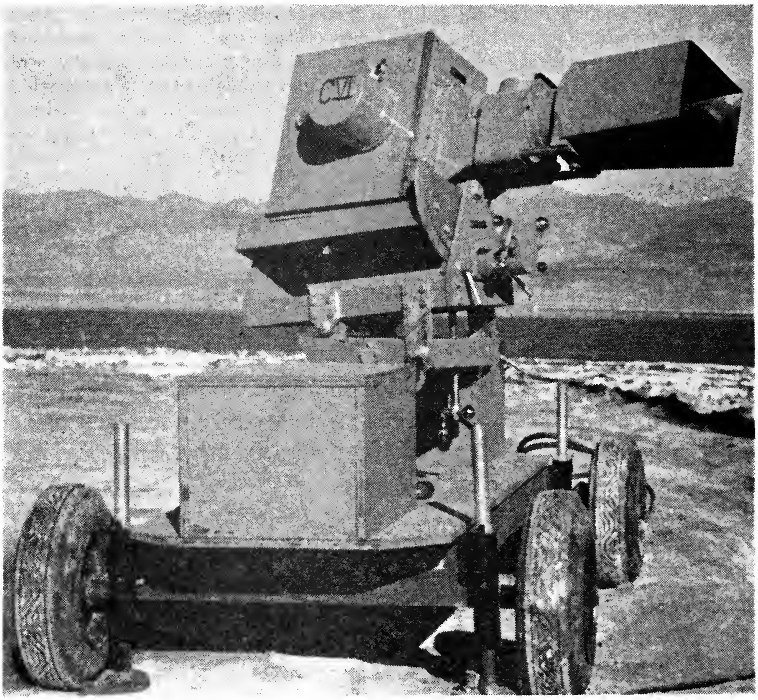

Fig. 1—Bowen ribbon-frame camera being used at present in the study of high-velocity rockets and guided missiles.

sign considerations and also the use of wide film (ribbon frame) to give sufficient coverage. The camera which evolved through three models from these considerations is shown in Fig. 1. Since 1944, this type of camera has been widely used at the various government rocket and missile test centers.

As time passed, the inevitable increase in velocities being studied made certain improvements necessary in the camera. So, within the last year, another step was made in the evolution of the ribbon-frame camera. The new camera, called the CZR-1, is shown in Fig. 2.

This camera was designed by J. A. Clemente and others according to specifications written by T. J. Obst and J. A. Clemente of the Measurements Division at the United States Naval Ordnance Test Station, China Lake, California. The Bureau of Aeronautics accepted the design and undertook the construction of 32 cameras. The camera shown was built by the Aeronautical Photographic Experimental Laboratory, Naval Air Matériel Center, Philadelphia, Pennsylvania,* and is presently being tested at the Naval Ordnance Test Station.

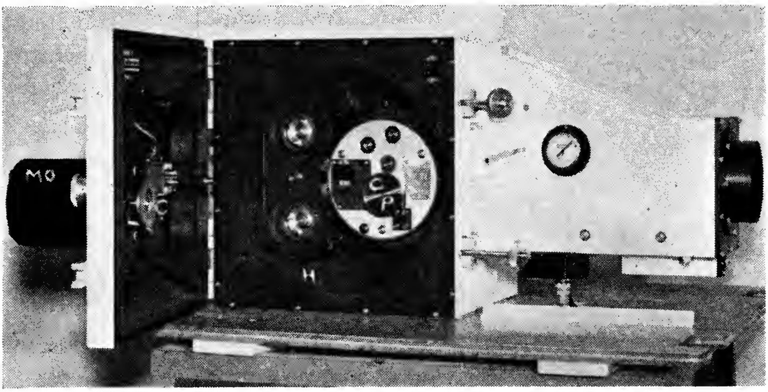

Fig. 2—Model CZR-1 Bowen ribbon-frame camera recently developed by the Naval Ordnance Test Station and the Aeronautical Photographic Experimental Laboratory to meet the increasingly higher requirements demanded in the study of rockets and guided missiles.

CONSTRUCTION OF CAMERA

All the Bowen ribbon-frame cameras in use have an internal mechanism as diagrammed in Fig. 3, and partially seen in Fig. 2. In the following camera discussion, the CZR-1 will be described since it contains all the essential characteristics of its predecessors plus certain improvements.

The camera parts in Fig. 3 are camera box, *B;* lens, *L;* shutter, *S;* housing inside shutter drum, *H;* film drum, *D;* framer, *F;* and magazine, *M*. The film comes off the upper spool, P_1, inside the magazine, loops around the film drum, and is rewound on the lower spool P_2. The "without-film" speeds of the feed and take-up spools are respectively lower and higher than the rate at which the film drum rotates,

* The lens mount, shown in Fig. 2, was designed by the Aeronautical Photographic Experimental Laboratory. The lens mount designed by J. A. Clemente is under construction.

and slip-clutches in the feed and take-up spools allow for speed variance so that the film is kept taut over the film drum. The film used is Eastman Aerographic Super XX, 5.5 inches wide, loaded in 100-foot rolls. Since there are no sprocket holes, the entire width of the film is available for pictures and the timing record which will be mentioned later.

The shutter, which rotates around the housing containing the magazine and film-drive mechanism, is a heavy cylinder 14 inches in diameter, in which are cut six slots $^1/_8$ inch wide and $4^3/_8$ inches long. The shutter is rotated at 1800 revolutions per minute by a synchronous 3-phase, 220-volt, $^1/_2$-horsepower motor that is bolted to the camera box in the position marked *SM* seen past the operator's right arm in Fig. 4. The shutter, built as a heavy unit for dynamic

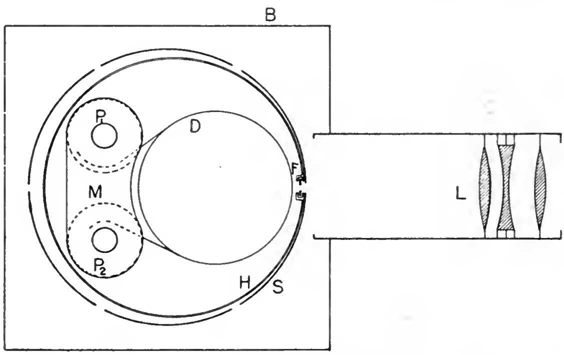

Fig. 3—Schematic drawing of Bowen ribbon-frame camera.

stability, is supported entirely by the motor bearings, the shutter and motor armature forming an integral element eliminating all in-between gears and mechanical linkage.

At 1800 revolutions per minute, the shutter makes one revolution in $^1/_{30}$ second, thus the six slots in the shutter drum produce 180 frames per second. The slots are as evenly spaced around the drum as possible. In a test made at Naval Ordnance Test Station, it was found that the interframe time interval was $^1/_{180}$ second ± 2.0 microseconds variation due to mislocation of shutter slots in the drum. Indeed, the Boulder-Dam power frequency supplied to the camera was in greater error. In assessing the film record, it was found that the line frequency was 60.06 cycles per second rather than 60.00. These results were obtained, incidentally, by taking Bowen pictures of a 1000-cycle-per-second linear oscilloscope sweep controlled by a

Hewlett-Packard secondary timing standard. The shutter-timing record was assessable to an accuracy of about 0.5 microsecond.

As mentioned above, the six shutter slots make possible a speed of 180 frames per second. By closing three slots, alternately around the drum, pictures can be taken at 90 frames per second. Four slots closed, leaving two openings 180 degrees apart, allows 60 frames per second; and all closed except one, allows 30 frames per second. In

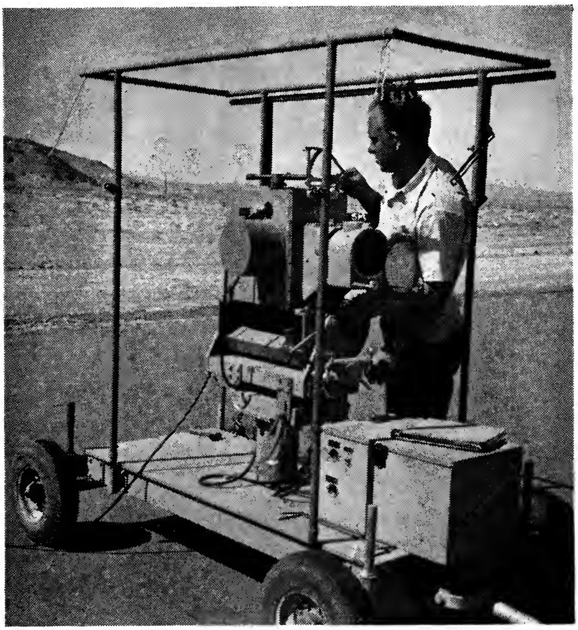

Fig. 4—Operator of a Bowen ribbon-frame camera orienting the camera in respect to the trajectory by use of a gunner's quadrant. The small telescope on top of the camera is used for setting one of the needed angles.

the camera type shown in Fig. 1, the exposure time is about 97 microseconds and the slot is either fully open or fully closed. In the CZR-1, however, various slides can be used in each shutter slot so as to give a shutter range from 100 microseconds to the 25 microseconds deemed necessary for future work.

The film moves continuously at 30 inches per second so that at a frame speed of 30 frames per second, $^{30}/_{30}$ of an inch or 1.0 inch of film is available for each frame. At 60 frames per second, the frame must be reduced to $^{30}/_{60}$ or 0.50 inch. Ninety frames per second allows 0.33

inch and at 180 frames per second, only 0.17 inch is available for the height of each frame. In practice, the 30 or 60 frames per second speed is normally used. The 180 frames per second, due to its narrow vertical field of view, is used only when the rocket is restrained on a track during the early part of trajectories or where such a frame speed is mandatory.

At each frame speed available, a framer of the necessary dimensions is inserted in the frame slot *F*, found in the housing *H*, just ahead of the film, Fig. 3. If the 30 framer is inadvertently used at a 180-frame-per-second exposure rate, sextuple exposure results.

Just inside the shutter drum is the housing *H*, Figs. 2 and 3, which contains the film-drive mechanism. The film drive is run by the motor *MO*, Fig. 2, which turns the clutch plate *CP*, by means of the clutch *C*, fastened directly to the motor shaft. The film drum is precision-mounted on special bearings so that the film plane is held constant to within 0.0002 inch, giving a positive film location.

The film-drive motor *MO* is a single-phase continuous-running nonsynchronous motor. When pictures are to be taken, a signal is sent to the camera by either radio link or ground cable. The signal actuates a solenoidal-clutch mechanism, not shown, which engages the film-drive mechanism with the running motor. Thus, the film moves quickly up to full speed, the motor momentum having supplied a considerable starting torque. The clutch, shown in Fig. 2, is the coupling by which the door-mounted film-drive motor is connected to the film-drive mechanism. The door mounting of the motor was designed in order to elminate as much strain as possible from the film-drive mechanism.

CAMERA MOUNT

The camera mount for the CZR-1 has been designed, but as yet has not been built. The mount described below is shown in Fig. 1, and is the present 3-axis mount. The camera can be positioned in azimuth and elevation and rotated about the optic axis of the photographic system. In this way, the framer can be set parallel to the trajectory being studied. With the camera properly oriented, the optic axis is perpendicular to the trajectory and a linear relationship exists between motion of the missile along the trajectory and the motion of the image on film. This, however, is more in the nature of a simplification of the assessment problem rather than an absolute necessity.

The camera dolly is built with four jacks, one by each wheel, so that the camera can be given a solid footing on the ground independent of the tires.

The angles needed to make the optic axis perpendicular to the trajectory are "set in" at the camera by means of a small sighting telescope mounted on top of the camera and a gunner's quadrant which is set parallel to the proposed trajectory. The quadrant is mounted on the camera and the bubble balanced at the angle of the expected trajectory, as shown in Fig. 4.

In the CZR-1, it is intended to mount the camera in a system of gimbals around the axes of which are fastened precise scales capable of being read to ±15 seconds of arc. The vernier on the telescope shown in Fig. 4 can be read to ±1 minute of arc.

AUXILIARY EQUIPMENT ON CAMERAS

In determining a trajectory, it is necessary to know the time at which each picture was exposed in respect to some instant called "zero time" presumably that moment at which the missile began its flight. In the Bowen ribbon-frame cameras currently used, the timing consists of small marks impressed upon the edge of the film every $^1/_{1000}$ second by a flashing neon bulb, in the manner shown at the edge of Fig. 5.

The timing light is so arranged that it is opposite the center of the frame when the frame is exposed, so the number of thousand-cycle marks on the edge of the frame between centers of adjacent pictures is the elapsed time between frames. At the present time, the timing marks are counted over a group of frames and divided by the group to increase interframe accuracy. This gives rise, of course, to certain errors. On the CZR-1, a system is being employed which remedies this situation, making accurate time difference measurable for adjacent frames. It consists of a binary counting system in which the light from a series of flashing neon bulbs is projected through the shutter itself and thereby impressed upon the film to give the time of exposure to an accuracy of 20 microseconds. A great advantage in the system is that the pattern of lighted bulbs impressed on each frame gives the additive time measured from "zero time" so that each frame has within itself an independent temporal record relating that frame in a definite manner to all preceding and succeeding pictures, and to zero time.

An assessment aid on both cameras consists of three reticles projected through the shutters and on to the film. These reticles appear on each frame as three small crosses, not shown however in Fig. 5. The reticle projectors are constructed so as always to project the reticles in a constant geometrical relationship in respect to the trajectory line of each frame. The reticles are then used in assessing the film as located points from which all rocket measurements are made.

In the CZR-1 there will also be included another device known as the "star projector." This consists of light from a point source being directed by a lens system to three small mirrors and reflected through the camera lens and shutter to the film. The three mirrors are plane

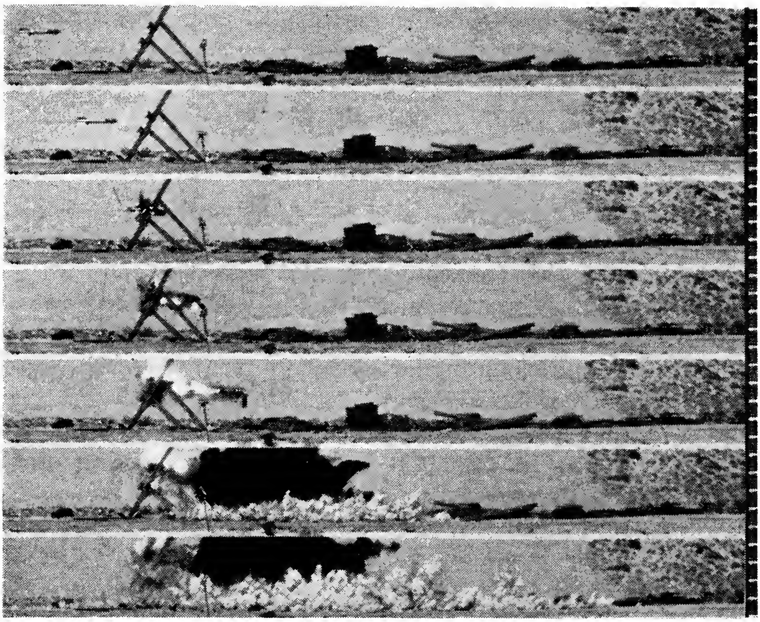

Fig. 5—Section of Bowen film in which the 1000-cycle timing marks are clearly visible on the right-hand edge. The heavy marks represent a 200-cycle beat used in assessment of film to facilitate counting.

surfaces ground at the proper angles at the end of small rectangular quartz bars which are later cemented together. The light from the point source is thus divided into three beams which are at a constant angular relationship. On the film there will then appear three small points of light in a line, the two end points being separated by several inches. Thus, each frame has impressed upon it a constant angular measure. This is of value in considering the change in focal length of a lens system due to the large changes in temperature to which cameras used at desert stations are subjected.

One innovation in the CZR-1 which will be of considerable advantage is the phasing device incorporated into the shutter motor design. By turning a worm gear, it is possible to rotate the field of the motor through any desired angular degree. Thus, if two or three CZR-1's are being used simultaneously at 30 frames per second (that is, only one shutter slot open), it is possible to adjust the open slots on the various cameras so that they are all in the same angular location on the rotating shutter drum at the same time. By opening a small triangular door in the upper right-hand corner of the camera box, above the shutter motor, it is possible to observe the rotating shutter by light from a stroboscope unit built in to give a measure of simultaneity at all cameras. The shutter-slot position is adjusted at each camera so that it lies at a given mark under the radio-synchronized stroblights. By the above device all the cameras can be adjusted to take pictures within a few microseconds of simultaneity. When desired, it will thus be possible to make allowance for the time delay between cameras since the radio carrier which transports the timing signal takes longer to reach some cameras than others because of their various locations on the range in respect to the transmitting antenna.

General

In the study of rocket-launching problems, it is generally necessary to have pictures from which acceleration records can be obtained from "zero time" up through the end of burning. Usually this distance is larger than can be obtained by a single Bowen ribbon-frame camera without making the image too small. The practice is, therefore, to use one camera opposite the launcher and as many others as are needed down range to cover burning time. The cameras are aligned so that the trajectory, covered by one camera, overlaps slightly the trajectory covered by the next camera down the line. In this way, a continuous record is available for study. One prominent reason for redesigning the mount to be used with the CZR-1 lies in the fact that the plotted trajectories obtained by each camera join or meet with an accuracy limited by the angular devices used to set up the camera's optic axis perpendicular to the trajectory. There is, of course, the operator error. No device is more accurate than its operator, but this is true in all research and testing and it is hoped that the CZR-1 will provide the means whereby a careful operator can obtain results at the high degree of accuracy which is becoming more and more necessary at development facilities.

Note: All photographs are official photographs of the United States Navy.

Physical Optic Analysis of Image Quality in Schlieren Photography*

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Summary—**This paper will consider the schlieren system as a problem in physical optics. On the basis of such considerations the effect of aperture, focal length, light-source size, and knife-edge position on the quality of schlieren photographs will be discussed. First, the mathematical analysis of the subject will be briefly presented. On the basis of this analysis the schlieren system will be considered using a point source. The case of finite-source size then will be discussed. A brief discussion of the effect of astigmatism on the focal length of the system also will be presented.**

INTRODUCTION

IN SCHLIEREN PHOTOGRAPHY one is usually interested in obtaining a photograph with maximum contrast between the images of the disturbed and undisturbed regions under study, and of sufficient density to render the photograph readily usable. A combination of these two factors, contrast and density, may be used as a measure of the quality of the schlieren photograph and also of the over-all system. The exact definition of quality will vary from individual to individual, but the above two factors will usually enter.

This paper is a discussion, from a theoretical point of view, of the effect of the several variables in a schlieren system on the two above-mentioned quality parameters. For a given disturbance these variables are (1) aperture of the system; (2) focal length of the optics of the system; (3) dimension of the light source; and (4) knife-edge position.

The conventional analysis[1] of the schlieren system based on geometrical optics is in many ways incomplete in its consideration of the

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above variables. A more complete analysis may be obtained by treating the schlieren system as a problem in physical optics, more specifically, as a case of modified Fraunhofer diffraction. Physical optic analysis of the Foucault test for astronomical objectives, which is the basis of Toepler's schlieren system, have been given by Zernike,[2] Linfoot,[3] and Gascoigne.[4] The present paper is an extension of previous work,[5, 6] based on these papers.

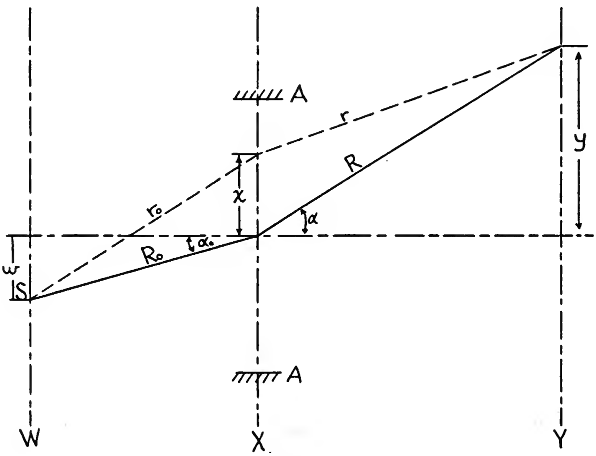

Fig. 1

ANALYSIS

Consider the general arrangement for analysis of the diffraction due to an aperture A-A in one dimension.

In Fig. 1, a point source S is located at a distance w from the optic axis in the W plane. Light from this source passes through an aperture A-A in the X plane. It is desired to study the light distribution $G(y)$ in the Y plane.

It can be shown[7] that the complex amplitude of the light vector at any point y in the Y plane is given by

$$G(y) = \text{const} \int_{-A}^{A} e^{ik\Phi(x)} dx \tag{1}$$

where

$$\begin{aligned}\Phi(x) &= (r + r_0) - (R + R_0) \\ &= x(\alpha_0 - \alpha) + \frac{1}{2}\left\{x^2\left(\frac{1}{R} + \frac{1}{R_0}\right) - \frac{1}{R^2}x^2\alpha^2 - \frac{1}{R_0^2}x^2\alpha_0^2 + \ldots\right\}.\end{aligned}$$

$k = 2\pi/\lambda$; λ is the wavelength of light emitted by the source S. λ will be assumed 5000 angstrom units.

$k\Phi(x)$ is a measure of the phase of any ray at y eminating from S passing through a point x in the aperture. $G(y)$ is the resultant of all rays passing through the aperture arriving at point y.

If the light through the aperture is parallel, R and R_0 are then essentially at infinity so that

$$\Phi(x) = x(\alpha_0 - \alpha). \tag{2}$$

Experimentally R and R_0 are made infinite by placing a lens or mirror between W and X so that W is in the focal plane of the lens or mirror. Another lens or mirror is placed between X and Y with Y in the focal plane of this second lens or mirror as shown in Fig. 2.

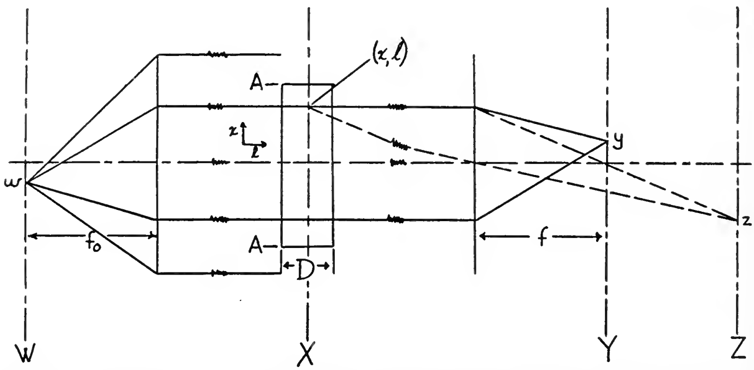

Fig. 2—Wind-tunnel schlieren system using lenses for collimator and objective.

If a wind tunnel of aperture A-A and span D is placed with its center line in the X plane, light from S to y through any point x in the aperture will have an additional optical path change of

$$\phi(x) = \int_0^D [n(x, l) - 1]dl \tag{3}$$

where $n(x, l)$ is the index of refraction of the gas in the wind tunnel at the point (x, l). If the flow is two-dimensional and the boundary layer on the wall perpendicular to the light path is neglected

$$\phi(x) = [n(x) - 1]D \tag{4}$$

$n(x)$ is related to the density of the gas $\rho(x)$ by the Gladstone-Dale law;

$$n(x) - 1 = K\rho(x). \tag{5}$$

With the additional phase change $k\phi(x)$, the complex amplitude of the light vector at a point y in the Y plane is then given by

$$G(y) = \text{const} \int_{-A}^{A} e^{ik[\Phi(x)+\phi)(x)]}dx. \tag{6}$$

For future mathematical simplicity the effect of the wind tunnel can be represented by a complex function $f(x)$ whose amplitude gives the light-transmission characteristics of the aperture and whose phase is $k\phi(x)$. Since no light is transmitted outside the aperture

$$|f(x)| = 0, \ |x| > A \qquad |f(x)| = 1, \ |x| < A \qquad f(x) = |f(x)|e^{ik\phi(x)}$$

(6) can be rewritten as

$$G(y) = \text{const} \int_{-\infty}^{\infty} f(x)e^{ik\Phi(x)}dx. \tag{7}$$

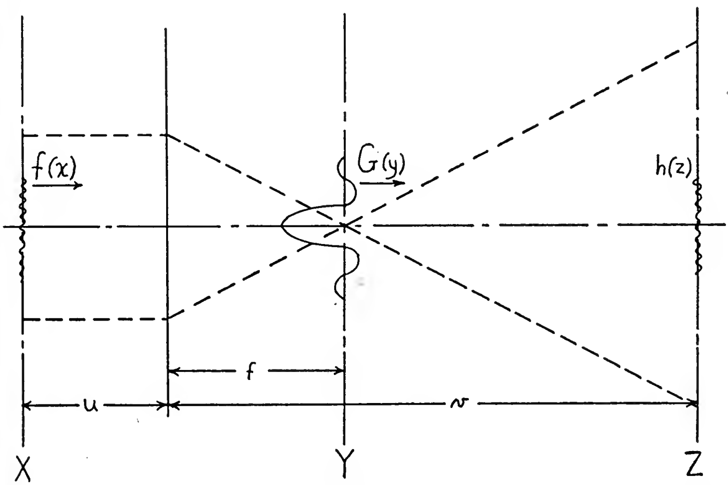

Fig. 3—Schematic diagram of the image formation in a schlieren system.

It can be shown[8] that (7) can be transformed into

$$f(x) = \text{const} \int_{-\infty}^{\infty} G(y)e^{-ik\Phi(x)}dy \tag{8}$$

where $f(x)$ and $G(y)$ are known as Fourier transforms of each other.

Equations (7) and (8) indicate that if the object $f(x)$ is known the diffraction pattern $G(y)$ can be calculated, and conversely, if the diffraction pattern $G(y)$ is known, the object $f(x)$ that gave rise to it can be calculated.

This result may be interpreted to mean that a given object $f(x)$ will give rise to a diffraction pattern $G(y)$ which will then illuminate some other plane Z in such a manner that the light distribution $h(z)$ in Z is the same as the distribution $f(x)$ in X which gave rise to $G(y)$. There is a 1:1 correspondence between all points in the X plane and those in the Z plane. The relative locations of the X and Z planes are given by the lens formula

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}.$$

In most wind-tunnel applications $f(x)$ involves only phase variations to which the eye or photographic plate are insensitive. Hence $h(z)$ in

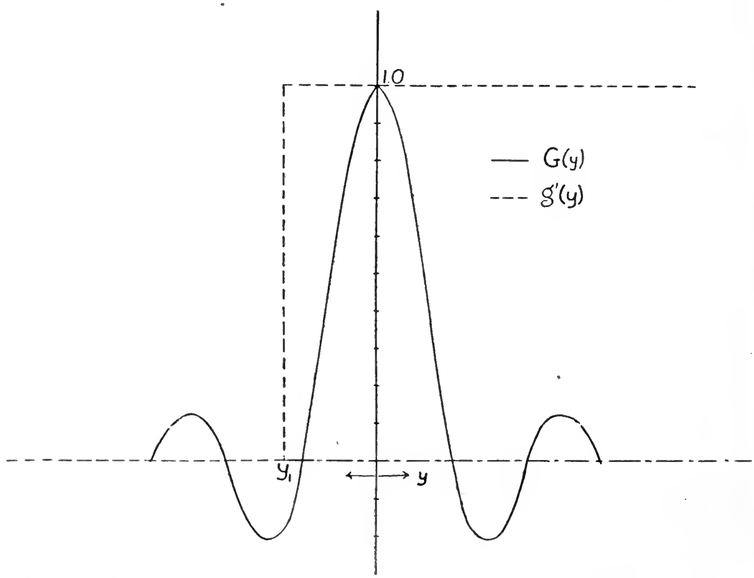

Fig. 4—Effect of modifying function $g'(y)$ on the diffraction pattern $G(y)$. y_1 denotes the cutoff position of the knife-edge.

the image plane will also involve only phase variation and no detail will be seen in the image.

In the schlieren system the technique employed to render phase variations visible is to modify $G(y)$ in some manner $g'(y)$ so that $h(z)$ due to this modified $G(y)$ or $g(y)$ is the image of an artificial $f(x)$ which would have given rise to $g(y)$; the amplitude distribution of the artificial $f(x)$, having a relationship to the phase distribution of the actual $f(x)$.

The modification of the diffraction pattern is usually obtained by blocking off a portion of $G(y)$ with a knife-edge or other obstruction.

In general, the modification function $g'(y)$ is similar to that shown in Fig. 4.

$$g'(y) = 0 \quad -\infty < y < y_1$$
$$g'(y) = 1 \quad y_1 < y < +\infty. \tag{9}$$

The modified diffraction pattern is then given by

$$g(y) = g'(y) \times G(y). \tag{10}$$

From (8)

$$h(z) = \text{const} \int_{-\infty}^{\infty} g(y)e^{-ik\Phi(z)}dy. \tag{11}$$

Combining (7), (8), and (10)

$$h(z) = \text{const} \int_{-\infty}^{\infty} f(x)\,dx \int_{-\infty}^{\infty} g'(y)e^{ik\Phi(z-x)}dy. \tag{12}$$

From Figs. 1 and 2

$$\alpha = y/f \qquad \alpha_0 = w/f_0$$

then (2) becomes

$$\Phi(x) = x\left(\frac{w}{f_0} - \frac{y}{f}\right).$$

However, since in most systems $f = f_0$,

$$\Phi(x) = \frac{x}{f}(w - y). \tag{13}$$

If (13) and (9) are substituted for $\Phi(x)$ and $g'(y)$ in (12)

$$h(z) = \frac{c}{2\pi f} e^{-(ik/f)(w+y_1)} \int_{-\infty}^{\infty} F(t + z)dt \int_0^{\infty} e^{(ikt/f)y}dy \tag{14}$$

where

$$t = x - z$$
$$F(t + z) = e^{ik[\phi(t+z)+(1/f)(w+y_1)(t+z)]} \tag{15}$$

on integrating (14)

$$h(z) = K\left\{\pi F(z) - i\int_{-\infty}^{\infty} \frac{F(t + z)}{t}\,dt\right\}. \tag{16}$$

Equation (15) indicates that the effect of varying the light source and knife-edge position are complementary and that either or both operations produce the same result as adding an optical wedge of angle $(w + y_1)/f$ to the disturbance $f(x)$.

To find the effect of a light source of finite size, rather than a point source one must integrate a function $h(z, w)$ over the dimensions $-w$ to $+w$ of the light source. This is best done by solving $h(z)$ for several point sources located at different distances from the optic axis in the W plane and graphically integrating the resultant.

The problem as stated in the introduction is to find $I(z, |f(x)|, w, y_1, f)$ for a given $\phi(x)$ where $|f(x)|$ gives the size of the aperture, w the size of the source, y_1 the knife-edge position, and f the focal length of the optics of the system.

$$I(z) = h(z) \times \overline{h(z)}. \tag{17}$$

To discuss the effect of the several variables mentioned above, a simplified disturbance in the X plane as shown in Fig. 5, typical of those for which the schlieren-type observation is useful, will be considered. This disturbance has two regions of different phase (1) and

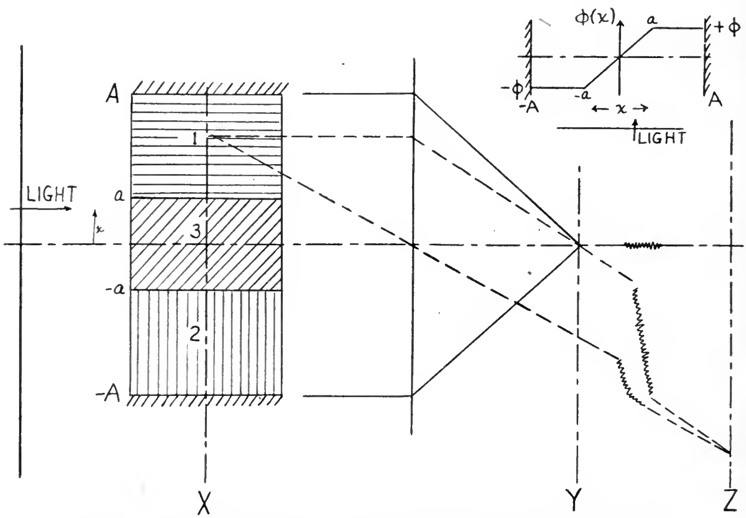

Fig. 5—Typical disturbance to be discussed throughout paper.

(2) connected by a linear transition region (3). If a-a is small this disturbance may represent a shock wave. If a-a is large it may represent an expansion or compression. If $-a = -A$, the disturbance may represent a boundary layer. In Fig. 5, the flow in a wind tunnel, or the path of a projectile, will be in the plane of the figure, perpendicular to the optic axis.

To find the light-intensity distribution in the image plane Z due to the disturbance of Fig. 5 in the object plane X, equation (16) must be integrated.

From the above figure

$$\begin{aligned} f(x) &= 0. & |x| > A \\ f(x) &= e^{-ik\phi} & -A < x < -a \\ f(x) &= e^{ik(\phi/a)x} & -a < x < a \\ f(x) &= e^{ik\phi} & a < x < A. \end{aligned} \qquad (18)$$

The integration of (16) then gives

$$\frac{h(z)}{K} = \pi \begin{cases} 0 & \text{for } |x| > A \\ \operatorname{cis} k(-\phi + (y/f)z) & -A < x < -a \\ \operatorname{cis} k(\phi/a + y/f)z & -a < x < a \\ \operatorname{cis} k(\phi + (y/f)z) & a < x < A \end{cases} \Bigg\} -i \{ \{\operatorname{cis} k(-\phi + (y/f)z)\}$$

$$\times \{ [\mathrm{Ci}\, k(y/f)(-a-z) - \mathrm{Ci}\, k(y/f)(-A-z)] + i[\mathrm{Si}\, k(y/f)(-a-z) - \mathrm{Si}\, k(y/f)(-A-z)]\} + \{\operatorname{cis} k(\phi/a + y/f)z\} \times \{ [\mathrm{Ci}\, k(\phi/a + y/f)(a-z) - \mathrm{Ci}\, k(\phi/a + y/f)(-a-z)] + i[\mathrm{Si}\, k(\phi/a + y/f)(a-z) - \mathrm{Si}\, k(\phi/a + y/f)(-a-z)]\} + \{\operatorname{cis} k(\phi + (y/f)z)\} \times \{ [\mathrm{Ci}\, k(y/f)(A-z) - \mathrm{Ci}\, k(y/f)(a-z)] + i[\mathrm{Si}\, k(y/f)(A-Z) - \mathrm{Si}\, k(y/f)(a-z)]\}\} \qquad (19)$$

where[9]

$$\begin{aligned} y &= w + y_1 \\ \operatorname{cis}(\theta) &\equiv \cos(\theta) + i \sin(\theta) \\ \mathrm{Si}(\theta) &\equiv \text{sine integral of } (\theta) \\ \mathrm{Ci}(\theta) &\equiv \text{cosine integral of } (\theta). \end{aligned}$$

The light-intensity distribution $I(z)$ incident on a photographic plate is given by the product of (19) with its compex conjugate.

$$I(z) = h(z) \times \overline{h(z)}. \qquad (17)$$

It is evident from (19) that it will be most difficult to find the inverse of (17); i.e., to determine ϕ and a from measured values of light intensity in order to obtain quantitative information from a schlieren photograph.

POINT SOURCE

The contrast of the schlieren image of a disturbance will be defined as the logarithm of the ratio of the maximum light intensity in the image of the disturbance to the minimum light intensity in the background. For disturbances of the type illustrated in Fig. 5, the maximum light intensity occurs at the point $z = 0$ corresponding to the center of the gradient region 3. This quantity will be denoted by I (0). The minimum intensity occurs in the vicinity of $z = 0.8A$ and will be denoted by $I(8)$. The contrast C is then given by

$$C = \log I(0) - \log I(8) \qquad \text{or}$$

$$C = \log \frac{I(0)}{I(8)}. \qquad (20)$$

The density D, is given by $\log I(0)$.

The solutions of (17) for several disturbances are shown in Fig. 6. From Figs. 6 and 7 it is apparent that the aperture of the system has a marked effect on the quality of the schlieren photograph. The larger

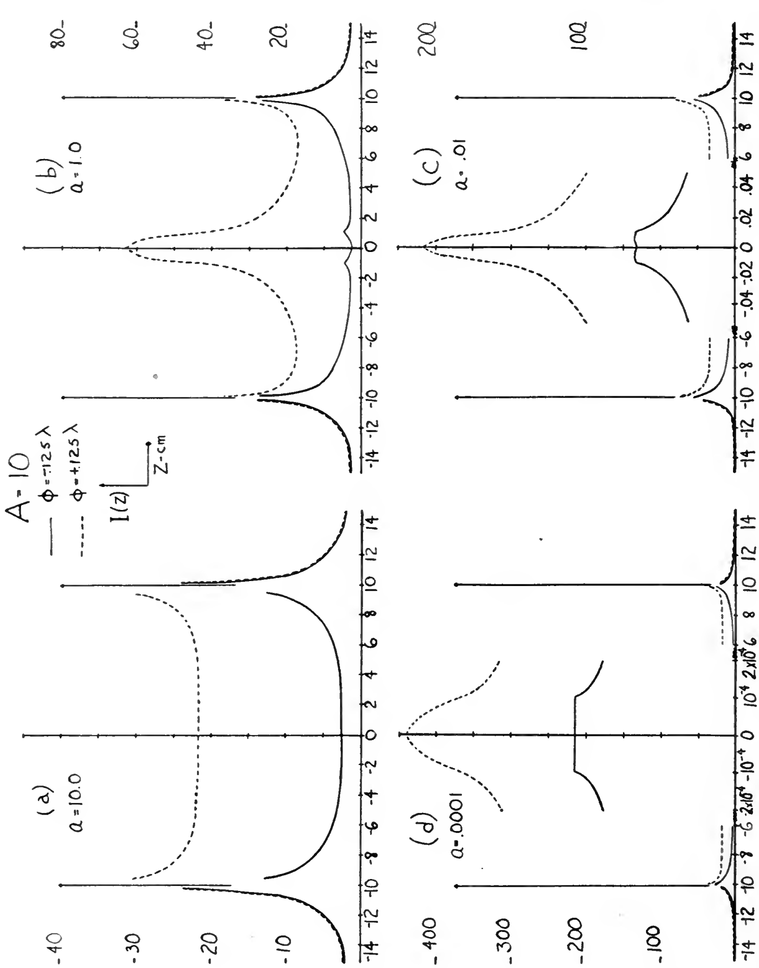

Fig. 6—Light-intensity distribution for disturbances of Fig. 5, using a point source located on the optic axis. The knife-edge extends from $-\infty$ to the optic axis. Changing the sign of ϕ is the same as extending the knife-edge from the optic axis to $+\infty$.

the aperture for a given disturbance, the greater will be the contrast and density of the image.

Fig. 6 indicates a halo around all opaque surfaces parallel to the knife-edge in a schlieren system. It is important that this fact be borne in mind when using schlieren pictures for boundary-layer studies. One must be careful to differentiate between laminar boundary layers and the halos of Fig. 6. This can usually be done by taking a schlieren photograph of the wind tunnel with all optical adjustments identical to those used under test conditions but with no flow in the tunnel. It should be possible by comparing this tare photograph with subsequent test photographs, to differentiate between a halo and a boundary layer.

There is no sharp line of demarcation between the images of the regions 1, 2, and 3 of Fig. 5, so that an actual size determination from

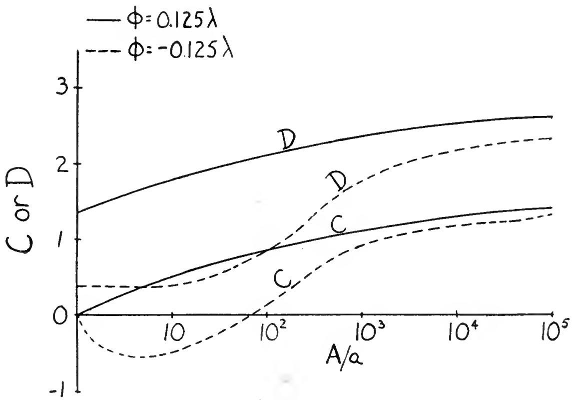

Fig. 7—Image contrast and density of Fig. 6 for disturbances of various geometrical size.

the schlieren picture is most difficult. The light intensity for the case where $a = 1$ falls to half its maximum value at $z = 1.5a$; for $a = 0.01$ it falls to half maximum at $z = 5a$ while for $a = 0.0001$ half maximum is reached at $z = 20a$. For a source of finite size these values may be different, however, the general tendency will still exist.

It is interesting to note that the solution of (17) for the above cases, i.e., $w = y_1 = 0$, using point-source illumination with a knife-edge at the optic axis indicates that the focal length of the optics used has no effect on the quality of the image. However, while the light distribution and contrast will not change, the shorter the focal length for a given aperture, i.e., the smaller the f ratio, the more light will be available for a photograph and the higher will be the density in the image.

A more complete analysis of the effect of the several variables on the quality of a schlieren picture can be obtained by examining the diffraction pattern caused by the disturbance and the effect of the knife-edge in modifying this pattern. The Fraunhofer diffraction pattern can be calculated from (7) and (18).

$$\frac{G(y)}{2} = \left\{\cos\phi \frac{A \sin kyA/f}{kyA/f} - \sin\phi \frac{A \cos kyA/f}{kyA/f}\right\} \text{(a)}$$
$$- \left\{\cos\phi \frac{a \sin kya/f}{kya/f} - \sin\phi \frac{a \cos kya/f}{kya/f}\right\} \text{(b)} \qquad (21)$$
$$+ \left\{\frac{a \sin ((kya/f) - (k\phi/a))a}{((kya/f) - (k\phi/a))a}\right\} \text{(c)}$$

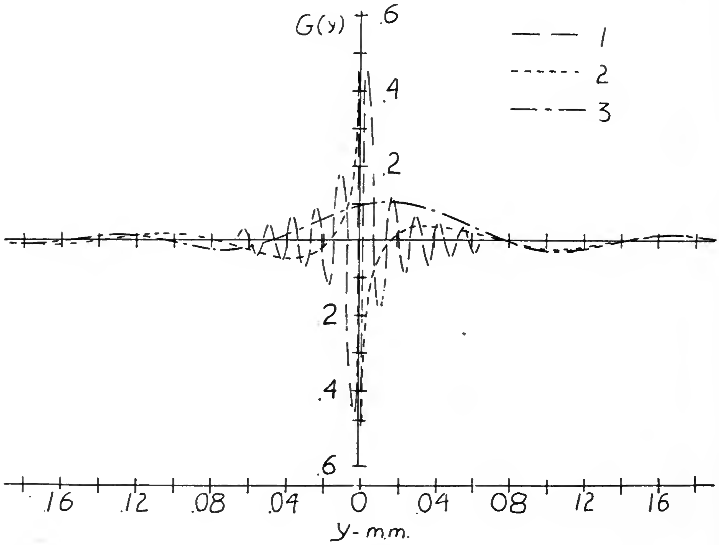

Fig. 8—Fraunhofer diffraction pattern due to disturbance of Fig. 5. $A = 10$, $a = 1$, $\phi = 0.125\ \lambda$, $f = 250$ cm. Letters on the curves refer to the several terms of equation (21).

The contribution of the disturbance region *a-a*, given by the terms (b) and (c) of (21), relative to the contribution of the aperture *a-a* is seen to be in the ratio of a/A. The terms (a) and (b) indicate how the diffraction pattern of the free aperture will be modified by the geometrical extent of the region *a-a*. The term (c), while also tending to modify the free-aperture diffraction pattern, is primarily the diffraction pattern of a free aperture *a-a* shifted in the Y plane by an amount $y/f = \phi/a$. This term contributes largely to the structure of the image of *a-a* in the Z plane. One criterion for the maximum width of light source is that the geometrical image of the light source in plane

Y should not appreciably overlap the diffraction pattern due to the region a-a as represented by term (c) of (21). The value of $y = f\phi/a$ indicates the position of the central maxima of the diffraction pattern due to a-a and represents an upper limit to the half width of a light source of finite size. It is interesting to note in Fig. 13 that a source of half width $w = f\phi/a$ located symmetrically with respect to the optic axis, gives the same contrast for both $\phi/a = 0.125\ \lambda$ and $\phi/a = 125\lambda$, i.e., $C = 0.4$, or 2.5 times as much light at maximum intensity as

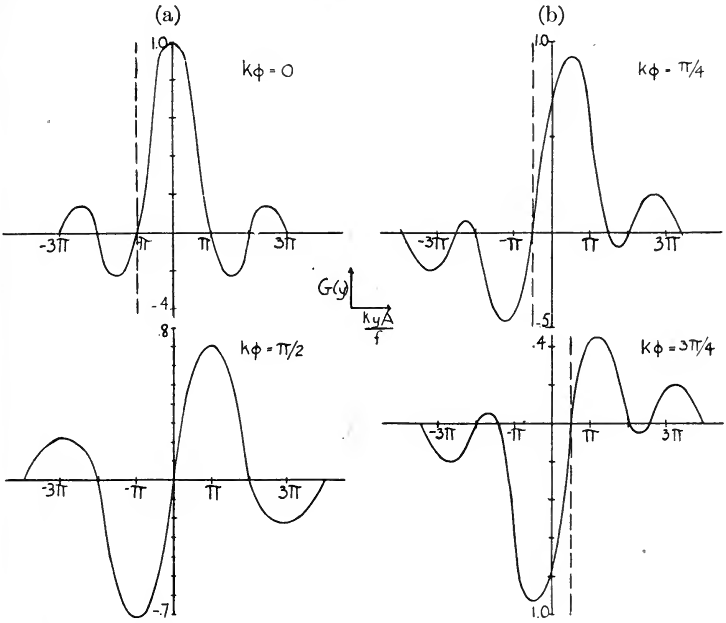

Fig. 9—Diffraction patterns for optical discontinuities of magnitude 2ϕ.

at minimum background intensity when the knife-edge extends from $-\infty$ to the optic axis.

If $a << A$ or $A/a >> 1$, as is usually the case for shock waves, the terms (b) and (c) of (21) can be neglected. The remaining term (a) indicates how the diffraction pattern varies for an optical discontinuity of magnitude[10] 2ϕ. Equation (21) then becomes

$$G(y) = 2 \sin \frac{1}{2} \frac{kyA}{f} \cos \frac{1}{2} \left(2\phi - \frac{kyA}{f} \right) \tag{22}$$

$$G(y) = 0 \text{ at}$$

$$2\phi - \frac{kyA}{f} = \pi. \tag{23}$$

The value of light amplitude at $z = 0$, $h(0)$ is found from (19) to be

$$\frac{h(0)}{K} = \pi - 2 \cos k \phi \left[\mathrm{Si} \frac{kyA}{f} - \mathrm{Si} \frac{kya}{f} \right] + 2 \sin k \phi \left[\mathrm{Ci} \frac{kyA}{f} - \mathrm{Ci} \frac{kya}{f} \right] + 2 \, \mathrm{Si} \, k \left(\phi - \frac{ya}{f} \right). \quad (24)$$

$I(0)$ will be a maximum when $h(0)$ has an extreme value. This will occur at that value of kyA/f for which $dh(0)/(d(kya/f)) = 0$. From this

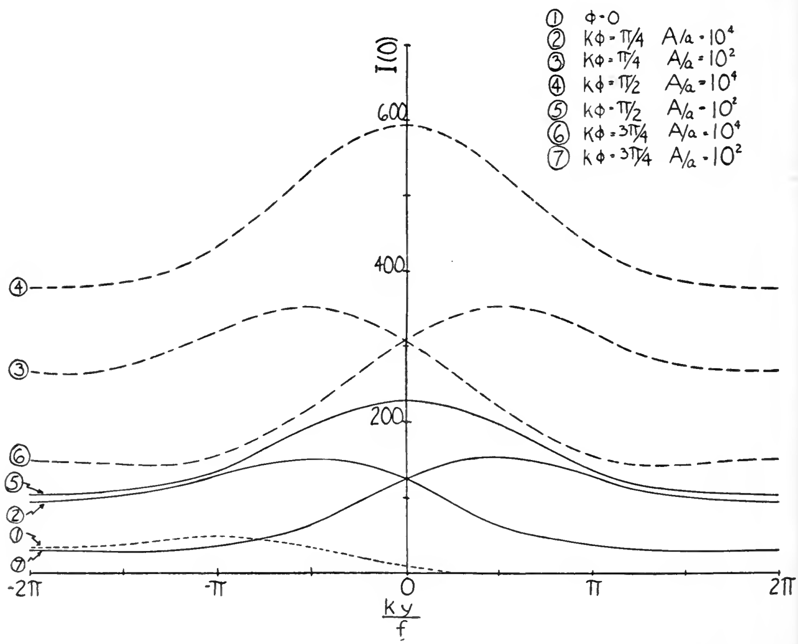

Fig. 10—Variation of maximum light intensity in the image of equation (24), for various knife-edge positions with point-source illumination.

value of kyA/f the value of the knife-edge position which will give rise to maximum $I(0)$ can be found.

Differentiating (24), assuming $a = 0$,

$$\frac{dh(0)}{d(kyA/f)} = 2 \sin \frac{1}{2} \frac{kyA}{f} \cos \frac{1}{2} \left(2 \phi - \frac{kyA}{f} \right) \quad (25)$$

which is identical with the expression for $G(y)$

$$\frac{dh(0)}{d(kyA/f)} = 0 \quad (26)$$

when $G(y) = 0$; i.e., the knife-edge should be placed at a position where $G(y) = 0$. More specifically it should be placed in such a position that only the positive central maximum and all higher spectral orders on one side of this maxima are not obstructed.

The actual position of the knife edge can be computed from (23)

$$y_1 = -\frac{f}{A} \times \frac{1}{k}(\pi - \phi). \tag{27}$$

The larger f or smaller A the less sensitive will be the actual knife-edge adjustment; however, it may be recalled that for a given disturbance

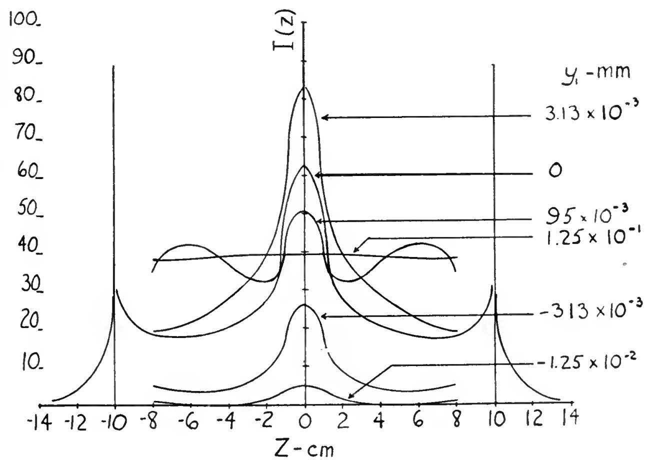

Fig. 11—Graph of $I(z)$ as a function of z for several knife-edge positions. $A = 10$, $a = 1$, $\phi = 0.125\ \lambda$, $f = 250$ cm.

size a-a, $I(0)_{max}$ is a function of A/a so that if A is decreased, the contrast will decrease although this will be compensated for by less critical knife-edge adjustment. Similarly, increasing f will require less critical knife-edge adjustment at the sacrifice of light-gathering power.

FINITE SOURCE

The effect of source of finite size can be determined by evaluating (19) for a series of noncoherent point sources located at different distances w from the optic axis. The values of $I(z)$ for each source position w are then plotted as a function of w for the several stations z in the image plane. A mechanical integration of these plots about a given knife-edge position y, between the limits $-w$ to $+w$ of the light source then gives $I(z)$ for a given light-source size, $2w$, and given knife-edge position, y_1.

Fig. 13 shows a maximum contrast at $w = 6.25 \times 10^{-2}$ mm. This is the half width R of the Airy disk of the system, which is the distance from the optic axis to the first value of y for which $G(y) = 0$, for a free

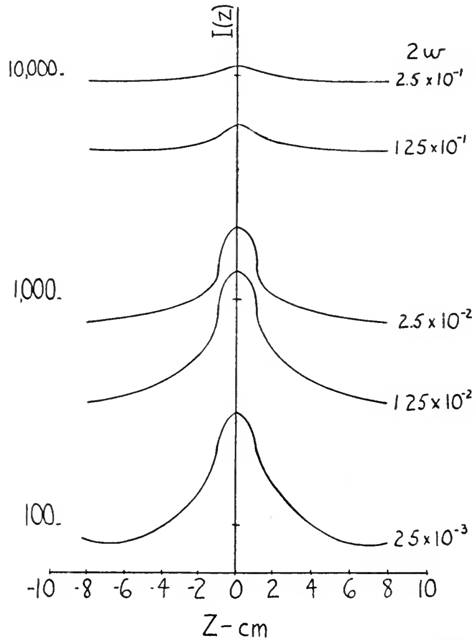

Fig. 12—Effect of source size on the light-intensity distribution in the image of a disturbance of Fig. 5. $A = 10, a = 1, \phi = 0.125\ \lambda, f = 250$ cm. The knife-edge cutoff position is at the optic axis.

aperture in Fig. 9(a). This distance is given by the f ratio of the system and the wavelength of light used

$$R = \frac{1}{2}\lambda\frac{f}{A}. \tag{28}$$

The abscissas of Figs. 12 and 13 can be nondimensionalized by expressing w or y_1 in terms of R.

The ideal light-source size for maximum contrast is $2w = 2R$. This value for a practical schlieren system is much too small to be realized.

In addition, it is questionable if sufficient density could be obtained from such a small source to render a usable photograph.

Fig. 13 indicates that for ballistic and wind-tunnel studies, where shock waves are the important disturbances to be photographed, source sizes of the order of 1 mm in width are satisfactory. Experience indicates that spark photographs taken with Charters- or Liebessart-type sparks at energies of the order of 5 watt-seconds have excellent quality, for source sizes of 1-mm diameter.

When working with sources of finite size the contrast and density in the image can be controlled by varying the knife-edge position as shown in Figs. 14 and 15.

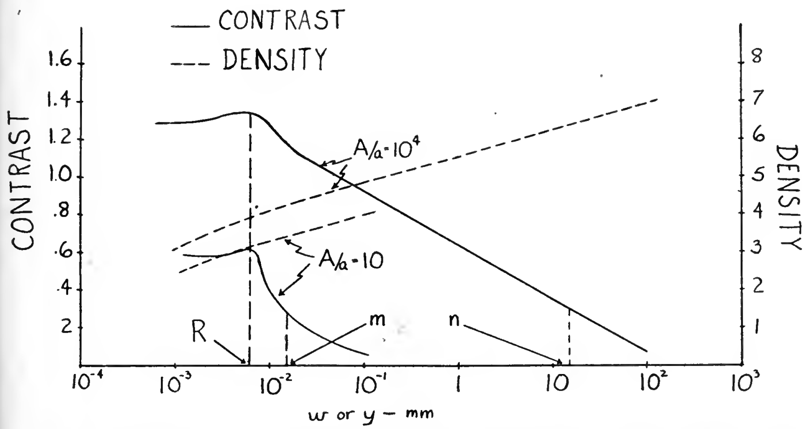

Fig. 13—Effect of source size on the contrast and density of the images of two disturbances of Fig. 5. *R* is the radius of the Airy disk of the aperture *A-A*, *m* is the position of the central maxima of the Airy disk for region *a-a* when $A/a = 10$, *n* is the position of the central maxima of the Airy disk for $A/a = 10^4$.

As the knife-edge is moved into the diffraction pattern from $-\infty$, the contrast varies more rapidly than the density. For the 1.25-mm source of Fig. 14 there is a small region in the vicinity of the optic axis for which the knife-edge position is not critical. As the cutoff is further increased, the density varies slowly. This is because of the decrease of light in the background at a much higher rate than in the center of the image. While higher cutoff will give very great contrast between the image of the region *a-a* of Fig. 5 and the background, small disturbances in the background will not be readily visible. As a general rule it is desirable to operate with the knife-edge in such a position that there is also a marked degree of contrast between the background and the image of any model in the tunnel. It appears from Fig. 14 that the knife-edge should be placed with its cutoff edge just at the optic axis for most general use. However, in specific cases it will be advisable to use other positions.

Astigmatism

In considering the focal length of the optics to use in a schlieren system, the problem of astigmatism will enter as an important factor.

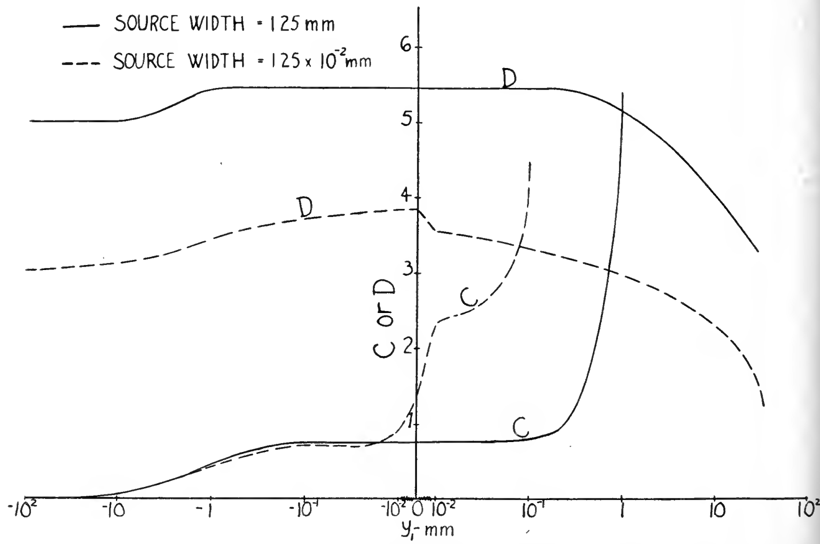

Fig. 14—Variation of contrast and density of the image of Fig. 5 with a light source of finite size for various cutoff positions of the knife-edge. $A = 10$, $a = 0.001$, $\phi = 0.125\,\lambda$, $f = 250$ cm.

It is the general practice to use mirrors rather than lenses in large schlieren systems since the former are inherently achromatic and less expensive. The use of mirrors presents the problem of introducing light into the system. Two arrangements are generally used; one a skewed or Z system; the other a Newtonian system.

In the Z system, which is the more common, there are possibilities of coma and astigmatism. Coma can be eliminated by making $\alpha = \beta$. However, the astigmatism is most difficult to correct for. This aberration is of importance when using different knife-edge orientations since the axial knife-edge position for horizontal and vertical cutoff will coincide with the tangential and sagital image of the source. The separation of these two images is given by

$$\Delta S = f \frac{\sin^2 \alpha}{\cos \alpha}. \tag{29}$$

To keep the light source out of the collimated beam, it must be displaced from the optic axis by a distance equal to at least one half the

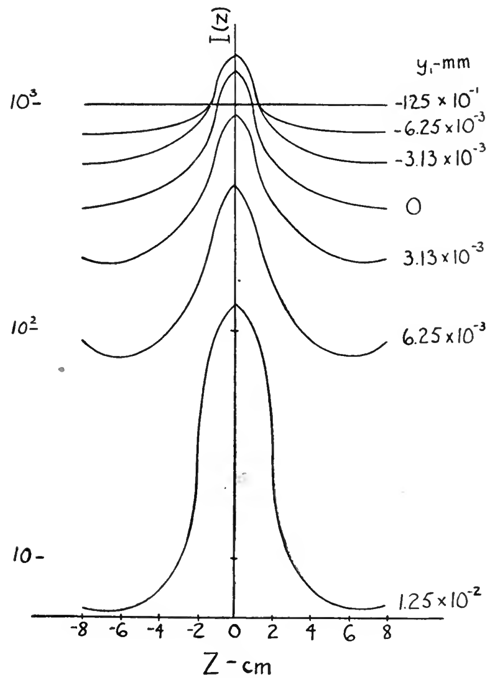

Fig. 15—Light-intensity distribution in the image of a disturbance of Fig. 5 with a source 1.25×10^{-2}-mm width for several knife-edge positions. $A = 10, a = 1, \phi = 0.125\lambda, f = 250$ cm.

aperture of the system. If α is small, $\cos \alpha = 1$, $\sin \alpha = \alpha = A/f$. Equation (29) then becomes

$$\Delta S = f\left(\frac{A^2}{f^2}\right). \tag{30}$$

Since for most wind-tunnel systems the aperture A will be fixed by other than optical considerations, the only variable involved in controlling the astigmatic distance S will be focal length f. To keep S as small as possible, the focal length of the mirrors should be large.

It has been found advisable to keep α smaller than 5 degrees; i.e., the f ratio of the system should be greater than $f/6$. An $f/6$ system of 250 centimeters focal length will result in an axial separation of tangential and sagital image of 1.73 centimeters. For an $f/10$ system of the same focal length, the separation will be 0.625 centimeter.

CONCLUSIONS

The general conclusions of the preceding discussion on the effects of the aperture of the system, focal length of the optics, size of the light source, and position of the knife edge are presented in tabular form below.

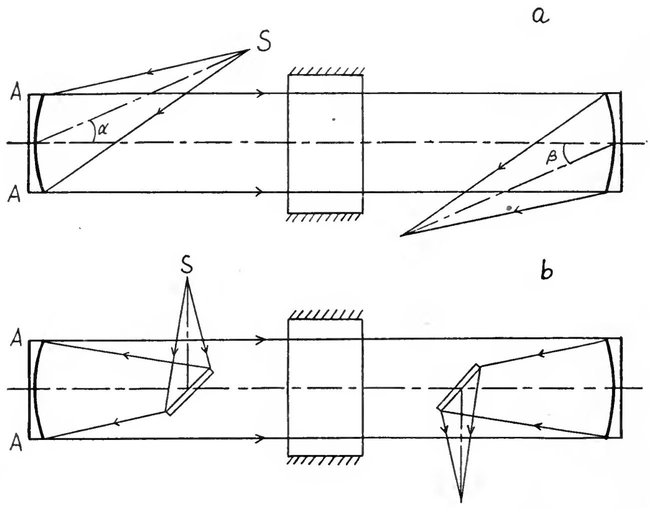

Fig. 16—General types of schlieren systems using mirrors for collimator and objective. *a*—skewed or *Z*, *b*—Newtonian.

1. Aperture

(a) A large aperture gives a high aperture-to-disturbance-size ratio with consequent high contrast and density.

(b) A large aperture gives a small Airy disk which will mean a small light source to approach optimum size. This effect will be amply compensated by item (a) above.

(c) A large aperture necessitates a large offset of source and knife-edge in *Z*-type schlieren systems giving large astigmatic distances.

2. Focal Length

(a) A long focal length will give rise to a larger displacement of the disturbance diffraction pattern from the optical axis, thus enabling the use of a wide light source.

(b) A long focal length will give rise to a large Airy disk thus enabling the use of large light sources.

(c) A long focal length will give rise to small astigmatic errors.

(d) A short focal length will give the system greater light-gathering ability.

3. Light-Source Size

(a) A large light source will give high density and low contrast.

(b) A small light source will give high contrast and low density.

(c) The optimum-size light source is one whose geometrical image in the focal plane of the objective is equal to the width of the Airy disk of the objective.

(d) The maximum-size light source is one whose half width is equal to the distance of the central maxima of the diffraction pattern of the disturbance under study, to the optic axis in the focal plane of the objective.

4. Knife-Edge Position

(a) A small amount of cutoff will produce small contrast with little change in density.

(b) A large amount of cutoff will produce high contrast with a subsequent decrease in density.

(c) In general the optimum knife-edge position appears to be at the optic axis.

The effects of aperture size and focal length can be combined in the effective f ratio of the system. From optical considerations a system of large f ratio should be favored even though such a system is relatively inefficient in its utilization of the available light. Experience indicates that an $f/10$ system is most satisfactory with presently available light sources. Since it is simpler to make large f-ratio mirrors than small f-ratio mirrors of the same quality, the economic factor also favors a large f-ratio system.

Actual light-source size can best be determined by experiment. The general trend of image contrast and density as a function of source size has been given earlier in this paper. The contrasts arrived at may be considered "absolute"; however, the densities are only "relative" and will depend to a large extent on the total light output of the source and the sensitivity of the film used. As was mentioned in the text, a Charters-type spark with a 1-mm-diameter source, through which about 5 watt-seconds of electrical energy are discharged, will give high-quality schlieren photographs at exposure times of the order of 10^{-6} second in an $f/10$ schlieren system.

The knife-edge position will depend largely on the phenomena under investigation and can best be determined ultimately by experiment. For large sources, the more the cutoff, the higher will be the image contrast with a subsequent decrease in density. This is, however, a very inefficient way to obtain high contrast; it is much better to use a smaller source.

Acknowledgment

The numerical calculations for this work were carried out by Mrs. Norma Gilbarg, Technical Assistant in the Aeronautical Engineering Department, Princeton University.

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Exposure Meter for High-Speed Photography*

By E. T. Higgons

Weston Electrical Instrument Corporation, Newark, New Jersey

Summary—This paper reviews the problems involved in the process of evaluating high-intensity illumination levels and the establishment of proper exposure criteria for high-speed motion picture cameras. The problems involved in the design of a suitable light-measuring instrument are discussed, concluding with a detailed description of a light meter which has recently been developed specifically for the purpose of determining proper camera settings for high-speed motion picture studies under any lighting conditions from normal daylight to illumination values as high as 300,000 foot-candles.

Exposure values in standard photography are at present determined by one of the following three methods:

1. By the individual's personal experience with his own particular photographic equipment operating under light conditions familiar to him.

2. Through reference to exposure calculator charts commonly furnished by the film manufacturers, the use of which are dependent entirely upon the user's ability to classify typical lighting conditions.

3. Through the use of photoelectric or extinction-type exposure meter.

All three of these methods involve either consciously or subconsciously the determination or evaluation of the scene brightness or illumination and a correct interpretation of its effectiveness in respect to the camera and the film.

When high-speed motion picture studies are to be made with normal daylight illumination, a standard photographic exposure meter may be readily adapted to the problem of establishing exposure criteria. Unfortunately, many high-speed studies cannot be made with sunlight illumination. In addition, it is sometimes very desirable to shoot at frame speeds far in excess of those possible with available sunlight. Therefore, it becomes necessary for most work to resort to

* Presented April 6, 1949, at the SMPE Convention in New York.

high-intensity artificial-light sources. Operating under these high-intensity-light conditions, the human eye is incapable of any reasonable accuracy. Quite often, the light levels are far beyond the illumination levels with which the eye is commonly familiar, in fact, the eye actually may approach the point of paralysis at these extreme levels. Therefore, the result is a complete or partial failure of the first two methods of exposure determination.

Fig. 1—High-speed light meter.

The use of an illumination meter or exposure meter thus becomes a necessity in order to obtain correct photographic exposures. To meet the above requirement, a direct-reading photoelectric illumination meter has been designed, the development and construction of which is the principal purpose of this paper. (See Fig. 1.)

A rather dependable source of high-intensity illumination can be obtained from the General Electric 750-watt, 115-volt intermittent-service photographic lamps. At 18 inches, this lamp produces an average value of 16,000 foot-candles of light in an 8-inch circle. However, when using a single lamp of this type, the 8-inch pattern of light is not completely uniform throughout its entire area and hot spots result from the filament pattern. When very small areas are to be studied with the camera, it is, therefore, desirable to be able to explore relatively small areas of the illumination to be sure that the actual subject area illumination is being measured. A $^1/_2$-inch exploring area appeared to be a satisfactory limit and, as a result, a $^1/_2$-inch-diameter light-sensitive cell seemed to be dictated, but since this small-size cell was not commercially available, a standard 1.75-inch cell was used equipped with a suitable mask having a $^1/_2$-inch-diameter aperture. This immediately introduced a problem.

For most consistent accuracy, it is desirable to illuminate the entire active area of a barrier-layer type of cell because of two conditions.

First, if accurate reregistration of a small area of light on a large cell is impossible, the output of the cell may be different at various spots on the cell and second, the unilluminated area of the cell becomes resistive in nature and the total series circuit resistance thus created is directly proportional to the area from the illuminated spot to the power take-off point or current-collecting ring of the cell. It was found, however, that the use of a properly selected white opacous material in front of the cell would satisfactorily diffuse the $^1/_2$-inch masked light spot over the complete cell area, thus disposing of the registration and resistance problems. Since the small exploring area is required only when using relatively high-level nonuniform artificial source illuminants, the transmission losses through the aperture and opacous diffusion screen could well be tolerated.

In order to achieve maximum camera speed, it is quite likely that banks of lamps of the General Electric type will be used focusing all of the lamps on the same area. Under such conditions, the filament patterns have a tendency to wash out, but the light rises to rather extreme levels. Several hundred thousand foot-candles of illumination may result from the use of a bank of eight lamps and at the same time substantial amounts of radiant-heat energy may be transmitted. In order to change the range or multiply the range of a photoelectric type of light-measuring instrument, it is common practice to shunt away from the measuring instrument a large portion of the total current developed by the light-sensitive cell. This is accomplished by means of a suitable resistor network ahead of the meter. However, the continual exposure of a barrier-layer type of cell to excessively high levels of illumination may, under certain conditions, contribute to cell deterioration. Therefore, it seemed desirable to depart from the usual electrical range-switching arrangement and resort to the use of suitably calibrated neutral-density filters for range multiplication. By the simple process of controlling accurately the density of the white opacous diffusion plate, any desired per cent of transmission loss could be achieved, thus multiplying the basic range of the instrument by ten or higher as needed. By facing the cell multiplier with polished aluminum and using the white materials throughout, the effects of radiant heat could be minimized.

The final design of a suitable light-measuring instrument for this application, therefore, has taken on the following form.

The light-sensitive cell is mounted in a small paddle equipped with an extension cable to permit more comfortable reading of the instrument away from the intense illumination area. The cell connects to an electrical instrument providing a basic range of 3000 foot-candles which will be found adequate for most outdoor work, except under rare conditions of very bright sunlight. Two carefully calibrated slip-on diffusion multipliers with $^1/_2$-inch aluminum aperture plates are supplied to extend the range to 30,000 and 300,000 foot-candles, respectively. An exposure table will be supplied with each instrument giving appropriate camera settings for the various types of cameras and films in common use today.

Thus, a completely reliable exposure determinant is provided for use with presently available illumination sources and with sufficient flexibility which probably will be capable of handling other ranges which may now be under development.

Acknowledgment

The writer wishes to acknowledge the very excellent assistance and co-operation of J. H. Waddell, A. T. Williams, and L. D. Smith, who played an important part in the development of this design.

Discussion

MR. A. J. SHAFER: What sort of allowances apply for reciprocity failure.

MR. E. T. HIGGONS: I believe the reciprocity failure does not enter into it too seriously.

MR. J. H. WADDELL: We might comment that the exposure tables that will be furnished with the meter are going to be established from actually running the picture tests. We know values now, and on the lower speed ranges, where one might be taking from 100 to 500 pictures a second, picture tests are under way for that particular range. We know, for example, that 150 to 170 thousand foot-candles will allow pictures to be taken at 5000 a second at $f/11$.

CHAIRMAN BRIAN O'BRIEN: Perhaps I may add one point on reciprocity failure at very low exposures. Many of you will recall that the Gurney solid-state theory of the photographic reaction predicts that after a certain minimum exposure time is reached, further shortening the exposure and increasing the intensity of the light correspondingly so that the product of time and intensity remains constant, will go from that point up to higher and higher intensities, and there is no new curve of reciprocity failure. The curve of reciprocity failure levels off. At exposure time less than 1 microsecond, a new reciprocity failure seems to come in for all thus far tested of the fast photographic emulsions. Therefore, in the event that any of you have occasion to work below 1 microsecond, and particularly below $^1/_{10}$ microsecond, this reciprocity failure, apparently not predicted by the Gurney and Mott theory, occurs. This is under investigation in our laboratory at the moment, and I expect within a few months some numerical data will be forthcoming.

Techniques in High-Speed Cathode-Ray Oscillography*

By C. BERKLEY and H. P. MANSBERG

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Summary—**The shortest photographic exposures are made while taking pictures of cathode-ray oscillographic patterns. Because of the unique characteristics of cathode-ray-tube images, many specialized techniques are required to record them adequately and to overcome the problems encountered. These techniques are considered in detail. Their proper use will result in considerable improvement in cathode-ray oscillography.**

The use of photography in connection with cathode-ray oscillographs and tubes considerably enhances the versatility and usefulness of such equipment. The permanency of the record and data obtained is sometimes an advantage in itself. For example, it is a common experience when working on a circuit to make some slight changes, seeking to effect an improvement in wave shape; and to continue making slight changes over a period of days, at the end of which time, one can no longer tell by looking at the cathode-ray-tube pattern whether or not the end result is any better than the original one. If oscillograms are available though, comparison by superposition immediately gives the desired information.

Fig. 1 shows a typical example of the result of slight changes in the parameters controlling the clipping action of a circuit. The fact that clipping is taking place at three levels because of the changes can be clearly seen.

Perhaps the best way of quickly specifying the behavior of some complex electronic equipment such as a television set, for example, is to describe the wave shape at as many points in the circuit as desired. This can be done rapidly by making a series of oscillograms showing these wave shapes. Drawings are generally insufficient for showing the fine details which sometimes make considerable difference in the performance of the equipment. In addition, there is an inherent advantage in the use of a camera in gathering data from the face of an

* Presented October 12, 1949, at the SMPE Convention in Hollywood.

oscillograph tube. That is because observation with a particular camera is always made from exactly the same point thereby avoiding any errors caused by the parallax of an observer whose viewpoint may be shifting. Also, because of the geometry of the usually curved face of the cathode-ray tube, certain geometrical distortions occur, which may in some cases be eliminated or discounted in the photograph. There is also the possibility of so designing the cathode-ray tube as to eliminate this problem, resulting in orthogonal pictures from a curved cathode-ray-tube face.

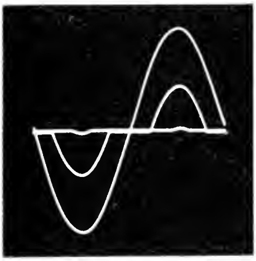


Fig. 1—Triply exposed oscillogram resulting from changes in circuit characteristics.

Frequently, oscillograms may be enlarged and studied in detail to show characteristics which otherwise would be overlooked in a reduced or even in a one-to-one recording. For example, Fig. 2 shows the recording of a sine wave from an oscillator whose frequency was being modulated very slightly by another frequency, an undesired one. This defect is not visible ordinarily unless the image is enlarged to many times its normal size, in which case, it can be seen that the separation between these two cycles is different than that between the other two cycles.

One of the limitations of most cathode-ray oscillographs is that they have only a limited persistence time for the screen image. In the case of very rapid transients, the persistence is too short to enable any retentivity for more than a few seconds. In the case of very long-time phenomena, the image at one edge of the screen may have disappeared at the time the image is being displayed on the other edge of the screen. By means of photography, we obtain what is virtually an infinite persistence. Photography may also be used to overcome one of

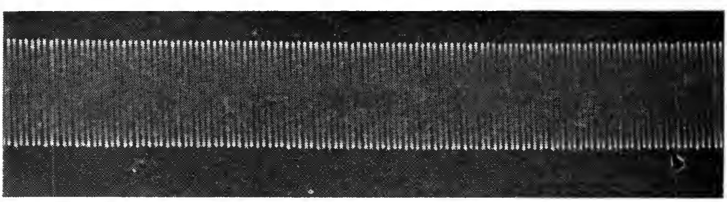


Fig. 2—Continuous recording showing defects not visible on oscillograph.

the basic limitations of the human mind, its bandwidth (as devotees of the science of cybernetics may find interesting). One of our basic limitations is the fact that most of us can usually visualize and understand only one phenomenon at a given time. If, for example, we have a four-channel oscillograph, and something is happening simultaneously or asynchronously on all four channels, one would really have to be a superman to be able to study and appreciate all four phenomena at once. By means of an oscillograph, we can make recordings of all four phenomena (Fig. 3) and study them at our leisure over a longer

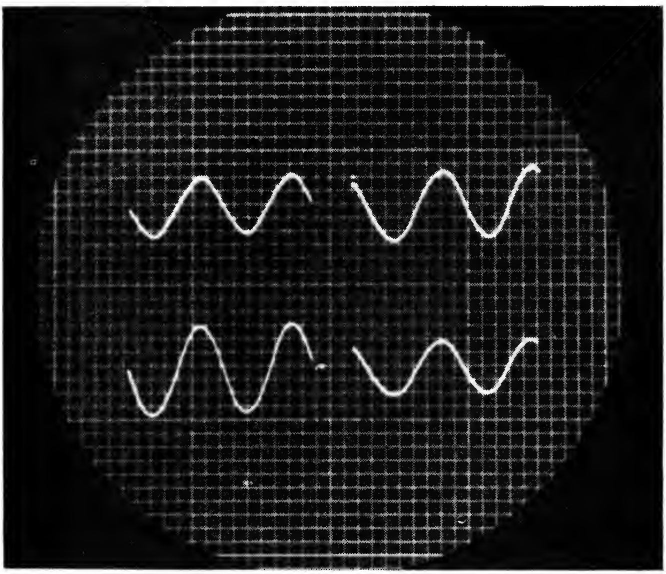


Fig. 3—Typical four-channel recording.

period using the more limited bandwidth of our minds. Fig. 3 shows four such phenomena which might vary independently of one another. This figure shows the input and output voltages and currents of a constant-voltage transformer.

Photography in connection with cathode-ray oscillographs may also perform monitoring functions so that it will instantaneously record whatever phenomenon is displayed on the face of the cathode-ray tube. To date, no anticipatory electronic circuits have been developed capable of such a wide range of usefulness. Another advantage which may be gained by the use of photography is the integration obtainable by means of the photographic process. It is frequently desirable to be able to average a phenomenon which is varying widely about some mean value. By giving a series of multiple underexposures resulting in a properly exposed average (Fig. 4), one obtains a clearer picture than would otherwise result. For example, Fig. 4 shows in polar co-ordinates the thread tension on a loom which varies widely from cycle to cycle or from thread to thread of the

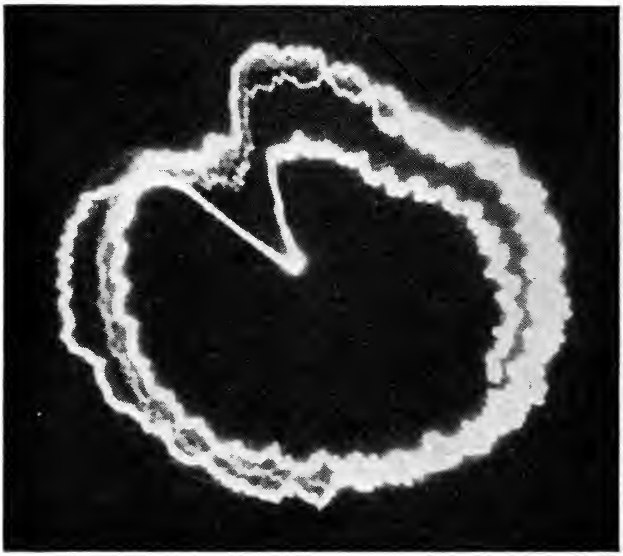


Fig. 4—Photograph of widely varying phenomenon.

weave. By underexposing for about 100 cycles, we obtain the average picture shown in Fig. 5.

So much for the advantages to be gained from cathode-ray-tube photography. In addition, improvements in cathode-ray tubes and oscillographs from the standpoint of brightness, resolution, stability, and accuracy, have enabled these instruments to supplant, and, in most cases, to surpass the direct writing or recording mirror and string oscillographs, when photography is used. Because of them, the use of photography has become mandatory for most cathode-ray-oscillograph applications. This is especially true for high-speed transients. Despite this widespread use, little information exists concerning the photographic techniques to be used with these oscillographs. While, of course, the basic photographic problems are the same, because of the different nature of oscillographic patterns, certain rather startling differences may appear in the conditions.

As an illustration, let us consider the photograph of a single transient having a writing rate of 400 inches per microsecond (which is obtainable with present commercial oscillographic equipment). The

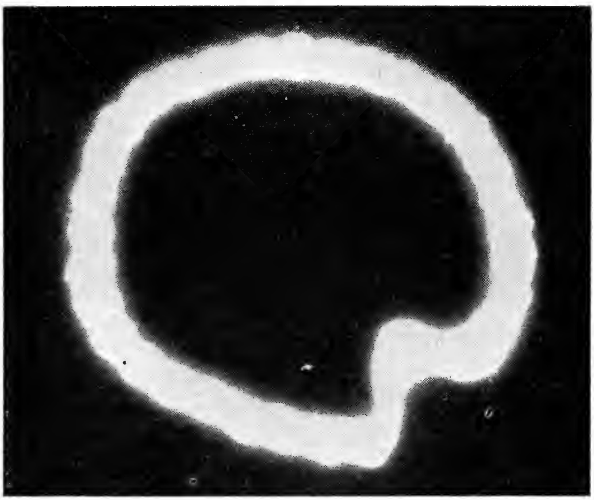


Fig. 5—Integrated phenomenon of Fig. 4 showing average value.

photographing of such a phenomenon results in the exposure of an individual portion of the film for a time interval of the order of 10^{-11} second! This exposure is far shorter than any exposure obtainable by means of any other photographic procedure.

In our experience, certain photographic problems have recurred frequently. We feel that considerable laboratory development time and effort can be avoided by use of the techniques described for obviating these problems. We intend to limit our consideration to the special photographic problems in *oscillography*, excluding those points which are treated in standard photographic texts.

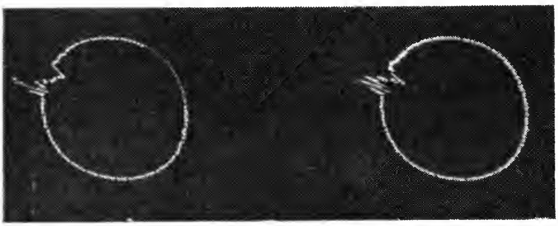
TYPES OF PATTERNS

We may divide the types of patterns to be photographed into three classes—recurrent, transient, and drifting phenomena. Recurrent phenomena are those which recur reproducibly from cycle to cycle without any interruption or deviation. Transient phenomena are those phenomena which occur once or at specific repetition rates, but which are not in general reproducible. Drifting phenomena are phenomena which have no specific repetition rate or no specific wave shape, or which may be random both as to wave shape, repetition rate or other characteristics, or may be entirely random.[1]

Let us first consider recurrent phenomena, that is, perfectly reproducible, stationary patterns on cathode-ray tubes. The first problem that one encounters in connection with any pattern is that of obtaining the proper exposure. For an oscillograph having continuous

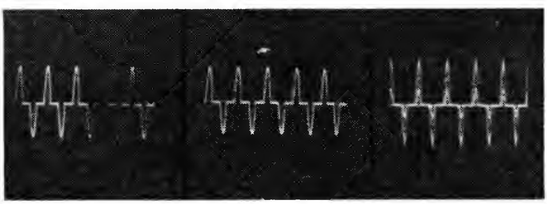
Fig. 6—Effect of overexposure and underexposure on line width.

sweeps, the general rule may be stated that at a particular setting of the intensity control, the exposure required with a particular camera will be constant irrespective of the sweep being used or the frequency recorded, and varying inversely with the area which the constant electron-beam intensity covers. For this reason exposure tables in the instruction books and specifications of oscillograph cameras for such cases have been found adequate. It will be noted upon reference to such tables that the exposure called for is constant over a very wide frequency range and is only required to be modified slightly at the very slow writing speeds where the spot is likely to be overexposed. A properly exposed oscillogram should have a quality and clarity capable of supplanting directly the present draftsman's drawings now used in many texts and papers. To demonstrate this, we have used the original negatives so far as possible as figures. Fig. 6 shows the effect of proper and improper exposure upon a repetitive phenomenon. The recording at the right has been underexposed resulting in a poorly visible trace; the one in the center is properly exposed, and the one at the left is overexposed. It can be seen that the apparent line width of the trace varies with the exposure because of the nonuniform light distribution across the trace. One may therefore, obtain any fineness of line required, within limits, by a choice of the proper exposure. In general, the exposure should be such as to include a sufficient number of cycles of this repeating phenomenon so that no part of the sweep is lost. If the exposure is shorter than this, there will be a visible interruption at the time of shutter opening or closing. This is not usually of importance except at very low speeds, because at high speeds one



(a) (b)

Fig. 7—(a) Partial loss of recording caused by improper length blanking gate; (b) proper blanking gate.



(a) (b) (c)

Fig. 8—Effect of exposure time on a varying phenomenon: (a) too short; (b) correct; (c) too long.

cannot open and close the shutter rapidly enough to include less than one sweep. Where the phenomenon is not reproducible, and it is desired to include only one cycle, one may use electronic control of the exposure by means of a gating pulse applied to brighten the beam. It is desirable to have the length of the gate as close to one cycle as possible.

Fig. 7 shows a typical polar co-ordinate recording of a vibration in connection with a rotating machine in which the gate in the first oscillogram is of proper duration, and in the recording next to it, is so short, that a portion of the recording is lost. If the pattern to be photographed is clear, stationary, and reproducible on the oscillograph, no difficulty is usually encountered if the proper exposure is given. Often the pattern lacks these requisites. For example, the pattern is frequently disturbed by some transient condition such as slow line-voltage variations. Or, we may be interested in the output of a transmitter upon which is superimposed some unregulated direct-current level. If we were to give the exposure called for in the tables, the result would appear as in the right figure of Fig. 8, the various

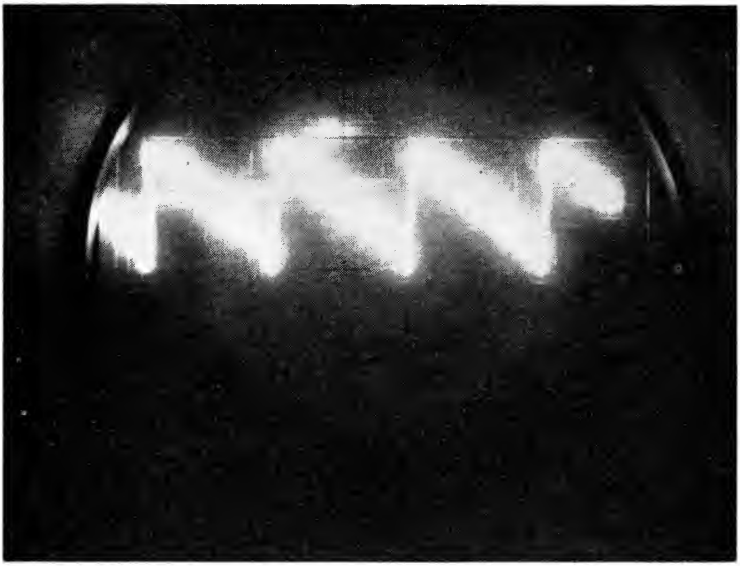


Fig. 9—Deliberately overexposed saw-tooth oscillogram to record fast rise time.

traces not being superposed. If sufficient brightness is available, this problem may be overcome by shortening the exposure just enough so that we effectively stop the motion of the phenomenon. This is analogous to stopping the motion of a high-speed moving object in standard photography. The published tables of the proper exposure to give are based upon certain average, normal conditions. In some cases, modifications of these exposures have to be made. For example, Fig. 9 shows an oscillogram of a perfectly reproducible saw tooth. But this is a good saw tooth and the saw time is much greater than the return time, so that if the recording is properly exposed for the saw, it will be impossible to see the rise time which may contain a number of interesting peculiarities. There are several things that may be done about this. One is to make two recordings, one showing the return time with the saw considerably overexposed, the other showing the saw with the rapid rise underexposed.

Another problem frequently encountered is that of 60-cycle or other modulation in the intensity of the cathode-ray-tube beam. See Fig. 10. This is a serious difficulty only with poorly designed oscillographs. Rather than redesign the equipment, it is usually sufficient to turn up the beam intensity and slightly overexpose the film in the upper portion of the *H*-and-*D* curve where variations in exposure are ironed out into a uniform high density. As a general rule, it will be found that

(a) (b)

Fig. 10—Effect of intensity setting on recordings in presence of beam modulation: (a) low intensity; (b) high intensity.

the photographic process is much more critical of the quality of a cathode-ray-tube trace than is the human eye. Recordings, being subject to closer scrutiny, show up many defects in an oscillograph that would otherwise go unnoticed.

Most of the problems encountered with stationary or recurrent phenomena are also encountered with transient phenomena. The matter of proper exposure is generally a much more critical one with transient phenomena however. In the case of transients, the problem is usually that of obtaining sufficient density for high-speed recordings. In designing equipment for photography it is desirable to know just how far to go electronically in order to obtain adequate density in the photographic image. There are a number of factors which should be considered, all of which affect the photographic density. One of these is the maximum writing rate to be encountered; another is the intrinsic unmodulated brightness of the spot measured under standard conditions; another is the grid drive available in connection with these single transients; another one is the total and second-anode accelerating voltages; another is the optical-reduction ratio to be used with the particular camera; another is that of determining how the repetition rate and brightness of the phenomenon will affect the final negative.

According to the so-called reciprocity law, to produce a particular density on the photographic emulsion, the light intensity and the duration of the exposure are reciprocally related. This relation holds quite well for ordinary exposures such as are found in standard amateur or commercial photography, but fails under very short time or intermittent exposures such as are found under our conditions. This failure of the reciprocity law has been investigated by many workers but is subject to so many considerations that it is not possible to evaluate it satisfactorily.[2]

Also it is not generally possible to evaluate satisfactorily under particular conditions the effects of the writing rate, brightness, drive, accelerating voltage, reduction ratio, or developer. For this reason, the best solution is to refer to the tables of proper exposure for single transients which are given in the instruction books either for the oscillographic equipment in use, or in connection with the camera supplied for oscillographic use. These proper exposures can only be determined well by empirical methods.

UNDESIRED FILM FOG

We have stated that when correctly prepared, an oscillogram should equal or surpass the best draftsman's drawings of a wave shape or cathode-ray-tube image. One of the reasons why this frequently is not accomplished is the presence of undesired cathode-ray-tube screen illumination from a variety of internal and external sources. It is sometimes desirable to photograph some cathode-ray-tube equipment in toto showing both the complete equipment with the control panels, knobs, and accessory personnel, including at the same time, a suitably exposed and illuminated oscillogram on the face of the cathode-ray tube. In the case where the cathode-ray tube is sufficiently bright and where the phenomenon is repetitive and stationary, a constant illumination of the general scene may well be employed. It is usually quite difficult to evaluate the effects of a flashlamp in connection with the exposure coming from the cathode-ray-tube image itself. Where the cathode-ray-tube image is of relatively low intensity, it is usually washed out by the light used for photography of the rest of the equipment.

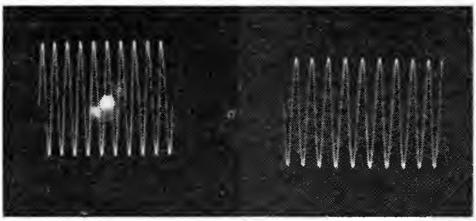
Some tricks must be resorted to in order to obtain proper exposure. One of these which we have used quite successfully is that of double exposure. The equipment is first photographed with black disks in place of, or over the face of, the cathode-ray tube; or the screen is

Fig. 11—Typical photograph of apparatus with oscillogram using double-exposure technique.

shielded from direct light. Then the lights are put out, the disk removed, and a separate exposure made for the cathode-ray-tube image alone, using the exposure tables of the cathode-ray-tube manufacturer. (See Fig. 11.) If then desired, a slight additional exposure of the cathode-ray-tube face without any image is then made, or the cathode-ray-tube face without any image is then made, or the cathode-ray-tube face may be practically shielded from the photographer's lights during the exposure of the rest of the equipment.

MOTION PICTURES OF OSCILLOGRAMS

It is sometimes desired to obtain motion pictures of an oscillograph trace for instructional purposes. If a conventional intermittent camera is used, difficulties frequently are encountered with a beating between the camera speed and the pattern repetition rate resulting in blank underexposed frames. The beat frequency is seen in the projected image. This effect may be reduced by using a long-delay phosphor such as the P7, and suppressing the initial blue flash with an amber filter. Where a drifting phenomenon is being recorded, the image tends to smear because of phosphorescence. In this case, the image may be recorded with a continuous motion camera adjusted in speed so that one frame on the film corresponds to an integral number of cycles



(a) (b)
(a) Recording fogged by cathode glow.
(b) Cathode glow removed with blue filter.

Fig. 12

of the phenomenon. If the resultant recording is then projected under standard intermittent conditions, the persistence of vision will give the same visual effect as the cathode-ray-tube image.

Another source of stray fog on the oscillograms is that of the glow from the cathodes of various tubes used in the oscillograph or from the cathode-ray tube itself. (See Fig. 12.) The cathode-ray-tube shield should be designed so as not only to shield for stray magnetic fields, but also for stray light beams. Cathode-ray-tube cathode-glow can best be minimized by using cathode-ray tubes in which special attention has been paid to stray light from such sources and in which a suitable screen application has been made so as to render the screen more or less opaque to the amount of light emitted by the cathode. Where very long exposures are required, as for example, where the cathode-ray tube and camera perform monitoring or anticipatory functions, some stray light cannot be avoided readily when exposures run over periods from one hour to several weeks. One solution to this problem is the use of orthochromatic recording film comparatively insensitive to the more or less orange light from the cathode-ray-tube cathode, or, the use of dark blue filters and P11 photographic screens whose peak emission is far removed from the emission spectrum of the incandescent filament. Fig. 12 shows this effect.

Another source of stray illumination on the cathode-ray-tube face is the stray emission of electrons from various portions of the tube. These stray electrons may result from secondary emission from sharp

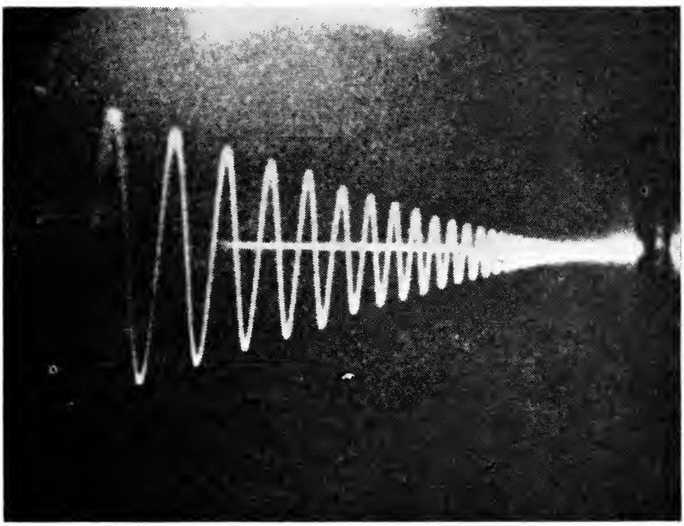
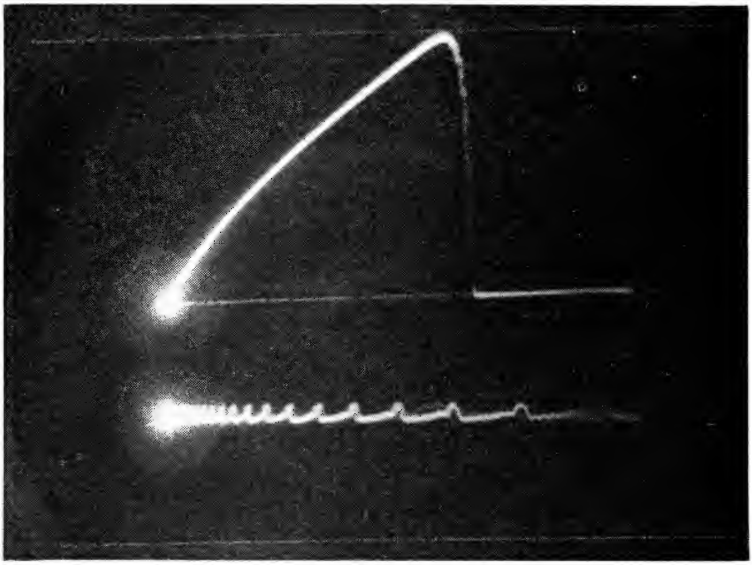
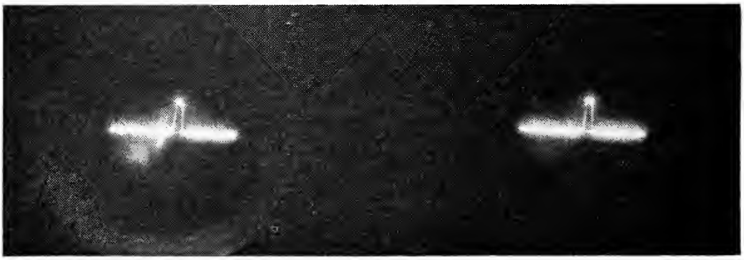


Fig. 13—Effect of electron reflection from deflection plate.

portions of the gun structure, from impurities in the cathode-ray-tube walls, from high accelerating voltage, or from secondary electrons reflected from the deflection plates. Fig. 13 shows such secondary electrons caused by reflection from the deflection plates of a cathode-ray tube. Fig. 14 shows stray electrons caused by high field emission and secondary emission from the rings of a Type 5RP tube.[3] Secondary emission caused by reflection from deflection plates usually can be minimized by the proper choice of the position of the cathode-ray-tube image, while stray emission caused by high field intensities may be minimized by so changing the accelerating-voltage distribution between second anode and intensifier as to reduce, so far as possible,



(a) Concentric rings caused by secondary emission from intensifier.



(b) Fogging of trace due to stray electron emission.

Fig. 14

electrons from this cause. Since these secondary electrons usually have a lower velocity, some work has been done toward the preparation of special tubes having metal-backed screens which are relatively opaque to these slow-speed electrons and relatively transparent to the completely accelerated electrons producing the desired image. Such metalized tubes completely eliminate the cathode glow.

Whenever recordings are made which include low plus high writing rates such as flat-topped, relatively long pulses with relatively fast rise times, the slower portions of the pattern become considerably overexposed causing halo around the cathode-ray-tube trace. This halo is a well-known phenomenon caused by the total reflection of the light from the cathode-ray-tube spot at angles beyond the critical angle for the glass-air interface.[4] This halo can be eliminated completely by effectively making the glass face as thick, approximately, as the nominal radius of the tube face. This is a somewhat impractical solution,

(a)

(b)

(c)

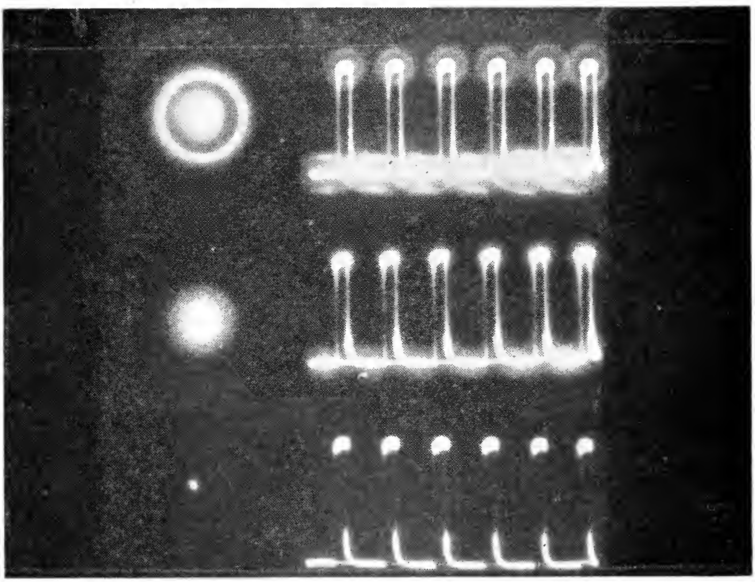


Fig. 15—Effect of screen-coating procedure on halo: (a) flowed screen; (b) settled screen; (c) with plastic face plate.

but the same effect may be obtained by placing in optical contact with the screen a cup-shaped lens of plastic, the contact being maintained by means of a liquid of suitable refractive index. Some work has been done on the cementing of plastic to the glass face in order to eliminate halo. The magnitude of the effect depends to a great extent on the proportion of the light which reaches angles near the critical at the glass-air interface. This effect may be minimized by a choice of screen-coating procedure which directs a large proportion of the light foreward rather than at angles close to the critical. Fig. 15 shows typical examples of halo from a screen put on by flowing, a screen put on by settling, and a screen covered by the plastic face plate just mentioned. It can be seen that the settling technique which is used on our cathode-ray tubes for photography today gives quite an improvement in the result. The use of the plastic face plate eliminates the undesirable halo completely. Another source of stray light sometimes is encountered in the case of single transient exposures, since the blanking gate causes transient changes in the direct-current level of the grid or cathode voltages of the cathode-ray tube. These changes cause an illuminated spot to appear at the edge of the pattern. The effect may be seen in Fig. 16. It can best be minimized by turning the

(a) (b)

(a) Fogging effect of transients in grid-cathode voltage.
(b) With transient eliminated.

Fig. 16

cathode-ray-tube average brightness down to such a value that no transient coming in can produce a visible stationary spot. A better solution to this problem is to use a blanking gate which is direct-current-coupled from the signal source.

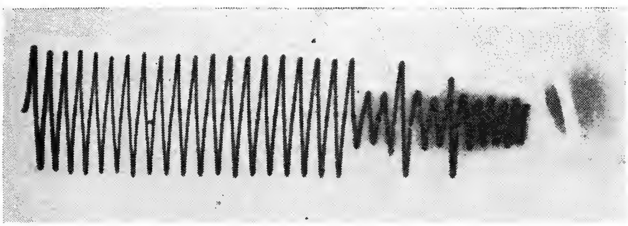
Because of the high voltages used in oscillographs designed for high-speed transients, unusual difficulties are encountered with static exposures on the film caused by charge leakage. To avoid this, metal parts such as the pressure plate and film gate should be grounded to a common point with the oscillograph. The use of all-metal cameras is indicated.

Because of the prolonged development times required to render the threshold densities visible, higher fog densities have to be tolerated in cathode-ray-oscillograph photography. Preferably, experiments should be run on each new emulsion batch to determine the optimum development conditions for the best threshold density above fog.

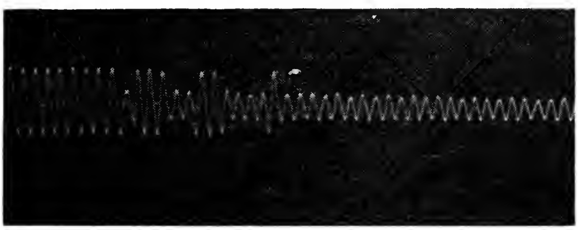
Under certain conditions X-ray fogging may be encountered because of the high accelerating voltages used. The X rays generated are generally so soft that they will not penetrate the cathode-ray tube or the camera. Any X-ray fogging usually originates outside the camera or cathode-ray tube from sources such as rectifier tubes or surge equipment. Simple shielding will obviate this.

RANDOM PHENOMENA

Where it is required to record random or drifting phenomena, certain advantages in the presentation of the data can be obtained by



(a) Single-frame recording of motor-starting current.



(b) Continuous-motion record of same phenomenon.
(Note increased amount of information.)
Fig. 17

carefully considering whether the recording should be made on a single frame or with a continuous motion camera (Fig. 17). These recordings show a motor-starting characteristic. The continuous-motion recording enables study of much finer detail. The type of presentation can also effect a saving in film. Fig. 18 shows a continuous-motion recording of pulses coming in at some frequency and repetition rate which varies from time to time. These pulses might have been recorded by the standard continuous-motion technique in which the film provides the time base. It can be seen that in using this technique as shown in the bottom portion of the figure, the pulses are crowded fairly close together and the wave shape is not very clearly seen. A better technique is to combine the sweep on the oscillograph with the motion of the film in order to obtain a better utilization of the film area as shown on the upper portion of the recording. Another example of this film-saving technique is shown in Fig. 19, depicting a nerve dying over a long period. In certain cases where we have a phenomenon which takes a considerable time, a fairly good picture of the result may be obtained on a single frame by using continuous sweep and allowing the signal to vary in its normal manner. By increasing the sweep speed, we obtain an expansion of the phenomenon but still use only a single frame. Fig. 20, which is a recording of

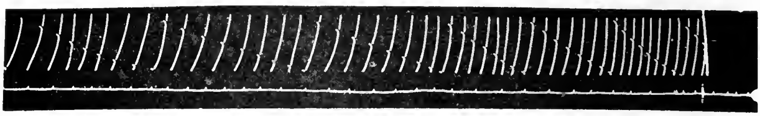


Fig. 18—Two methods of continuous-motion recording.

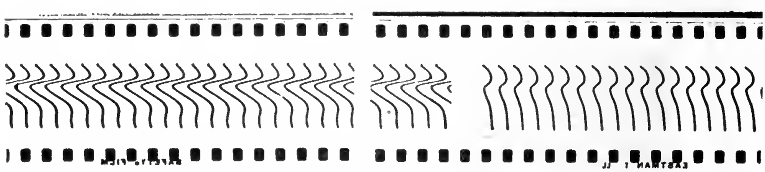


Fig. 19—Action potential of a nerve over a long period. (Obtained through co-operation of Dr. H. Grundfest.)

the light build-up of an incandescent lamp, is a typical example of this. The manner in which the build-up occurs can be readily seen; the fact that the image is broken by the return time of the sweep is of little importance. Where we have a phenomenon which is random, it is necessary to use the film motion as a time base.

The exposure the phenomenon produces depends on the mode of recording. In continuous motion and single-sweep recordings, the spot image traces its path over any point only once and the required exposure, therefore, is the same as that for a single transient. In complicated cases, as in Fig. 20, where multiple exposure of the steady state is obtained, and only single exposure of the transient portion, the camera setting should be chosen to record the highest writing rate in the phenomenon.

In some cases it is of advantage to run the sweep along the direction of film motion. This enables expansion or contraction of portions of the phenomenon. Fig. 21(a) shows such a vibrational pattern in which the detail in the initial shock wave is lost due to the high frequency. By using a fast single sweep which runs only during the start of the phenomenon, in addition to the film motion, we obtain the pattern of Fig. 21(b) showing the requisite high-frequency components.

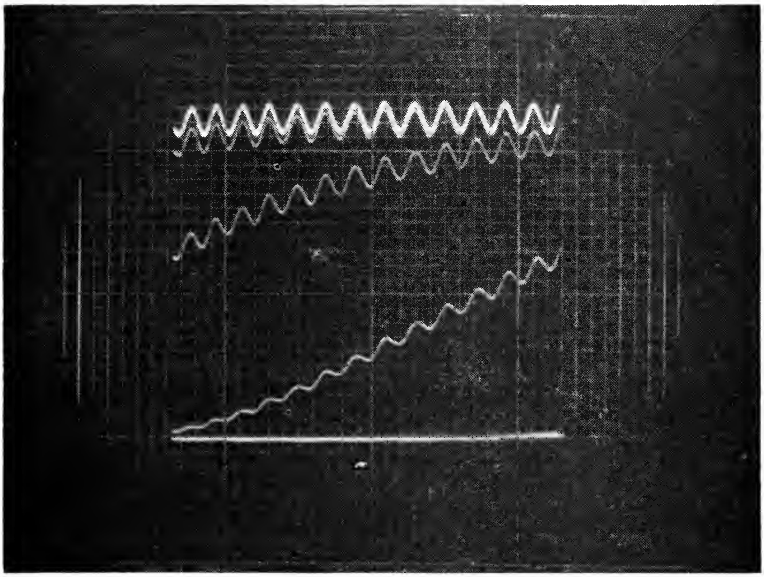


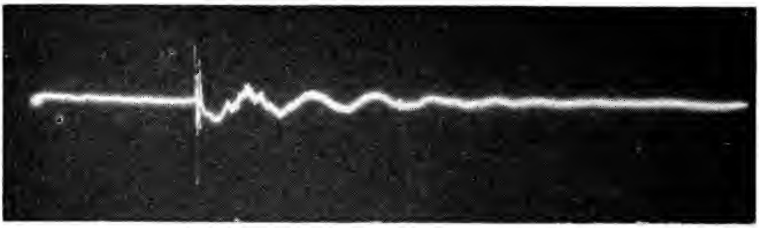
Fig. 20—Incandescence of a lamp showing steady and transient states.

Since the writing rate is higher during the sweep interval, it is also desirable to provide a grid intensifying pulse during this time to avoid underexposure.

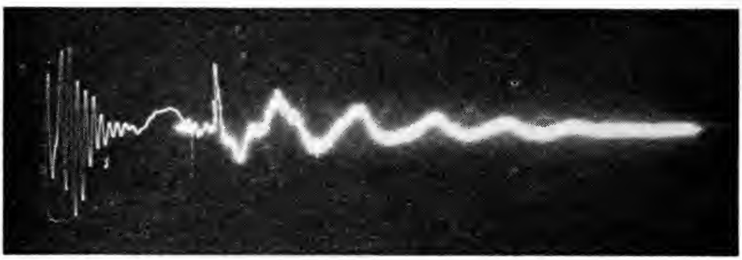
CATHODE-RAY-TUBE SCREENS

Careful consideration should be given to the type of cathode-ray-tube screen used for photography. If a particular oscillographic equipment is to be used only for photography, the screen type should probably be a short persistence, blue, highly actinic screen such as the Type P5 or P11. If continuous-motion recordings are to be made at very high speeds of over, roughly, 100 feet per second, then the P5 or calcium tungstate screen must be used to avoid blurring.

As is usually the case, however, the same oscillograph is to be used both for development work or visual observation, and for photographic recording. In this case, it is desirable to use a screen which is capable of efficient operation for both purposes. Two such screens are the Radio Manufacturers Association's standard Type P2 and P7 screens. If the oscillograph is to be used to observe high-speed transients, but is intended for only low-speed continuous recordings, the P2 screen will generally prove quite satisfactory.[5, 6]



(a) Unexpanded.



(b) Expanded.

Fig. 21—Use of sweep and film motion in combination to expand portion of trace.

When continuous-motion recordings are made, a blue filter can be used to isolate the blue light which has a relatively short persistence while if visual observation of the transients is required, the filter is removed. In some cases the residual persistence of the P2 screen will prove too long and, therefore, will require a rather dark filter to remove any traces of the persistence completely. This will reduce the light efficiency so that a better solution would be the use of the P7 screen in which the phosphorescence and fluorescence occur in rather widely separated portions of the spectrum, phosphorescence being amber in color, and the fluorescence a blue having the same characteristics as the P11 screen. Another problem is that of the resolution required in the final recording. Certain screen types are considerably better in resolution than others. For example, the Type P7, being a two-layer screen, tends to diffuse the image more than the Type P1 which is a thin homogeneous material. The requirement of high resolution also places certain limitations on the film type. As a general rule, the higher speed films give relatively coarse-grained images. If extremely high speed is desired, it is also necessary to use developers whose activity is such that they also

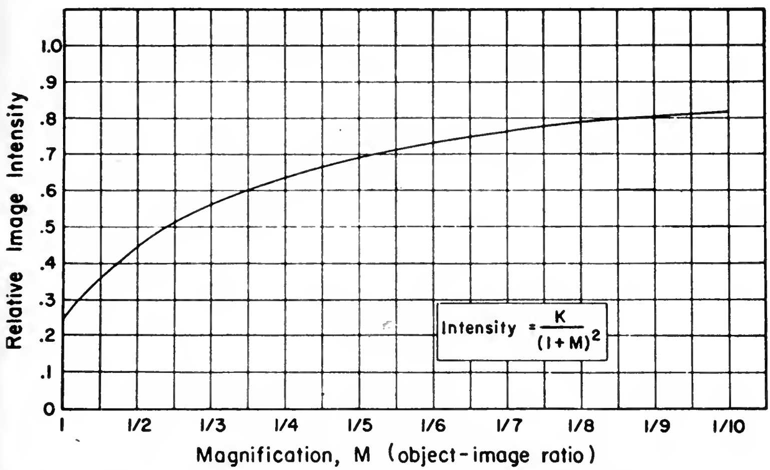


Fig. 22—Relation between magnification and image intensity.

tend to produce relatively coarse images. The coarseness of the grain of the images may be so great as to spoil completely the resolution of an otherwise good recording. Where sufficient exposure is available, it is better to use a relatively slow-speed film such as Panatomic-X which, even under adverse development conditions gives fine-grained images which can be enlarged considerably for study. If speed is the prime requisite, then the fast coarse-grain films and fast coarse-grain resulting developers must be used. The use of faster sweeps will then enable the apparent resolution to increase.

There are two types of special high-speed films manufactured by the Eastman Kodak Company specifically for oscillography. These are known as Linagraph Panchromatic film and Linagraph Ortho film. Where extreme speed is desired, the Linagraph Panchromatic Film has a slight advantage over the Ortho film. If difficulties are encountered with cathode-glow, or if it is desired to use safe lights while developing, the Linagraph Ortho film should be used. Because of the failure of the reciprocity law, no general statements can be given as to the proper exposure for various types of films over wide writing-rate conditions. The results must be expressed empirically in the form of tables based upon particular assemblies of oscillo-

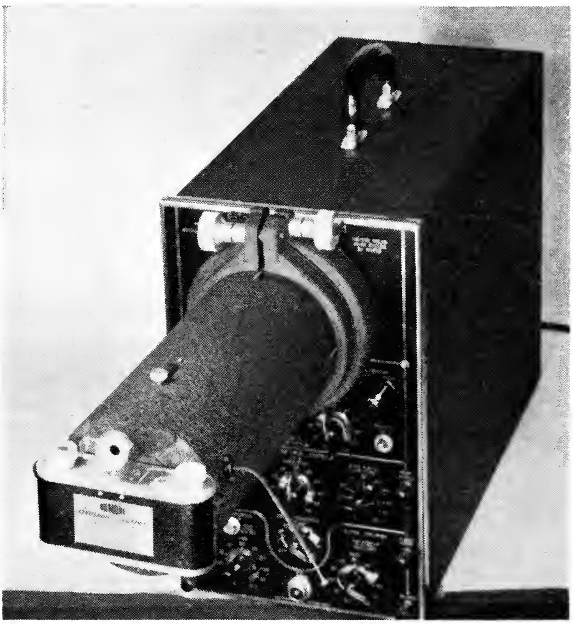


Fig. 23—35-mm cathode-ray oscillograph camera for single frame.

graph cameras and films. In general, there is no good relation between the Weston speed or other speed rating of a film and its applicability for cathode-ray-tube photography, although the higher speed films usually give a higher oscillogram density than the lower speed films.

Optical Considerations

It is sometimes advantageous to obtain recordings which are exactly the same size as the original image on the cathode-ray-tube film. It should be borne in mind, however, that when this is done, there is a loss in recording speed because of the fact that the effective aperture of the lens used is halved from its value at infinity. That is, if an $f/1$ lens is used to photograph a pattern with a 1:1 reduction ratio, the effective aperture of the lens will be only $f/2$. Where high speed is important, it is generally preferable to reduce the image size in order to gain an increased density advantage. Fig. 22 is a graph showing just how this advantage varies with the reduction ratio. As a practical matter, a reduction ratio of approximately 5:1 has been chosen so that 35-mm film can be used in cameras having relatively

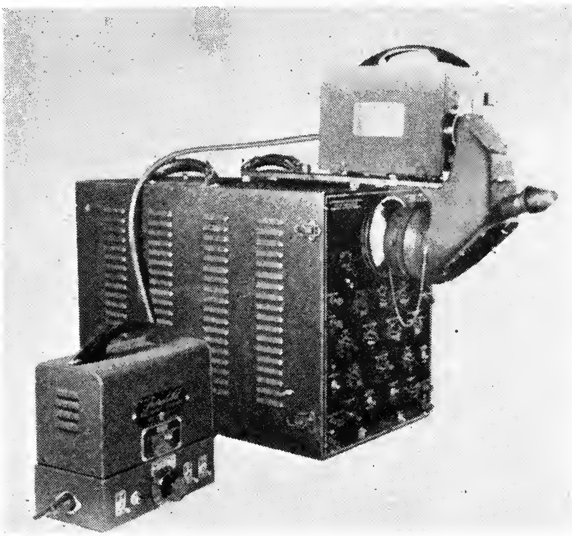


Fig. 24—35-mm cathode-ray oscillograph continuous-motion camera.

inexpensive lenses. This consideration also governs the camera, type, and size used. Where it is desired to use a wide variety of films for different conditions, the most indicated camera will be one which can use 35-mm film. Most 35-mm films have a resolution more than adequate to portray everything the cathode-ray tube is capable of resolving. There is another consideration which dictates the use of a 35-mm film size. If one attempts to obtain 1:1 pictures, it is found that in order to cover the 4 $\times$ 5 film adequately, for example, it is necessary to use a lens of about 6-inch focal length. In order to obtain focus, it is therefore necessary for the image to be approximately two focal lengths from the lens, and the lens to be two focal lengths from the cathode-ray tube. This results in an over-all distance of 24 inches of the camera film from the cathode-ray-tube face. This long distance results in an awkward assembly of equipment. For these reasons, most oscillographic cameras have chosen the 35-mm film.

Where continuous-motion recordings are to be made at high speed and the film is to be brought up to speed quickly, the inertia represented by the mass of even 100 feet of film becomes considerable and

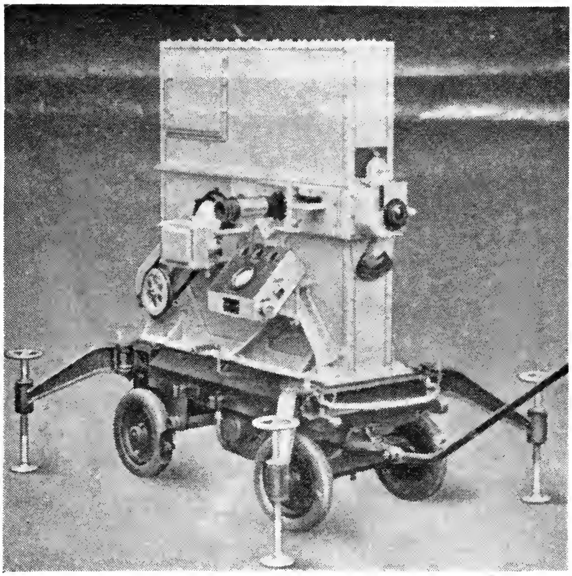


Fig. 25—Avimo drum camera.

the rapid acceleration or deceleration required may result in breakage of the film. For this reason, in the Fastax camera, it is more desirable to use 16-mm film because of its lower inertia. In some cases it is only possible to attain required speeds without loss of film by use of a drum camera in which a continuous loop of film is brought up to speed and the transient then displayed on the face of the cathode-ray tube. A somewhat similar condition can be obtained in the use of a continuous-motion camera by loading a continuous loop and running the camera at its highest speed. This is of some advantage also in the measurement of random phenomena where one desires to conserve film. Figs. 23 and 24 show some typical cameras designed for oscillography, the Type 271-A camera, a 35-mm camera which fits directly on most standard oscillographs; and the Type 314 camera designed for a wide range of relatively slow speeds. Fig. 25 shows an Avimo drum camera which has a 3-foot drum resulting in a complete loop of about 10 feet, and is capable of being used at speeds up to 250 feet per second.

When recording low-speed phenomena, the resolution obtained from the usual photographic objectives is more than adequate to avoid degrading the cathode-ray-tube image. In attempting to record the highest writing speeds, one must try the highest aperture lenses obtainable. For oscillographic use the highest rated aperture lenses (either *f* or *T*) are not necessarily the fastest. The lens resolution is at least as important in obtaining the highest writing rates. The lens preferably should be designed for the object:image ratio used. Not enough attention has been given to the design of high-aperture objectives, particularly for oscillography. Our experience to date has indicated that the Wray *f*/1 cathode-ray-tube copying lens designed for a 4:1 reduction is the most suitable.

PROCESSING

Most electronic laboratories now have some darkroom photographic facilities. For the purposes of developing oscillograms, however, one can usually dispense with a darkroom by the use of the proper daylight processing equipment. The processing procedure used should be that which gives the maximum writing rate. This will not usually be the film manufacturer's recommended technique, but rather one which gives the maximum threshold density above fog, regardless of actual fog level. We have found so far, that Linagraph Pan film with prolonged development in D-19, gives the best results. Because of the extremely short exposure times obtained in oscillography causing reciprocity-law failure, there is no evident relation between the Weston or Scheiner film speeds and the speeds for oscillography. With recent improvements in Kerr cells and flash-lamps, some basic emulsion research is indicated in order to determine those factors which contribute high sensitivity to short exposures.

After the film is developed there are a number of chemical processes which may be used for after-treatment in order to obtain improved results. The process of intensification is one which in ordinary photography results in an improvement in the printing density of the negative and therefore in the improvement of the print or lantern slide. Where high-speed recordings are to be obtained, and where the density is much less than 0.1, no intensifiers which we have as yet tried have produced any worth-while improvement in the printing density of the deposit although they do cause considerable improvement if sufficient density is already available to enable an evaluation of the recording.[7]

Intensification as such, will not cause any improvement in the maximum writing speed of cathode-ray-oscillograph recordings. In

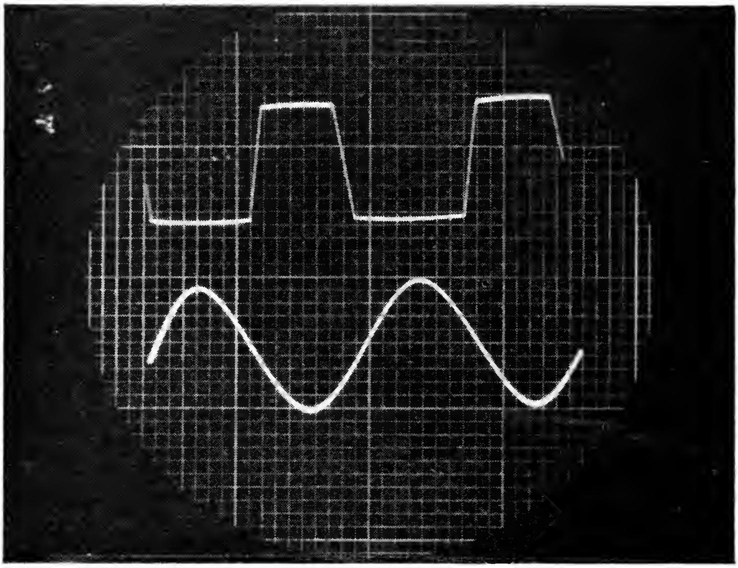


Fig. 26—Calibration using an illuminated calibrated scale.

some cases, the process of chemical reduction may be used to advantage. In this process, silver solvents of various types are used to reduce the density of the deposit. Certain reducers known as subproportional reducers affect some densities more rapidly than they do others. This type of reduction is of advantage where low and high writing rates exist together since one may reduce the high densities without affecting the lows proportionately in order to obtain suitable recordings showing both the slow and rapid portions of a pattern properly. Frequently, however, one obtains densities which are perfectly readable but which are not capable of satisfactory engraving. The only solution for these is to obtain a greater density of deposit either by the use of higher voltages or higher speed lenses. In general, the improvement can be obtained more readily from the use of a higher speed lens than by increasing the accelerating voltage or drive of the oscillograph.

AMPLITUDE CALIBRATION

By the use of suitable calibration methods, an improvement in the appearance and the accuracy of oscillograms may be readily effected. This calibration may merely take the form of a graduated scale, as

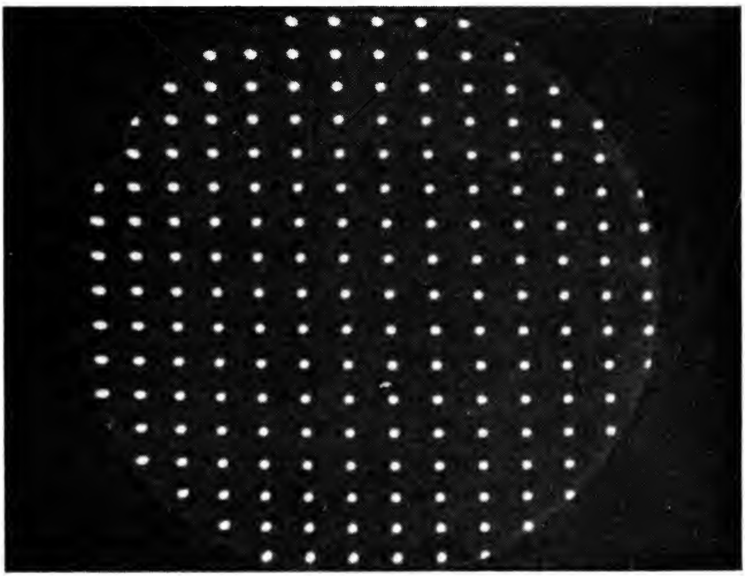
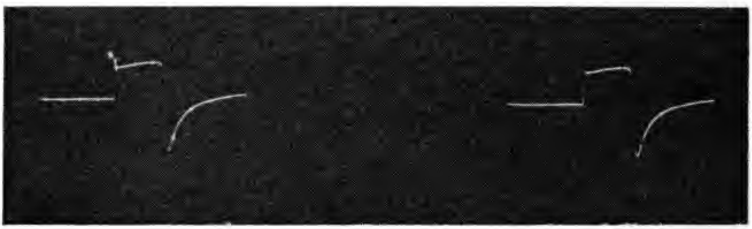


Fig. 27—Matrix used for calibration.

seen in Fig. 26, which makes the assumption that the deflection across the face of the cathode-ray tube is linear. The use of such a scale greatly enhances the appearance of such an oscillogram, and gives one the illusion that he is making an accurate recording.

In order to obtain very accurate measurements from the face of the cathode-ray tube, the trace preferably should be self-calibrated. No convenient circuits have yet been described for this purpose. A suitable calibration which takes into account the nonlinearity in the cathode-ray tube and amplifiers is the use of a double-exposure technique in which a matrix of calibrating spots is used to display the position of the cathode-ray-tube spot for any vertical or horizontal input voltage. The appearance of such a matrix is shown in Fig. 27. After this calibration, the desired oscillogram is produced on the screen and double-exposed onto the same film. This method has the advantage that if it is done immediately prior to recording, it produces a more or less uniform distribution of electronic charge over the screen. The oscillograph trace is then not disturbed by stray screen charges which may be quite troublesome. This is particularly true in the case of equipment which is warmed up with an uncharged screen and a single transient flashed thereon. A more expensive solution to the screen charge problem can be obtained by the use of the metalized screen cathode-ray tubes mentioned previously which hold the potential of the screen uniform and constant. In this case, the method of calibration produces good results.



(a) (b)

Fig. 28—Same oscillogram with bright and dark markers. (Note how overshoot is missing because of dark markers in (b).)

IDENTIFICATION

Where trace markers are used, bright markers have some advantages. (See Fig. 28.) After making more than three or four oscillograms, the problem of proper identification of the various wave shapes on a single roll of film becomes important. A useful accessory for this purpose is the illuminated data card which may be used to double-expose data or calibrations on the recording, as seen in Fig. 29.

EQUIPMENT CHOICE

In starting out to photograph a phenomenon, one should make certain preliminary considerations as to the best equipment for the purpose. In order to obtain adequate recordings, the oscillograph should have a screen capable of producing sufficient density at the voltages and frequencies used; should be capable of displaying the phenomenon without blurring for the continuous-motion recording; and, should have sweeps fast enough so that the resolution capabilities of the cathode-ray-tube screen, lens, and photographic film are not exceeded; the accelerating voltage and drive should be adequate. The amplifier should be so stable, that over the data-taking period no drift should be encountered. The whole assembly should be rigid so that no spurious movements of the recording trace occur due

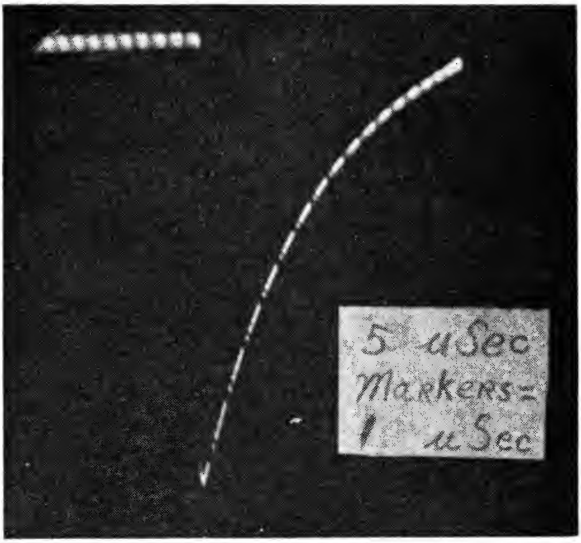


Fig. 29—Double exposure with handwritten data.

to microphonics or movement of the camera parts because of motor operation, stray magnetic fields, or shutter operation.

The oscillograph specifications frequently offer but few clues to the photographic capabilities of an assembly of equipment. The most suitable specifications is the maximum writing rate obtainable with particular assemblies or oscillograph and cathode-ray equipment. These specifications must be carefully interpreted to obtain meaningful recordings.[8]

INTERPRETATION OF RECORDINGS

Now that we have solved all our photographic problems and have suitable bright, clear, and understandable recordings, we are faced with the problem of their proper interpretation. One of the best devices that we have found for evaluating oscillograms, either single-frame or continuous-motion, is a standard microfilm reader which gives an image about fifteen times normal size or three times that on a standard 5-inch oscillograph. The use of such a microfilm reader or of a projector, usually enables the appreciation of details which would otherwise go unnoticed.

In this paper, we have attempted to clarify some of the factors which the oscillographer should consider in choosing, specifying, and using photographic equipment. It is believed that proper use of this information correlated with that in standard photographic texts, and in the catalogs of some oscillograph manufacturers, will result in considerable economy in photographic work and in oscillograms which are far superior to those which are sometimes found in the present literature.

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Measuring Shock with High-Speed Motion Pictures*

By J. T. MULLER

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Summary—The use of high-speed motion pictures has made it possible to analyze extremely rapid motions associated with explosion phenomena and high-impact shock. In order to do this efficiently, certain techniques have been developed in the preparation of the test specimen and the calibration and measurement of the results on the film.

The use of motion pictures as a tool for the measuring of physical quantities has been a valuable aid in the analysis of vast or explosive motions. It has been particularly helpful in the laboratory study of mechanical shock which is a simulation of an underwater explosion near the hull of a ship.

High-impact shock is the name given to the action which hammer blows produce in a suitable machine to test the mechanical sturdiness of certain types of apparatus. These hammers are of considerable size. The one used in the lightweight machine is 400 pounds with a 5-foot arm and in the medium-weight machine 3000 pounds on a 5-foot arm. A more precise definition is that shock is the physical manifestation of the transfer of mechanical energy at extremely short intervals of time. The order of magnitude of the time interval is milliseconds and quite frequently microseconds. A transient motion is always associated with such a transfer of energy, and since the displacement is a parameter easy to visualize and to work with, it has been chosen as the final indication to be recorded.

Although the analysis of shock phenomena is usually confined to one direction only which is a perfectly plausible method to obtain an insight into the behavior of the apparatus under test, it is never experienced when a shock is produced on our high-impact machines. On the contrary the equipment may bounce around in all directions

* Presented October 12, 1949, at the SMPE Convention in Hollywood.

and go through many modes of motions. Granted that there is a major direction, it is nevertheless important to know about the minor ones.

An easy way to perceive these complex motions is to observe them visually and in order to accomplish this we have to resort to motion pictures which can reproduce the action in slow motion. For the study of sound vibrations, the Bell Telephone Laboratories developed a high-speed motion picture camera known as the Fastax which

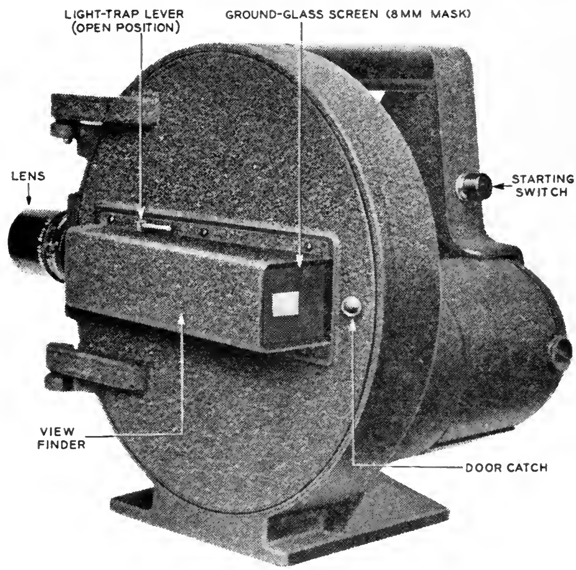

Fig. 1—The Fastax camera.

seemed to be ideally fitted to do the job of recording shock displacements. Fig. 1 shows a view of this camera.

The Eastman Kodak Company has also developed a high-speed motion picture camera equally well suited for the purpose and is shown in Fig. 2. In Fig. 3 we have a simple schematic showing the use of a prism to obtain an image on the film; in other words, both cameras belong to the rotating-prism type.

Either 8- or 16-mm film can be used. The average maximum exposure is 4000 frames per second for 16-mm and 8000 frames per second for 8 mm. For shock work, we rarely, if ever, use the 8-mm. We have found that 16-mm at 4000 frames is quite satisfactory.

The speed of film going through the camera is at the rate of 100 feet (one roll of film) per second and is driven by two motors (one pulling, the other "pushing").

Fig. 2—The Eastman Kodak camera.

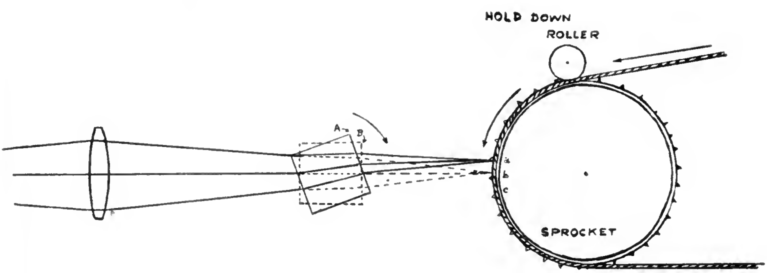

Fig. 3—Schematic of operating mechanism.

The speed of the film varies somewhat, starting at 2500 and ending at 5000 frames per second approximately (Fig. 4). To time the film there is a small argon-filled lamp, producing alternate white streaks on the margin near the sprocket holes, the length of this white strip

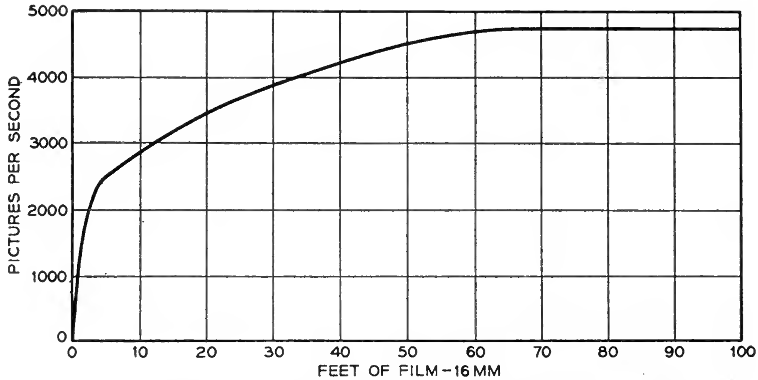

Fig. 4—Relation between frames per second and exposed film.

being accurately related to one cycle of the standard 60-cycle current. To give you an idea of the exposure time involved, it may be stated that of the $^1/_4$ millisecond or 250 microseconds between frames, approximately 80 microseconds are used for exposure, the rest for film transit.

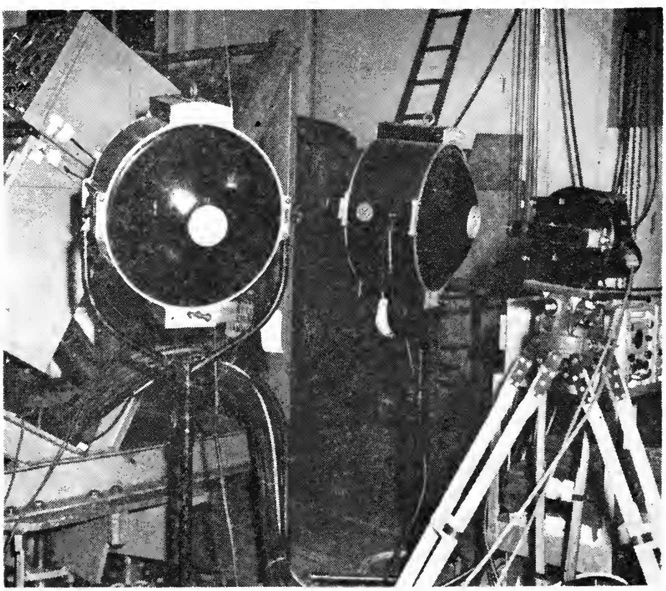

Fig. 5—General camera setup.

One of the secrets of good photography is proper illumination of the object and high-speed motion pictures are no exception. It stands to reason that since the exposure time is so extremely short the intensity of the light source must be great. Special projection lamps are used capable of delivering approximately from 10,000 to 100,000 foot-candles. About three of these spotlights are used and a general camera set up with lights in place is shown in Fig. 5.

We must provide proper reference marks if a film is to be of use for measuring displacements. We have found that fine twine of a white

Fig. 6—Timing streak on film.

material strung across the particular spot to be photographed in a vertical and horizontal manner is quite satisfactory. Special care must be exercised to secure the lines to fastening points which are not affected by the shock. Next a piece of tape of known width, usually 1 inch, is fastened to the object to establish a dimensional scale factor. The salient parts to be recorded are outlined, if possible, and then the cameraman proceeds to set up his camera to find the proper distance for the right field and finally obtains a sharp focus of the picture. Next, the timing signals are worked out. There is always a delay between the release of the hammer and the subsequent shock. If it is possible to obtain an electrical signal at the moment of release then this signal is fed into a time-delay box, thus closing the switch to the driving motors of the camera after a predetermined time interval which can be controlled within wide limits. This means that the cameraman does not have to be near his camera at the time the shock is administered which is important from the point of view of safety to operating personnel. If no release signal is available then the cameraman starts the time-delay mechanism manually.

After the shock has been given, the film is removed from the camera and properly marked for future identification.

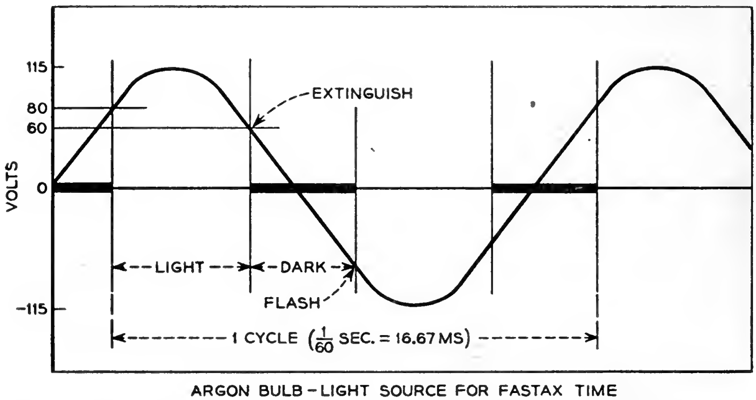

Fig. 7—Relationship between 60-cycle alternating voltage and flashing of timing bulb.

So much for the picture taking. After the films have been developed, they are first examined for any unusual occurrences or to demonstrate some mysterious happenings which could not satisfactorily be explained at the time of the shock. Next comes the procuring of specific data, which in our case means the measuring of the displacement of a particular part with respect to the reference lines. To examine the film frame by frame, we use a commercially available projector called a Recordak, which will enlarge the picture approximately ten times. We first mark off that portion of the film which is to be measured and establish the time interval between two successive frames by means of the marking on the side of the film (Fig. 6). We simply establish the length of one cycle and count the number of frames (Fig. 7). The action we are interested in is usually not too long so that this frame-interval determination does not have to be repeated. The frames are also numbered from a chosen starting point, marking every tenth frame. Next the tape is measured to establish the dimensional scale factor which will enable us to find the actual displacement in inches. Then a tabulation is made, measuring the displacement of one or more parts, which is a somewhat tiresome

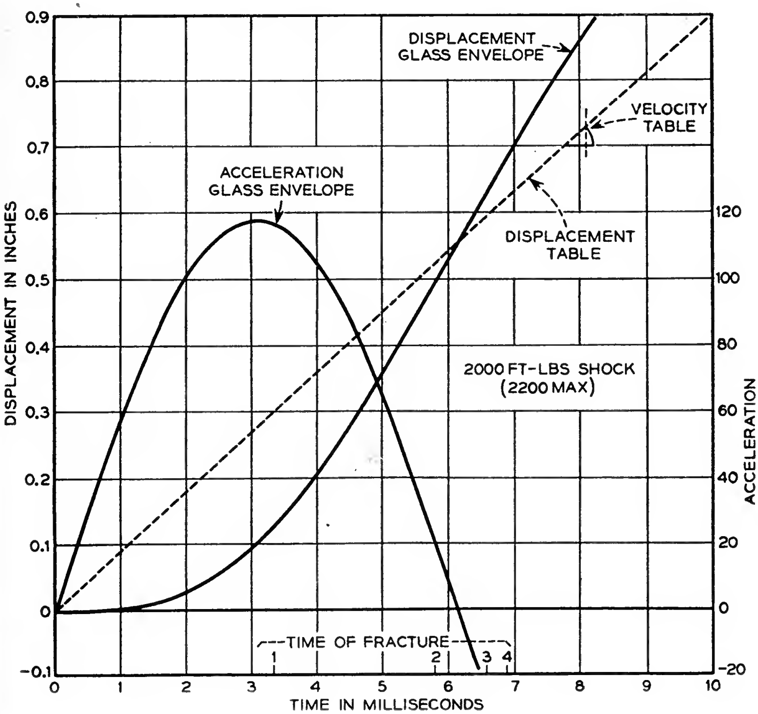

Fig. 8—Typical data obtained from film.

and monotonous job. The tabulated data are then plotted and the final results are time-displacement curves, which are then processed further to obtain supplementary information (Fig. 8).

Some of the advantages of this method of recording are:

1. The high-speed motion picture provides a complete over-all view of a group of complex motions occurring at very small time intervals.

2. It lends itself to a detailed analysis of the motions of a particular point or part. We can also measure relative displacements of one or more points.

3. It is not necessary to determine beforehand the motion of what specific part or location shall be investigated, but rather an opportunity is provided, within limits, to examine the various displacements and choose the best. This is a most important consideration for it is not always obvious through what kind of motion a certain part will go.

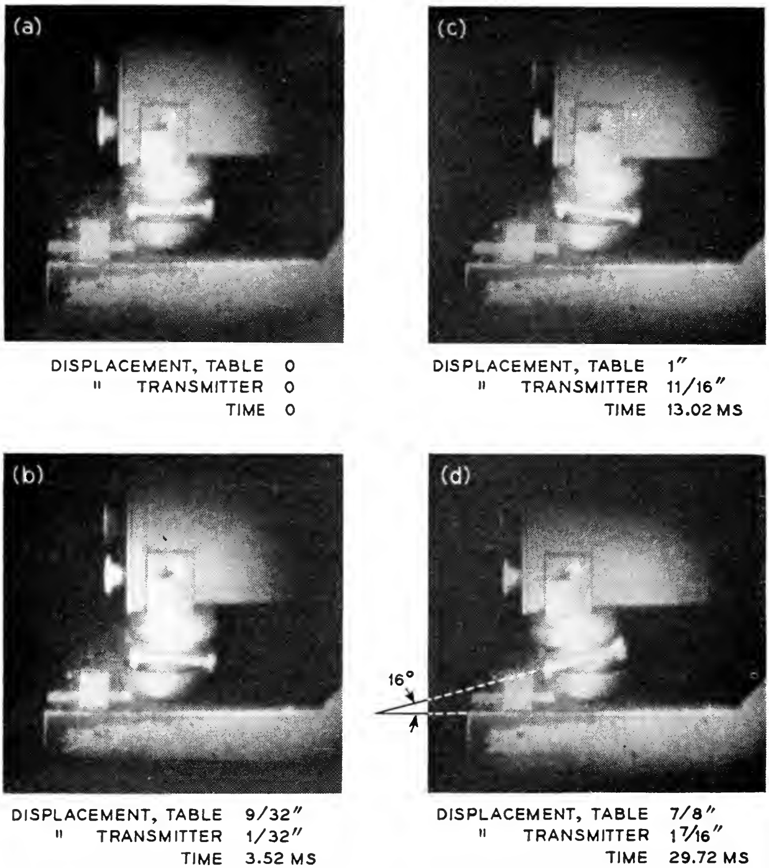

Fig. 9—Four frames from a film showing the complex motion of a shock mount.

4. Another important point and one which is not often realized is the superposition of displacements. By this, we mean that a part may have a displacement relative to the fundamental displacement because this part is not rigidly connected to the main body. Now most of the radar equipments are highly complex mechanisms and a cabinet is not a rigid body. It is, therefore, extremely difficult to determine the over-all fundamental displacement of such a cabinet by merely taking the displacement measurement of one location. It is this sort of thing which will make "grass" grow on an acceleration record and ripples on a displacement record. In quite a few instances the high-speed motion picture has revealed these complex displacements.

5. The high-speed motion picture permits a study of relative displacement of a rotational order. This is shown in Fig. 9. Here are four views representing a shock mount in action at different time intervals. Note the rotational motion of the center part of the mount.

Among the disadvantages must be counted:

1. The considerable amount of time and effort which must be spent in order to obtain numerical data. Although it takes only 1 second or less to produce a film, it may take anywhere from 10 to 50 hours before the information is processed. And, as already has been mentioned, it is not only a tiresome task to read the film, but it is also very unpopular. If the data, which have been obtained with the high-speed motion picture, are of sufficient value and interest to warrant the design of automatic reading equipment, then the technique of preparing a specimen for high-speed photography can be refined so as to correlate it better with the method of automatic picking off of the required data.

2. Another disadvantage is the time delay caused by developing of the film, which is perhaps inherent to photographic recording. This is particularly true when for one reason or another the camera or film does not function properly. Since a camera setup is a fairly elaborate procedure, it is almost imperative that the photographic equipment operate properly. A failure means considerable waste of time and effort.

High-Speed Motion Pictures in Full Color

By FRANKLIN M. TYLEE

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Summary—**This paper relates to techniques which have been developed at the Bell Telephone Laboratories for taking high-speed motion pictures in full color. Different types of incandescent light sources necessary to provide the extremely high level of illumination are described and illustrated.**

During the past 15 years great advances have been made in the art of black-and-white high-speed motion picture photography. In that period, techniques have been developed for taking such pictures at speeds up to 15,000 pictures per second on a standard 100-foot roll of film. In many cases pictures taken at this speed have been lighted only by incandescent light with the cameras stopped down to *f*/8. With such accomplishments it seemed reasonable that high-speed color photography might also be possible. Many kinds of apparatus contain a variety of materials of different color; black-and-white photography leaves much to be desired in distinguishing among these colors. Color photography naturally is a great improvement in such cases.

One of the first efforts at the Laboratories to take high-speed motion pictures in color was in 1940 when color pictures of the vocal cords were attempted. This was an exceedingly difficult subject and in the first runs a speed of only 1000 pictures a second was used. A 2000-watt lamp rated at 70 volts and operated at 120 volts, was used as a light source and the image of the filament was projected onto the vocal cords through an aspheric condenser and a series of mirrors. An 8-inch water cell was employed to absorb heat from the filament so as not to burn the cords. Fig. 1 shows such a setup. We found that the usual speed relationship between the standard Super XX reversible (black-and-white) emulsion and the Kodachrome Type A (color) emulsion used in these tests did not hold at speeds of 1000 pictures per second. Instead there was a noticeable loss of emulsion speed with the Kodachrome. Except for this the results were quite satisfactory, but because of the pressure of other work, no further studies were made in Kodachrome until the conclusion of World War II.

Exploratory work was resumed in 1945 when some trials were run on Ansco Color and Kodachrome Type A. When these films were processed and projected an almost unnoticeable difference was

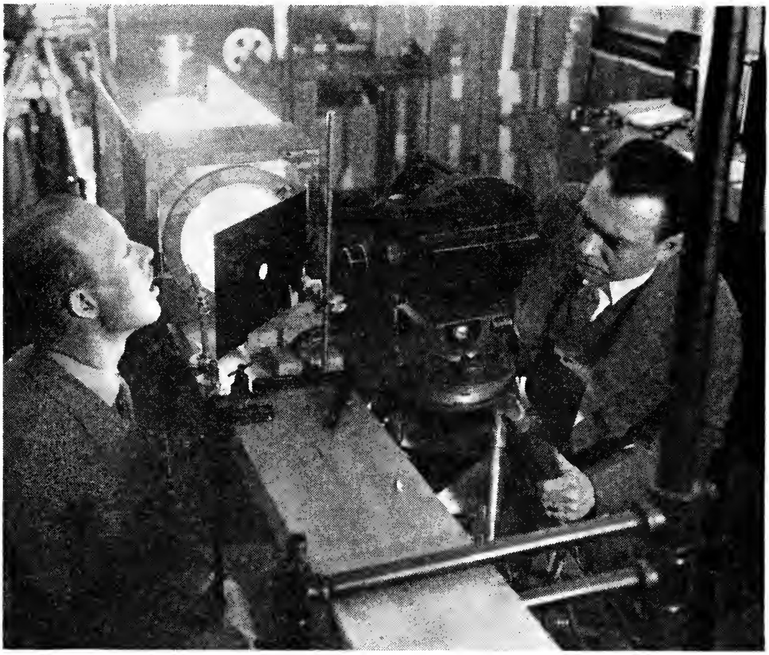

Fig. 1—Setup for photographing the vocal cords showing placement of **Fastax** camera, lamp, water cell, condenser, mirrors, and subject.

detected in the brightness at the beginning of the film and its end. This results from a difference in the exposure caused by the increase in velocity as the film progresses through the camera. There was no particular difference in the speed of the Kodachrome and Ansco Color in these tests and only a very small difference in color rendition. This difference was no greater than would occur from roll to roll of any given brand of film.

The light source used in these tests consisted of four No. 201 Rosslites rated at 750 watts, at 100 volts each and operated at 120 volts. A spherical mirror was used back of each lamp and the assembly was so arranged that the images of the filaments were focused on the subject. (A 100-cubic-inch water cell was used to protect the subject from heat.) Four such lights were used to take pictures of many subjects at 4000 and 5000 pictures per second with a Western Electric 16-mm Fastax camera, at an aperture of $f/3.5$. For example, the countershaft cam and follower of a gasoline motor were

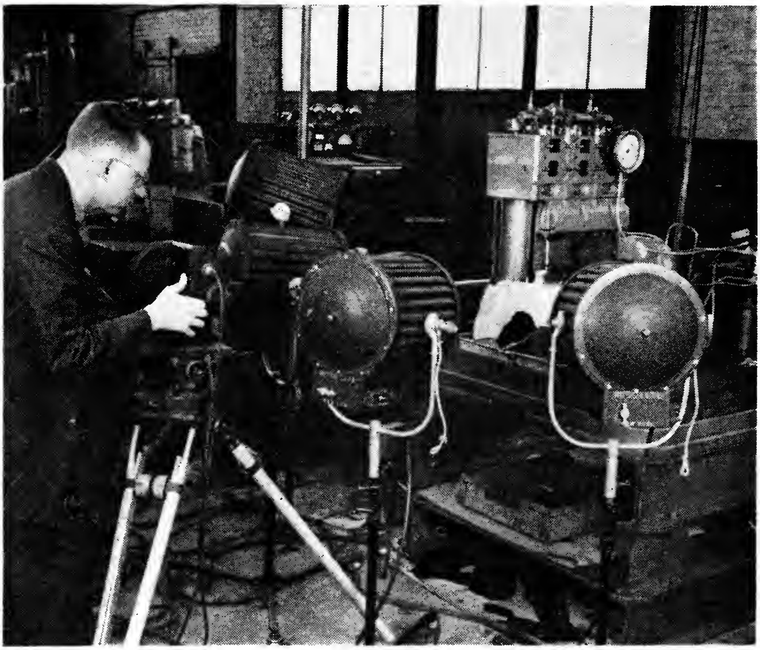

Fig. 2—Four No. 201 Rosslites being used to photograph the countershaft cam and follower of a gasoline motor.

photographed in this way after having been painted in appropriate colors to make various parts stand out (Fig. 2). A series of high-speed motion pictures made at this time with such a setup is still used for demonstration purposes.

For larger field subjects, roughly to 12 inches square, No. 241 Rosslite sunspots are usually employed. These lamps use a 95-volt, 2000-watt lamp and are operated at 120 volts. The optical design is similar to the smaller No. 201 Rosslites except that they are not equipped with a water cell. In Fig. 3 these lights were used to photograph a circuit breaker, a subject inherently well suited to color photography. The telephone alarm fuse illustrated in Fig. 4, is also such a subject.

A very extensive series of Kodachromes has been made of the burning of photoflash lamps. We have made long shots which show failure of the lamps and closeups which show that the supports holding

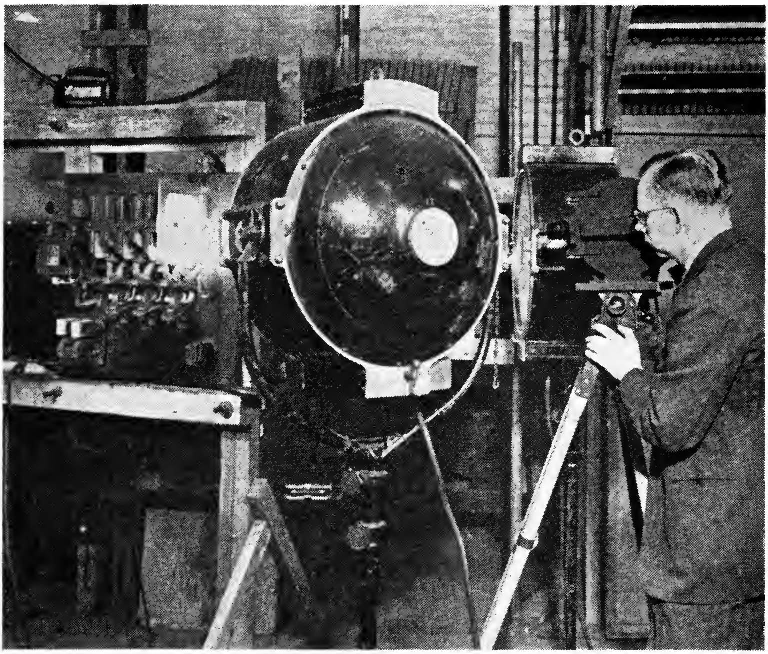

Fig. 3—Photographing a circuit breaker, using the No. 241 Rosslite sunspots to cover the large field size.

the fuse of the lamp are not stable. This instability is a major factor in blowing house fuses and in short-circuiting batteries when such lamps are used.

The flow of metal is very easily detected in color photography. Black and white does not have the "feeling" of melting metal present when the same action is observed in color. Extensive studies have been made by the United States Navy in making pictures of arc welding with color photography.

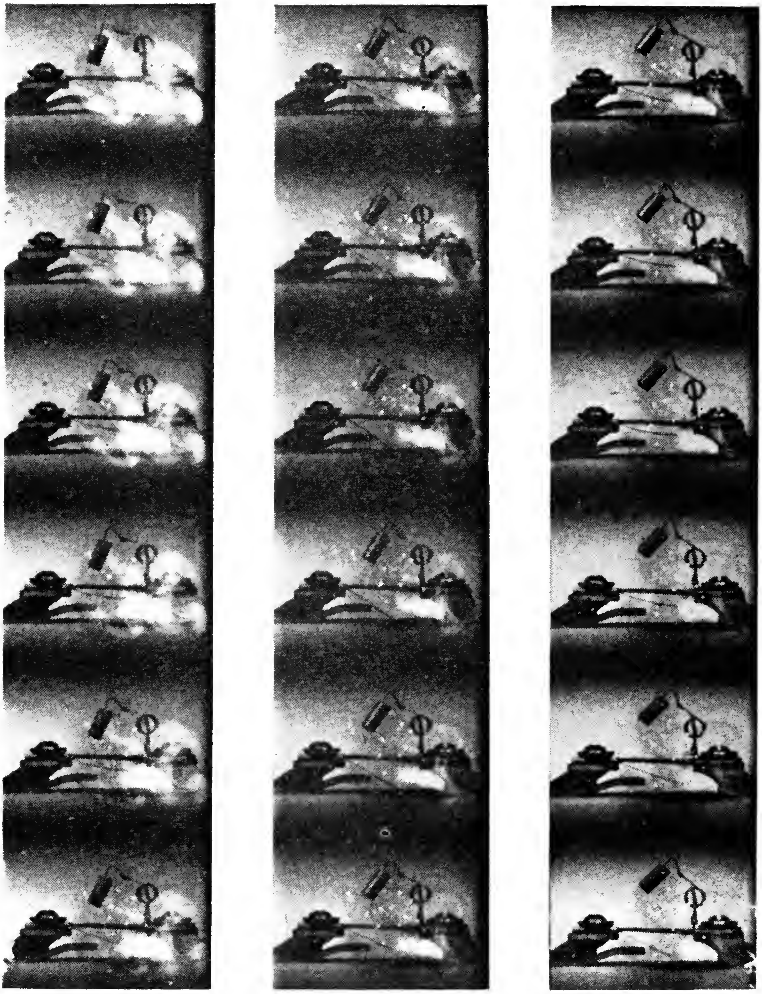

Fig. 4—Enlargements of successive frames from a 16-mm film taken at 4000 pictures per second, showing the action of a telephone alarm fuse.

With the advent of the New General Electric 750R high-speed photographic lamp, color pictures are much easier to make, for the lighting equipment is small and compact.

In an analysis of the relationship of exposure, the Eastman Kodak Company has quoted that the reciprocity loss when making pictures in the range of from 1000 to 5000 pictures per second on Kodachrome is $1^1/_2$ stops, while on Super XX film it is only $^1/_2$ stop. Therefore, instead of having a speed relationship of one to eight, the speed relationship becomes one to sixteen. The Kodachrome requires approximately 16 times the exposure that black and white does for an equal degree of sensitization.

Successful color pictures have been made by the Laboratories out of doors in New Mexico at 1000 pictures per second. In these cases the light values were approximately 10,000 foot-candles as measured on the new 757 Weston exposure meter. These pictures are not quite as brilliant as can be obtained with an intermittent camera at $f/5.6$ and $^1/_{50}$ second but from the engineer's point of view they are entirely satisfactory.

For incandescent lighting, it has been found at the Laboratories that color pictures can be made at 5000 frames per second with 400,000 foot-candles' illumination and a lens aperture of $f/4$ for an average subject.

Color photography tells the engineer far more in his analysis of motion than a corresponding picture in black and white. This is particularly important when some portion of the picture may be self-luminous such as spark and arc phenomena and the burning of fuels. However, color photography aids the analyst to differentiate various portions of his picture and is, therefore, not necessarily confined to pictures which may have a self-luminous point in the picture. The Armed Services are finding great use for color film in their high-speed motion picture photography and other organizations are beginning to experiment with it.

Water-Cooled High-Pressure Mercury-Discharge Lamp for Direct-Current Operation*

By W. ELENBAAS and E. W. VAN HEUVEN

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Summary—A water-cooled high-pressure mercury-vapor lamp operated on direct current which has been used for motion picture projection is described. When mounted in a suitable reflector, it is a powerful light source for high-speed photographic applications. The lamp has a bore of somewhat less than 2 mm and an arc length of $12^1/_2$ mm. It can be operated continuously at 1000 watts and has a brightness of about 320,000 candles per square inch along the axis of the arc. With the reflector described, an area 5 inches in diameter can be illuminated to 50,000 foot-candles with one lamp unit. With a lamp of double length consuming 2 kilowatts, the illumination level may be increased considerably.

The Lamp

High-speed photography requires very high illumination levels. It is also necessary that the illumination be constant during the time the exposures are made. Therefore, a light source operating on 50 or 60 cycles alternating current is not generally useful if the source is of the gaseous-vapor type. High illumination levels may be reached if a light source of high intensity, for example, a water-cooled high-pressure mercury-vapor lamp with a suitable reflector is used. The Philips Company has been manufacturing for a number of years a lamp of this type operating on direct current for use in motion picture projection. It has a brightness of 320,000 candles per square inch along its length. The lamp is illustrated in Fig. 1. It consists of a quartz capillary of 2 mm inside diameter and 4 mm outside diameter with an arc length of $12^1/_2$ mm. It is operated on 1000 volts direct current at 2 amperes with an arc voltage of 500 volts. The arc load thus amounts to 1 kilowatt. The light output of the lamp is 60,000 lumens. Fig. 2 shows a disassembled view of the unit.

The Reflector

In order to get an even distribution of light over the object area, a reflector of special design was used. The idea underlying this design was as follows:

* Presented April 6, 1949, at the SMPE Convention in New York.

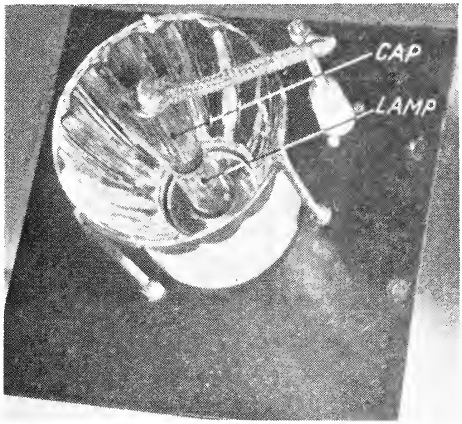

Fig. 1

Consider an ordinary paraboloid reflector with a line-shaped discharge-tube light source placed on the axis of the reflector near the focus. If a segment is cut out of the reflector by two planes through the axis forming a small angle between them, a narrow band of illumination will be produced. The point in the light source which is at the focus of the parabolic segment will give a line of illumination, the length of which equals the diameter of the reflector. Light coming from points in the light source nearer to the reflector will also produce an illuminated area in the working plane which is somewhat wider

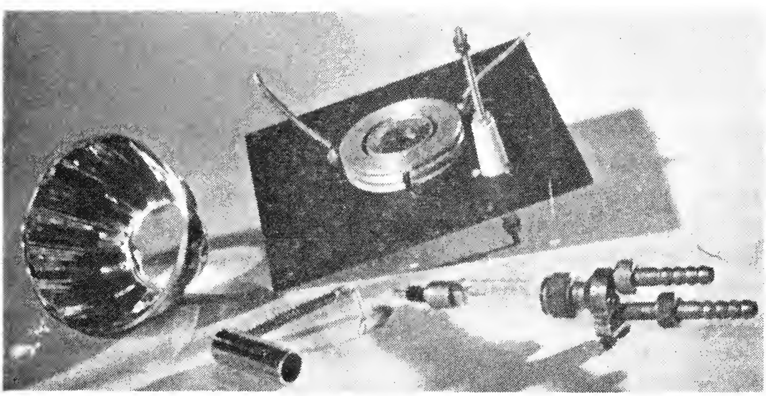

Fig. 2

than that produced by the light originating from the focus. On the other hand, the light from the part of the discharge tube farther from the mirror will cross the axis and contribute to the illumination of the working plane. It is possible to design the reflector (focal distance and width depending on the length of the discharge) so as to obtain a substantially even illumination of the band produced by a pair of opposite segments of the reflector.

Now, if the total illumination produced by the reflection of the light on the whole circumference of the reflector is considered, all of the radiated strips from each pair of segments have to be added. This

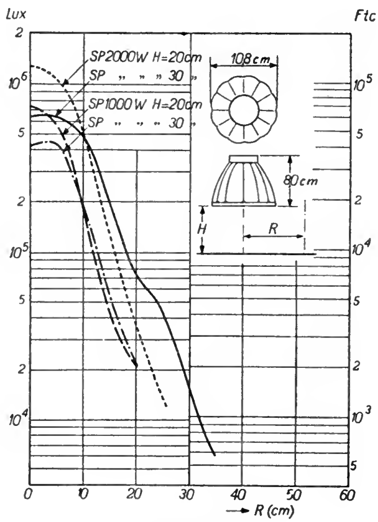

Fig. 3

means that a sharp spot of high illumination will be obtained on the optical axis as here all linear illumination sections coincide. The illumination curve as a function of a radius from the center will thus show a steep maximum at the center.

In order to flatten the top of this curve, the paraboloid has been modified into the umbrella shape indicated schematically in Fig. 3. Here the reflector is divided into 12 identical segments. The radius of curvature of these segments perpendicular to the axis of the reflector is smaller than the radius of the reflector, thus the width of the area illuminated by each pair of segments, will be increased so as to produce an approximately square evenly illuminated area. This value of curvature at each point has been determined experimentally.

The total illumination produced by the whole reflector will be the sum of that produced by the six pairs of reflector segments and thus be the sum of the six squares shifted over angles of 30 degrees with respect to each other. This will give a constant illumination within the inscribed circle of all squares.

In Fig. 3 the illumination of a plane at distances of 20 and 30 centimeters to the reflector is plotted logarithmically. At a distance of 20 centimeters an area 12 centimeters in diameter is illuminated with more than 50,000 foot-candles. The dimensions of the reflector are large enough to permit the use of a longer light source; actually this reflector is the outer bulb of a high-pressure mercury-vapor lamp of the air-cooled type which has an arc length of 25 mm. Therefore, a water-cooled lamp of this same length can be used. Operated at the same current and mercury pressure, the arc load of such a lamp is 2 kilowatts. The results with this lamp are plotted in Fig. 3 as well. An illumination of more than 100,000 foot-candles is now reached within a circle 12 centimeters in diameter at a distance of 20 centimeters from the reflector.

These lamps may be operated continuously for longer periods. Their life depends on the burning period and the accumulated burning time. For 20-minute operating intervals the life is from 50 to 100 hours.

New View Finder for the Fastax Camera*

By ALFRED L. LIDFELDT

Wollensak Optical Company, Rochester 5, New York

Summary—**The bright-field view finder recently developed for the Fastax 16-mm high-speed motion picture camera is described. Its advantages over the currently used ground-glass view finder are discussed. Two new special purpose lenses have also been designed for the Fastax.**

The increasing variety of applications of the Fastax 16-mm high-speed motion picture camera has shown the need for an improved system of view finding and focusing. The ground-glass type of view finder currently used with this camera has certain inherent disadvantages resulting from its low power of magnification and low image brightness. Ambient-light conditions often necessitate shielding the eye and the ground glass when studying the image and focusing. Some users prefer not to use the ground glass while focusing but use a tape and set the lens footage scale to the measured distance when the subject is near the camera. Because of the low finder magnification an auxiliary loupe is often used. Furthermore, the texture of the ground glass sometimes may be bothersome. There are some delicate subjects which are adversely affected by the heat of the lamps sometimes necessary for illumination while focusing and composing.

To overcome these difficulties a bright-field focusing and viewing system has been designed for this camera. It is mounted on the camera door in place of the ground-glass view finder. The camera with the new view finder is shown in Fig. 1.

The view finder mounted on the camera is shown in Fig. 2 with its housing removed. It is essentially a 10-power microscope with a reticle and focusing eyepiece. The image formed by the camera lens upon the film plane is viewed by this microscope through the finder prism system. A bright field of view is seen with a cross line and field frame superimposed. A focusing eyepiece is provided for adjustment to the user's eye. The general optical layout is shown in Fig. 3.

* Presented October 12, 1949, at the SMPE Convention in Hollywood.

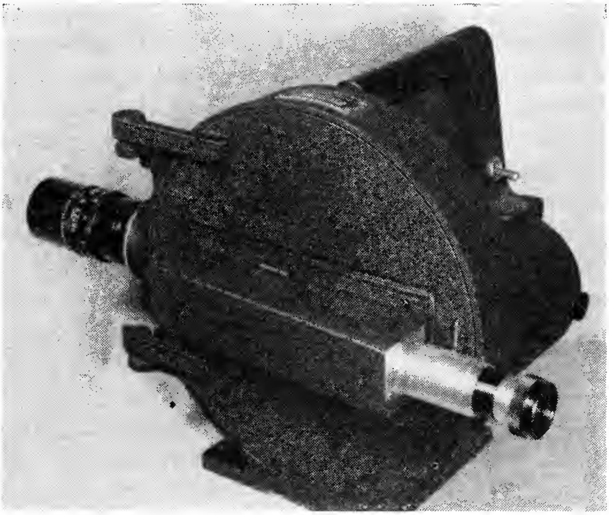

Fig. 1—Fastax with new view finder.

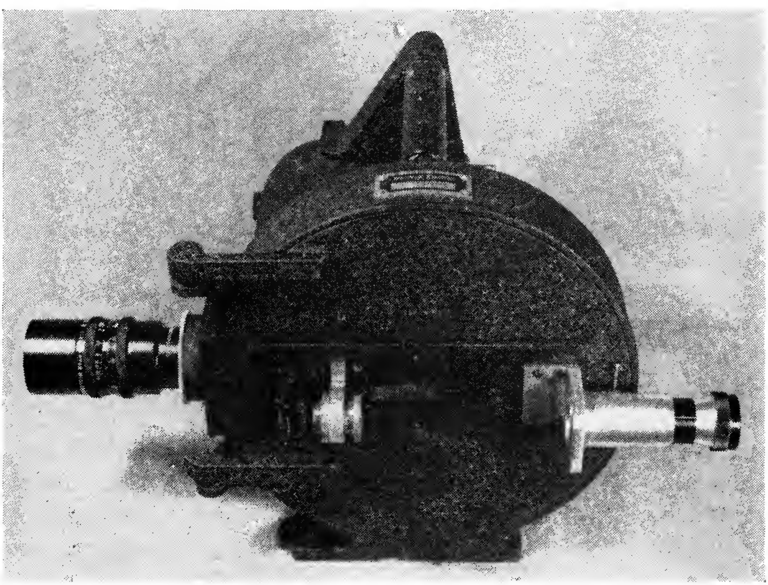

Fig. 2—View finder with housing removed.

An important feature of the new finder is that it can be mounted in place of the ground-glass finder without disturbing the camera proper since it is located on the camera door. The conversion is accomplished by eliminating the objective located between the two viewer prisms and replacing it with a $1^3/_4$-inch objective located behind the prism system and on the camera door. The ground glass is replaced by a fixed plano-convex collective lens with a frame and cross line etched on the plano surface. This collective or field lens gives a full and more evenly illuminated field of view. The image and reticle are viewed by a 5-power achromat which serves as the eyepiece which is mounted in a focusing arrangement similar to that used in prism binoculars. In

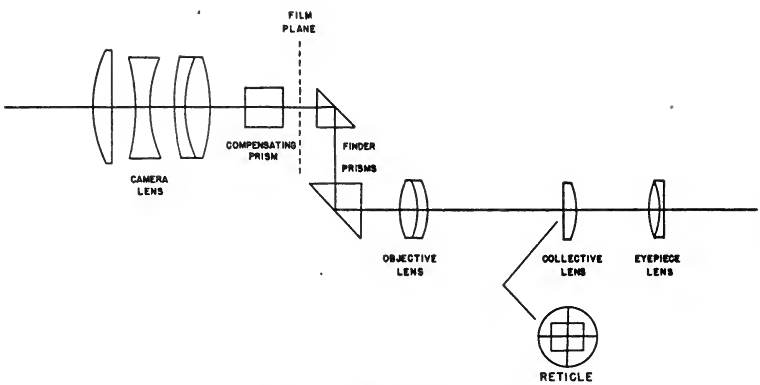

Fig. 3—Fastax view finder.

the initial adjustment and alignment of the view finder, its objective is accurately focused on the camera-film plane so that there is no parallax between the image in this plane and the image formed by this objective upon the collective-lens reticle. The objective is then locked in place. To insure maximum accuracy, all lenses to be used with a particular camera are checked against this setting. This completes the adjustment of the view finder.

In using the view finder, the photographer focuses the eyepiece on the reticle, puts the desired camera lens on the camera, and then trains the camera on the subject. He then focuses the taking lens by turning the focusing ring until there is no parallax between the image and the cross line on the reticle.

The view-finder image is usually bright enough to permit accurate focusing and study of subject detail without the use of auxiliary lighting during this operation. This is an important advantage where special lighting is to be used during the actual filming and where such light (perhaps because of its intensity, duration, or other special characteristics) may not be suitable for this purpose. Furthermore, heat from lights (even at reduced voltage) may affect the operation of certain subjects containing delicate materials or mechanisms. Eliminating auxiliary lighting during focusing and composing has proved to be a definite help in such cases.

The 10-power view finder permits study of detail in distant objects since it acts as a telescope when used with the taking lens. For example, with a 10-inch telephoto lens the combined system acts as a 10-power telescope; with a 4-inch lens, it is a 4-power telescope.

The rectangular frame on the reticle represents the field of view of the camera. Because of a slight cutoff by the compensating prism, the entire vertical field is not seen in the finder except by slight rotation of this prism either side of its central orientation.

In addition to the seven lenses ranging from the 35-mm $f/2$ to the 15-inch $f/5.6$ telephoto, a new 1-inch $f/2.5$ lens has been developed for special work where a wider field (horizontal field equals 22 degrees) is needed. A special 30-inch $f/11$ telephoto lens is also in the process of design.

Report of High-Speed Photography Committee*

The high-speed photography Committee was formed January, 1948, at the Bell Telephone Laboratories. At the first meeting of the committee the organization was set up with Harold E. Edgerton as Vice-Chairman and Arthur Neyhart as Secretary of the Committee. Various subcommittees were formed. As time has gone on, the work of some of these subcommittees has been somewhat altered from the original view.

The Lighting Committee has prepared a report in the form of a paper by Ralph Farnham on incandescent lights used in High-Speed Photography. The Lighting Committee sponsored the development of a lamp which was capable of taking pictures at rates up to 10,000 pictures per second at stops as low as *f*/5.6, with a rotating-prism-type camera. Slower operating speeds mean further stopping down which is of great advantage. The Lighting Committee has also recommended the development of an exposure meter and that development is being reported upon at the second symposium. The Lighting Committee is going to undertake the study of improvements in timing system marker lamps.

The Papers Subcommittee has presented two symposia covering fundamentals, design of flashing light, rotating-prism lens, and mirror cameras as well as studies in lighting and applications of high-speed photography by the industry. A third symposium was held at the October, 1949, meeting in Hollywood.

The Committee on Methods of Evaluation has prepared a report in the form of a paper on the Methods of Analyzing High-Speed Motion Pictures. Further investigations are being conducted by the Committee in improved methods of the evaluation of data.

The Subcommittee on Industrial Requirements has sent a questionnaire to the field, both military and industrial users, requesting information as to how they apply High-Speed Photography and what techniques they use. Reports from this questionnaire have come in and a report of the findings of this Committee was made at the Fall meeting.

* Presented April 6, 1949, at the SMPE Convention in New York.

Discussions in the committee have proved of value to the participants in those meetings and it is hoped that the High-Speed Camera subcommittee will, in the not too far distant future, be able to present a summarization of the characteristics of the various high-speed motion picture methods as well as recommendations as to what is required in high-speed photography.

HIGH-SPEED PHOTOGRAPHY COMMITTEE

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* Representing Photographic Society of America
** Representing Photographic Engineering Society

A. G. D. West

By the death of Captain A. G. D. West at the age of 52 while mountaineering in Switzerland, television has lost one of its outstanding pioneers.

Captain West, who joined J. Arthur Rank in 1947, was head of Rank's television organization. He had developed a large-screen television system of high quality, and it was he who was responsible for the first practical demonstration of large-screen television given in December, 1948, at a Bromley, Kent, theater.

Captain West attended Cambridge where he received his Master's degree with first-class honors. Later he attended London University, then proceeded on a research studentship at the Cavendish Laboratory, Cambridge.

During World War I he was wireless experimental officer with RFC and RAF. From 1923–1929 he was assistant chief engineer and head of research with the British Broadcasting Corporation. For the next three years he was head of design and development with the Gramophone Company, and in 1932 he went to the Ealing Studios as their chief sound engineer. From 1933 to 1947 he was technical director for Baird Television at which time his company was merged with J. Arthur Rank.

He was deeply interested in the scientific aspects of television and was one of the forces behind the setting up of the Television Committee and vice-president of the International Television Committee.

As president of the British Kinematograph Society from 1938–1946, and later Fellow, and president of the Royal Photographic Society in 1938, he was well known to American theater television experts.

At the time of his death last August, he was vacationing with his elder son, before going to the International Television Exhibition and Convention at Como and Milan, where he was to present the first demonstration of large-screen television on the Continent, on behalf of Cinema-Television.

Book Reviews

The Blue Book of Audio-Visual Equipment

Published (1948) by Business Screen Magazine and The National Association of Visual Education Dealers, 845 Chicago Ave., Evanston, Ill. $8^1/_2 \times 11$ inches, plastic ring bound, 62 pages. Price, $4.50.

Your Blue Book has in a very short time become a standard reference work on audio-visual classroom equipment. It is especially useful to all directors and coordinators of audio-visual education in schools, colleges, universities, and churches. It provides quick information on practically all the standard makes of projectors for any person having the responsibility for the purchase of such equipment. Perhaps it would not be so useful for smaller school systems or individuals who buy in small quantities.

Accuracy of these descriptions of course is not guaranteed by national audio-visual education dealers since they only reprint descriptions and specifications which are supplied by the manufacturers. Prices quoted cannot be relied upon since prices on this type of equipment fluctuate quite rapidly. The book is issued as an annual.

PAUL R. WENDT
University of Minnesota
Minneapolis 14, Minnesota

Look and See, by Colin Beale

Published (1949) by Edinburgh House Press, Edinburgh House, 2, Eaton Gate, London S.W. 1, England. 109 pages + 3-page index. 42 illustrations. $5^1/_2 \times 8^1/_2$ inches. Paper covered. Price, 3/6*d;* post free 3/9*d*.

Mr. Beale's book contains a great deal of useful information in its 100-odd pages. Although the subtitle of the book is "Visual Aids in the Service of the Church," there is actually very little mention of the adaptation of visual aids for this particular function. It is up to date in discouraging the use of the word "aids" and recommending the word "materials," and it refers to these materials as complementary rather than supplementary as in the older point of view. It contains good diagrams for students of education on the mechanics of projection. It is a well-written discussion of all audio-visual materials and equipment with a few outstanding exceptions. It does not do justice to the subject of the making of hand-made lantern slides. It devotes only one page to the important topic of the evaluation of teaching fiims. Two pages are not enough for discussing the reasons why motion pictures are an effective teaching medium. The creation and maintenance by the classroom teacher of a picture file is also slighted. In the bibliographies, many of the newer postwar American books on audio-visual education are missing as are "Educational Screen," "See and Hear," and "Film World" from the list of periodicals. The book has some terms such as diascope and episcope, mute films, and references to $9^1/_2$-mm film and $3^1/_4$-inch square slides which are not common in

Book Reviews

the United States. However, the book is very clearly written and the author shows good judgment in assigning for the most part the right amount of space to each topic within the field.

An item of special interest to the SMPE is the generous amount of space devoted to showmanship in the presentation of films and other visual materials. The author quotes a paragraph from the SMPE JOURNAL of March, 1938, by C. L. Green. Most operators of 16-mm projectors need Mr. Green's contrast between amateur and professional projectionist techniques. Mr. Beale should be complimented for doing his part to raise the standards of classroom projection.

PAUL R. WENDT
University of Minnesota
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Meetings of Other Societies

November—	
Acoustical Society of America	November 17 through November 19 St. Louis, Missouri
December	
American Association for the Advancement of Science	December 26 through December 31 New York, New York
March, 1950—	
Institute of Radio Engineers National Convention	March 6 through March 9 New York, New York
Optical Society of America Winter Meeting	March 9 through March 11, 1950 New York, New York
May, 1950—	
Armed Forces Communications Association Annual Meeting	May 12 New York City and Long Island City May 13 Fort Monmouth, New Jersey

FORTY-ONE YEARS AGO

On account of the number of school absentees that have been caught in the act of absorbing their knowledge from the pictures in the nickelodeons the proprietors of the halls in Jersey City have been warned to cease admitting children.

—*The Moving Picture World, March 14, 1908*

New Products

Further information concerning the material described below can be obtained by writing direct to the manufacturers. As in the case of technical papers, publication of these news items does not constitute endorsement of the manufacturer's statements nor of his products.

Tele-Spot Meter

The Tele-Spot Meter, supplied by **Photo Research Corporation,** 15024 Devonshire Street, San Fernando, California, is a sensitive and accurate photoelectric light-measuring device, which has an optical system enabling it to measure the light coming from a small area, or a narrow angle, such as a one-inch circle at ten feet.

On the front of the case is the objective, and on the rear side are the electric controls, view finder, and the foot-lambert meter. In use, it is aimed at the area or object to be measured, which is clearly seen in the view finder. When it is aimed correctly, a reading is taken, the mirror behind the lens swinging up to let the light fall on the sensitive photocell. The scale then indicates the brightness in foot-lamberts. A supplementary switch makes available several ranges on the meter. Such an instrument may be used to measure the range of brightness and distribution of illumination in a scene.

For the measurement of visual brightness, a filter is provided which matches the color sensitivity of the cell to the sensitivity of the human eye. For the measurement of photographic values, a different filter converts the cell sensitivity to that of panchromatic film.

Several types of Tele-Spot Meters are in production. One is for operation on alternating current only; another, extremely portable, is designed for battery operation.

T-Stop Calibration Service

One of the specialized services rendered by the same corporation is the photoelectric recalibration of lens apertures in terms of *T* stops.

A few years ago, some of the major film studios in Hollywood began to recalibrate their lenses in terms of actual light transmission instead of the theoretical *f*-stop values, because of the increasing accuracy demanded by color. Finally, this procedure has been given official standing by the recommendation of the National Bureau of Standards that lenses be marked in what it calls "*T*-stop" values, instead of the older *f* scale.

When a lens is recalibrated by the corporation, new marks are placed on the scale which represent true transmission values. The stop marked *T*-4, for example, transmits exactly the amount of light that would be transmitted by a theoretically perfect *f*/4 lens, in which there was no light loss whatsoever and no inaccuracy of focal length or scale marking.

EMPLOYMENT SERVICE

POSITION OPEN

MECHANICAL ENGINEER, college graduate, 30 to 35 years old, minimum three years' detailing experience and five years' design experience in acceptable field. Someone from the sound motion picture equipment field or the like. We offer a top job with a comparatively new company in a new but accepted industry. Location: Chicago. Appreciation of electronics helpful. Salary and opportunities: depend on the individual and his ability. Give complete and detailed personal history in first letter. All replies confidential, and will be returned if requested. Address c/o Duo Tape, 360 N. Michigan Ave., Chicago 1, Illinois.

POSITION WANTED

PRODUCTION SPECIALIST: Twelve years' script-to-screen experience in 16-mm and 35-mm industrial, instructional, and documentary films. Presently employed in advertising agency creative department. Age 35 years. Desires position with short-subject, television, or industrial producer. Write William T. Straley, 765 Fulton Ave., San Antonio 1, Texas.

POSITION WANTED

PROJECT ENGINEER: Mechanical engineering graduate experienced in designing from specifications; optical instruments, precision cameras, mechanical servo, and gear or three-bar computers, analytical work in stress and vibration, R. A. Barbara, 663 Ovington Avenue, Brooklyn 9, New York.

SMPE Officers and Committees

The names of Society Officers and of Committee Chairmen and Members are published annually in the April issue of the JOURNAL. Changes and corrections to these listings are published in the September JOURNAL.

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Television Studio Lighting*

By A. H. BROLLY

Television Associates, Michigan City, Indiana

Summary—Intensity, color, and directivity are important factors in the proper design of television studio-lighting facilities. Good color response can be attained with image-orthicon tubes using a combination of fluorescent and incandescent lights, together with simple filters on the camera lens. The characteristics of these lamps and filters are presented along with means of estimating power requirements for various sizes of studios.

It is perhaps natural that the novelty of television should divert attention from some of those older arts that are essential to its own progress. A case in point is illumination in the television studio. While the artistic and scientific principles of illumination required for television are known, their application in the television studio has not advanced in step with television equipment.

Many of the principles developed for motion picture photography and the stage apply also to television. But their application must be tempered by the knowledge that the characteristics of an electron tube are interposed between the illuminated subject and the viewer. Because of this fact brightness, color, concentration, and direction of the light assume greater importance and a given light source should be rated in terms of its effectiveness in conjunction with the television camera tube. A light that appears visually bright may be less efficient in terms of transmittable signal than another of different color characteristics. This characteristic of the television camera tube is the key to the solution of the main problems of television illumination.

There have been various types of television camera tubes used in past years, but because of its several advantages, the image-orthicon tube is coming to be used almost exclusively for all television pickups except motion pictures. The characteristics which make it so useful are sensitivity, good resolving power, and good signal-to-noise relationship with practical light intensities.

* Presented April 5, 1949, at the SMPE Convention in New York.

LIGHT-INTENSITY REQUIREMENTS

Phenomenal sensitivities to light have been attributed to the image-orthicon tube. In fact recognizable pictures have been produced with a light intensity (incident) of less than 1 foot-candle. But under such low light conditions the picture is marred by a snowy or rainy appearance of the picture field, an effect which has come to be called noise in television parlance.

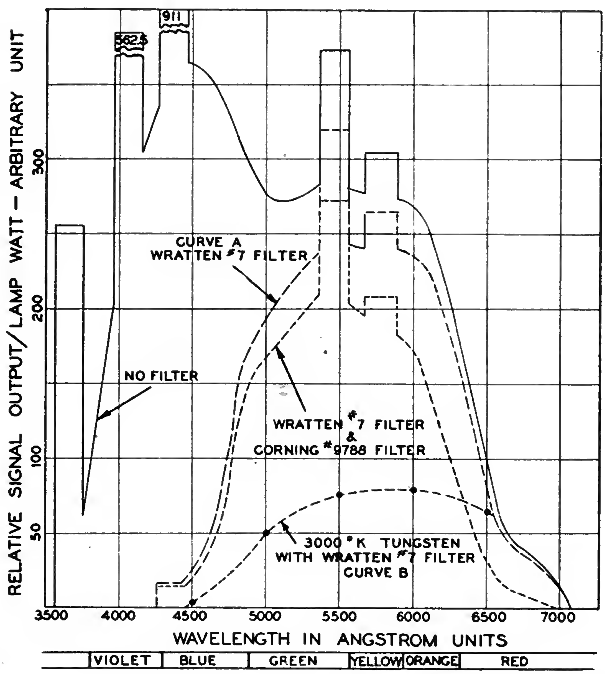
Three factors affect the light intensity required for television pickup. They are: the sensitivity of the image-orthicon tube, the amount of amplification used, and the lens aperture or speed. Considering these points in reverse order, the following facts are important.

The phenomenal sensitivities and operation with low light levels are usually achieved with large lens apertures of the order of *f*/2.0 or better. Such large apertures produce very shallow fields of focus, so they are not practical for production of programs. Apertures of the order of *f*/11 are more practical and such a reduction of aperture (*f*/2 to *f*/11) requires more than 30-fold increase of light intensity to produce the same intensity of image on the screen inside the image-orthicon camera tube.

It might seem that since we amplify the television impulses created by the camera tube, we could increase this boosting almost indefinitely to compensate for weaker illumination. But there are practical limits to this also. At extremely low light levels the electrons released by photoelectricity in the camera tube become so few that the so-called shot effect produces noise or rain effects which seriously mar the picture. The same effect also may take place in the first amplifier tube of the camera chain. Under these circumstances further amplification increases the noise or rain along with the picture. So we have no alternative but to use more light.

Now with regard to the image-orthicon tubes themselves, we find quite a range of sensitivities. There are three different types of image-orthicon tubes. They all look alike and the principal difference among them is in the treatment of their photoelectric screens. Of the three, the one which usually exhibits the phenomenal light sensitivities has considerable sensitivity in the deep and infrared part of the spectrum. This is an unavoidable result in the present stage of development of the art of photosensitization. This red sensitivity is no great handicap to televising of sports events but it is a definite drawback to studio programming where true representation of colors, in terms of appropriate grays, is important. Accordingly, studio work is usually done with one of the two other types of image-orthicon tubes whose sensitivity is lower by a factor of 2 to 5 times.

Adding up the effects of the three foregoing factors, we come out with a practical requirement of from 200 to 300 foot-candles of incident-light intensity for good television studio work.



General Electric Lamp Department

Fig. 1—Photoeffectiveness of 5655 image orthicon with 4500-degree white fluorescent lamps and 3000-degree-Kelvin tungsten lamps.

All of the above curves are based on the fluorescent lamps except curve *B*.

COLOR REQUIREMENTS

The curves of Fig. 1 show the variation with color of signal output from a typical image-orthicon camera tube under illumination with fluorescent and incandescent lamps. The ordinates of these curves are proportioned to the actual electrical signal voltages developed in the transmitting channels following the camera. It will be noted that with fluorescent illumination much of the response (without filters) is in the blue region. It is well known that radiation from incandescent lamps is predominantly red. This suggests the advantages of combining the types of illuminants, a point that will be discussed in a later paragraph.

Through long acquaintance with black-and-white photographic representation of colors we are accustomed to a character of scale in which green and yellow are represented by light grays, blues by a little darker gray, and reds by a still darker gray. In fact this kind of a representation of colors by gray shades is derived from the behavior of the eye. Therefore, the response of the eye to colors serves as a good criterion for combining illuminant and camera-tube characteristics to get natural rendition of colors.

It will be noted that curve *A* of Fig. 1 approaches quite closely to the characteristic of the normal eye whose sensitivity peaks at 5600 angstrom units. Hence this combination of 4500-degree fluorescent-lamp illumination with a typical image-orthicon camera and a Wratten No. 7 filter provides a good color rendition. Likewise, curve *B* indicates that 3000-degree-Kelvin incandescents with the same camera tube and filter render a fair approach to the eye characteristic though inclined slightly toward the reds.

If these characteristics are not worked out properly, very unnatural effects develop. For instance, an over-all characteristic which is heavy in reds makes a performer's lips appear white, and rouge on the cheeks appears as a white smear. It is such unbalanced color response that has lead in the past to a lot of strange forms of make-up for television performers. Now that we have the means and knowledge to correct color response, these odd make-ups are no longer necessary.

An unfortunate circumstance connected with color response is the effect of line spectra. Some of the gaseous lamps: high-pressure mercury, sodium, or neon are efficient light sources, but they produce only discrete colors. Light from such sources is reflected only from certain textures or colors and not from others. The result of its use in television is a picture decidedly lacking in half tones, an apparently hard and excessively contrasty picture.

ILLUMINANTS

Of the various sources of illumination the choice for television studio use narrows down to incandescent and fluorescent lamps.

Gaseous lamps are ruled out by characteristics just described and arc lamps require too much attention, discharge fumes, and are apt to be noisy.

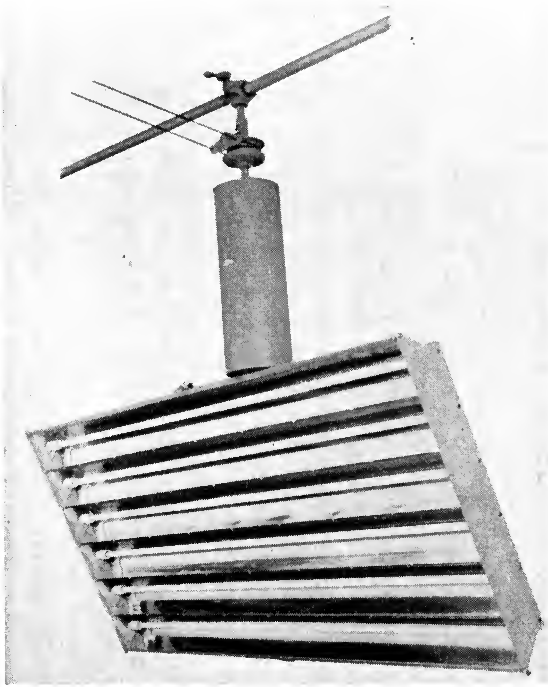
It would be desirable to secure all of television studio illumination from fluorescent lamps, because of the lack of heat and apparent breadth of spectrum. But there are two handicaps. First, fluorescents are inherently not adaptable to directivity, because of their size. And one cannot achieve artistic illumination without directivity. Another characteristic of fluorescents is that some of the mercury spectral lines pass through the fluorescent coating and take part in the illumination. This, together with the large proportion of the fluorescent illumination in the blue end of the spectrum produces a rather hard and contrasty picture unless filters are used. A very satisfactory remedy for these shortcomings is to add some incandescent illumination. The porportion is not critical. The incandescents add red components in which the fluorescents are slightly deficient and present a concentrated source which is easily directed.

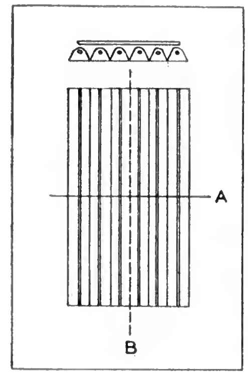
A good arrangement in line with the above points is to provide the basic illumination with fluorescents and the high lighting, back lighting, and artistic modeling light with incandescents. This combination is widely favored and is being put in by a number of stations.

A very useful fluorescent lighting unit for television is shown in Fig. 2. It uses six of the Slimline type of tubes. They operate at 300 milliamperes each and 600 volts. They have no filaments and are instant starting. The 4500-degree white-type lamp is preferred. The tubes have a long life and produce about as intense an illumination as is available from any fluorescent.

The tubes are mounted in individual reflectors to concentrate the light in the desired direction. Fig. 2 shows that a desirable degree of concentration is achieved in one plane. As the unit is mounted with the tubes horizontal, this directivity is vertical. It will be noted that the half-candle-power points are about 35 degrees off the axis. Hence a field over 10 feet high will be illuminated at a distance of 10 feet. There is very little directivity in the horizontal plane. This is good as the television field is wider than it is high by the ratio of 4:3 and most of the action of a performance takes place laterally.

The intensity on the axis perpendicular to the center of the unit is 7000 candle power. That means an incident illumination of 70 foot-candles on a scene at a distance of 10 feet. Where two of these





LAMP	
TYPE	G.E.CO. 4500° WHITE
LAMP NO.	
WATTS	6 X 51
VOLTS	LINE 120 V
AMPS.	0.30 NOMINAL
LUMENS	
BULBS	64" T 6

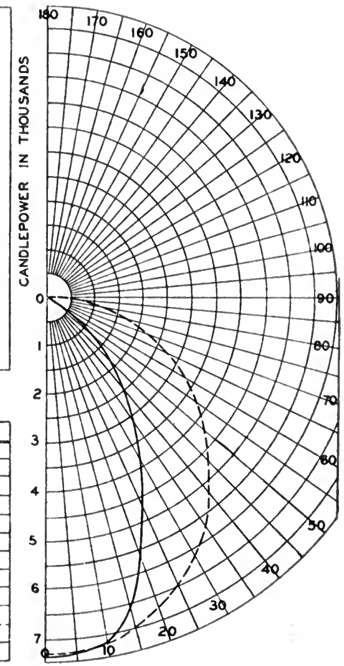


Fig. 2—Fluorescent lighting unit for television studios.
The color characteristic is such that when used with the image-orthicon tube, good gray representation of colors is obtained. Intensity is high and the fixture can be tilted and rotated remotely.

units can be brought to bear on a scene, they provide all the basic flat illumination required in an area 20 feet wide by 10 feet high. And they do this with a power consumption of only 450 watts per unit, a very efficient illumination.

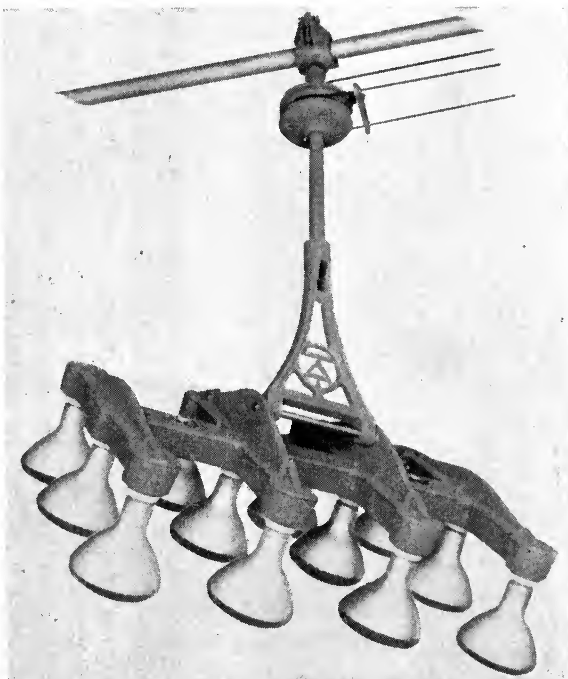
Compare this effectiveness with incandescent lights. Fig. 1 shows spectral curves for a 4500-degree fluorescent and a 3000-degree incandescent. When filters are used to correct color response, watt for watt, the fluorescent produces about $2^1/_2$ times more signal than the incandescent.

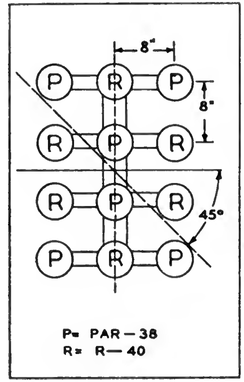
As previously suggested a combination of fluorescent with incandescent lamps furnishes a well-balanced spectrum for use with the typical television camera tube. Since the fluorescents are not seriously deficient in reds (assuming no filters on the camera) not a very large proportion of incandescent illumination is required to provide the balance. The requirements as to directive light for artistic effects are usually sufficient as to color also. Limiting usage of incandescent lighting to these requirements cuts down the heat dissipated in the studio and reduces the requirements as to cooling equipment.

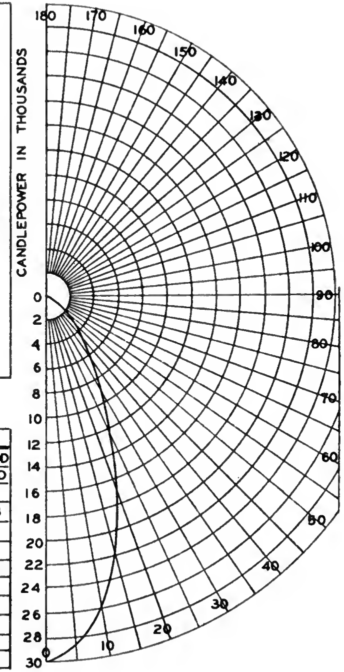
Fig. 3 is an incandescent fixture equipped with internal reflector bulbs. This type of light is efficient for an incandescent because with relatively inexpensive facilities it achieves quite good directivity. The degree of concentration achieved with this 12-lamp unit provides a very intense beam as may be seen. Hence, it can be operated a little farther from the scene than the fluorescent and its greater intensity overrides the basic light of the fluorescent enough to give the desired character of high lights and shadows.

It is good practice to use bulbs in these units at a voltage higher than their rating; for instance a 105-volt bulb on a 115-volt source. This shortens the life of the bulbs, to be sure, but it increases the radiation in the blue end of the spectrum and thus increases the effectiveness so far as the television camera is concerned.

Of course, the power used by this bank of lights is considerably in excess of that of a fluorescent unit: 1800 watts when equipped with 150-watt bulbs. This produces considerable heat which is unavoidable. A balance of 1 or 2 of these banks to each fluorescent provides good color response and sufficient directive illumination for most artistic effects. Where more sharply beamed illumination is required an incandescent spotlight may be used, but it should be equipped with a high-temperature-type bulb.







LAMP	
TYPE	G.E. REFLECTOR FLOOD & PROJECTOR FLOOD
WATTS	12 X 150
VOLTS	R-40, 115, PAR-38 & 105
AMPS.	
LUMENS	
BULBS	6-R-40, 6-PAR-38

Fig. 3—Incandescent lighting unit for television studios.
This unit has sufficient directivity for good modeling and high-lighting effects. The fixture can be tilted and rotated remotely.

FIXTURES

Let us consider television operations for a moment. All who have watched a television show realize that it must progress smoothly from act to act and scene to scene without interruption. The lighting facilities must be adaptable to this kind of continuity. Hence in addition to being kept out of the way of activity on the studio floor they must be capable of quickly changing the center of illumination from one part of a scene to another or even to a different scene instantaneously. And this must all be done silently. After long experience it has been found that the only solution for this problem is not only to have the lights remotely controlled, but to have enough lighting units available to make two or more scene setups in advance of the show. The remote control can be handled very nicely by the rope controls apparent in Figs. 2 and 3. They permit tilting through a vertical angle of 90 degrees and a rotation in a horizontal plane through 360 degrees.

STUDIO INSTALLATIONS

To provide for advance setups requires a number of lighting units. That may sound expensive, but its cost is small compared to the television equipment with which it will be used. $5000 spent on lighting would go along with $75,000 to $100,000 for television gear. It is found that from 20 units for a small studio to 50 units for a large studio are normal requirements. Fig. 4 is a typical plan.

Hanging so many lights in a studio poses a problem of one lighting fixture shadowing the light from one behind it. This has led us to a scheme of locating fixtures in the pattern of an inverted pyramid (Fig. 4). To lay out an arrangement of this kind, lines are drawn from the top of the scenery at one end of the studio to the probable camera lens level at the other end. Where these lines intersect the light locations on the plan, the height of each light above the floor is determined. Lighting units farther from the staging area are lower, hence shadows caused by the close-in banks are avoided. Also so long as the camera field of view is limited to the top of the scenery, the lighting fixtures will never intrude upon the picture.

The television-lighting planner gets one break from nature. We are so accustomed to having daylight fall from overhead upon the things we see that it is natural to have the majority of our light in the television studio do likewise. This fits in beautifully with our desire

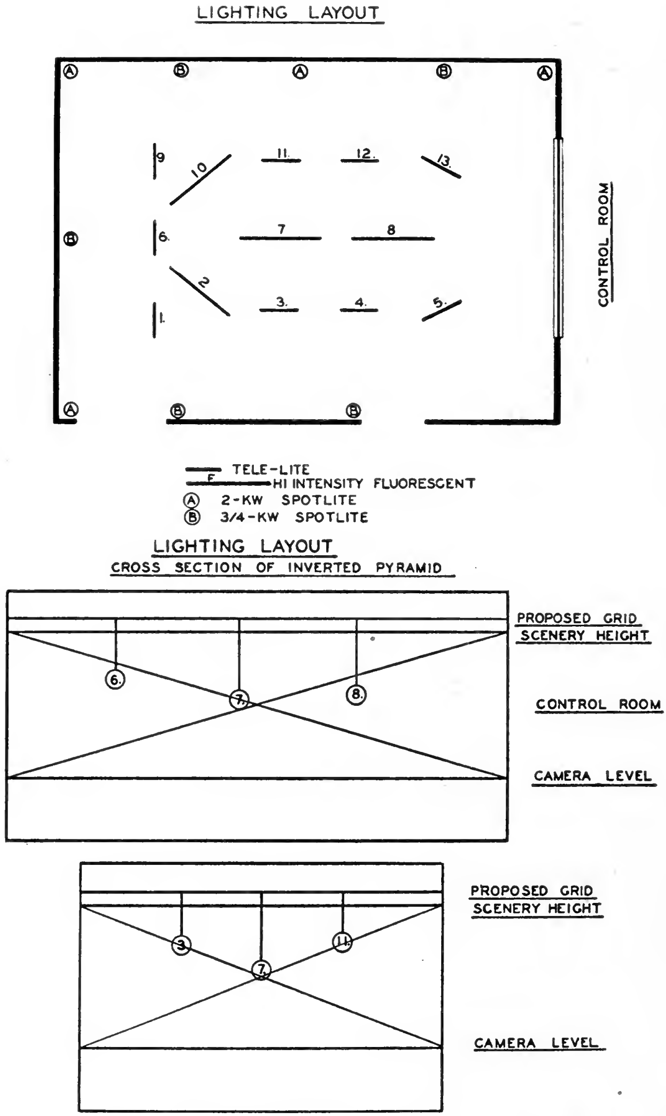


Fig. 4—Typical television studio-lighting plan.
Provision is made for basic illumination with fluorescents and highlighting with incandescents.

to hang most of our lighting equipment from overhead where it is out of the way of scenery, props, cameras, and personnel.

It will be apparent from the foregoing that a considerable amount of power is required for lighting. It is considerable, but not nearly so bad as in the days before the image-orthicon tube. With image-orthicon cameras and approximately half of the lighting units of the fluorescent type, we come out with a requirement of about 25 kilowatts connected load for a small studio of the order of 25 by 30 feet. For a large studio, perhaps 40 by 60 feet, the connected load would probably be around 60 kilowatts. A good rule-of-thumb for estimating lighting power is about 30 watts per square foot of floor area in the studio.

One should distinguish between "connected load" and actual load at any one time. It will be understood from preceding references to preset lighting that all the lighting units are never expected to be used at one time. The broadcast operator would probably not use more than 25 or 30 per cent of the units at any one time. The electrical codes will not permit one to economize on wire, conduit switches, and fuses on the basis of this probability. However, a real saving can be effected in air-conditioning facilities by taking account of this partial usage of lighting facilities.

There are a few incidental points that must be taken into account in any good studio lighting installation. Mention has been made of the need for quietness in operation. The devices shown for tilting and turning the lighting fixtures meet the requirements of silence in movement. Quiet operation of switching is also necessary. Snap-action switches cannot be tolerated in the studio. For small installations there is a silent toggle switch with mercury contacts. For a little larger installation there is a mercury-contact relay whose coil circuit can be switched with the silent toggle switches. For the largest installations a separate relay room is worth while. Then it does not matter how noisy the relays may be and their coils can be operated with push buttons in the studio.

Some fluorescent-lamp ballasts develop an objectionable hum. These cannot be tolerated in the studio. A lot of wiring can be saved if the ballasts are near the lighting units. Therefore, it is wise to select good quiet operating ballasts and mount them so that hum vibration cannot get into the fixtures or supporting grid where it can radiate noise. These points are given due consideration in the manufacture of lighting units shown in the accompanying illustrations.

Some types of fluorescent lamps generate electrical oscillation which radiate and interfere with operation of the television equipment. This can be taken care of by intelligent choice of lamps and their installation.

Thus it may be seen that television studio lighting is a major problem but it can and has been solved in many cases through application of fundamentals of illumination and mechanics.

ACKNOWLEDGMENTS

The author wishes to acknowledge, with thanks, the encouragement and assistance of the following men in the developments which are the background for this paper: Captain W. C. Eddy, U.S.N. (Retired), President of Television Associates, Inc., and Richard Blount of the General Electric Company, Lamp Department, Nela Park, Cleveland.

DISCUSSION

DR. F. G. BACK: Captain Eddy has talked about filters in conjunction with his lights. I should like to hear more about those filters which he is using.

CAPTAIN W. C. EDDY: The filter system that I referred to was the one that was first proposed at NELA Park in our last lighting conference out there. These were used to get rid of some of the mercury lines that exist in all fluorescent lights, in addition to balancing out the spectrum. They do, however, cut down the sensitivity because we add two negative filters. It has been pointed out in the conference that filters at the camera will give a close representation of the perfect eye curve; in other words, the camera will see the picture as the eye sees it. Using the Ansco color charts at WBKB last June, we ran extensive tests to find out whether filters in front of the tubes are satisfactory. We found that if you have a good tube, you can use filters, but if you have a tube that is ready to be retired, it will not work. The use of filters opens up a brand new field in television lighting.

Then again, Dr. Back, I know you are interested in the matching of tubes. Each tube has to have a separate filter. You cannot take one tube and say the next one is going to be just like it. It may and probably will require a different type of filter, so each one has to be cared for separately.

DR. BACK: Also the tubes vary widely. I tested quite a number of tubes at the ABC studio and almost every one was different.

CAPTAIN EDDY: We in television know that every tube is different. We do not even have to go through a test. They all give a different response, and it is hard to match those tubes in production work.

MR. O. W. HUNGERFORD: You mentioned in your talk that two incandescents were used to one of your fluorescent fixtures. On what do you base the output level of these lamps to give you that ratio?

CAPTAIN EDDY: That is a rule of thumb. When we light a studio, we actually take our projected curves, that is, our light curves, lay them over the floor area, knowing the position of those various units, and we can determine from the knowledge we have of those particular types of lights exactly how many foot-candles you build up in a certain area and what color coefficients you will achieve. We say, though, for rule of thumb in computing a television studio, that even though the incandescents are going to be farther back, they have more throwing power, and if your fluorescents are placed halfway in to the staging area two to one seems to be a reasonable standard in roughly estimating a studio. Before we came down with a final layout, we necessarily would have to see the height of the ceiling and the aspect ratio of the studio.

MR. A. M. ZAREM: Have pulse-light sources ever been experimented with on television?

CAPTAIN EDDY: Possibly, but not to my knowledge. Certainly our company, which has been in this lighting field, has not done anything along that line. We have experimented with mercury lights, various types of incandescents, and fluorescents and have arrived at something that appears to be satisfactory to us. However, I do not believe that television is going to stagnate on one lighting system when a new and better system is developed. When this happens, I believe it should be tested, but I know of no experimentation in pulse lighting at the present time.

MR. HUNGERFORD: What power source do you use on those lights? Does that make much difference?

CAPTAIN EDDY: That is a matter which has led to considerable controversy and some difficulties. One complete direct-current installation in a television studio led to magnetic fields which seriously affected the framing of the television picture. Alternating current is satisfactory for lighting but high-current conductors should not be placed close to the cameras as their fields may cause trouble. Use of alternating current for lighting does not cause hum bars to appear in the picture with either incandescent or fluorescent illuminants, but the lighting fixtures should be balanced on a 3-phase system wherever possible.

Each one of these units I have shown you connects to two circuits. A three-wire balanced system sometimes helps you cut down the amount of basic wiring needed. The reason why we have divided the units between two circuits is to permit half illumination during setups and rehearsals while maintaining the same distribution of illumination that would be obtained with full illumination. All light distribution problems can be worked out under half illumination and the balance of the lighting turned on only when needed.

MR. EDWARD P. SUTHERLAND: Do you use 60-cycle single-phase power on the fluorescent lights?

CAPTAIN EDDY: Yes, sir.

MR. SUTHERLAND: Do you have that in phase with the generators at all?

CAPTAIN EDDY: The single-phase alternating-current supply to the fluorescent lights is split into two phases in the ballast units connected to the fluorescent tubes. As a result of this, flicker is smoothed out to such an extent that hum bars are not produced in the television pictures. Consequently, phasing of these lamps with the synchronizing generator is not necessary. Since ordinarily both the lights and the synchronizing generator are supplied from the same source, there will be a fixed-phase relationship between them, but it is not a prerequisite to use the fluorescent lights.

MR. J. A. OUIMET: We have a problem in the Toronto area where we have 25-cycle alternating current. What would you say would be the problem in this case?

CAPTAIN EDDY: How difficult can television get? I do not really know. It is possible that fluorescent lights balanced on a 3-phase circuit and containing phase-splitting ballasts within them might be satisfactory. Also, incandescents would be less subject to flicker from the low frequency. You might have to use incandescents entirely. It might even be necessary to use direct current.

MR. OUIMET: Would you say that the use of 3-phase, 25-cycle, or even more phases if necessary, tends to give the same effect as direct current would?

CAPTAIN EDDY: I should think so. That would be my method of approach to it. I cannot tell you what the results would be until we have tried it. In fact, we have not approached the Canadian situation in lighting.

* * *

MR. F. T. BOWDITCH (written comments): Mr. Brolly states that "arc lamps require too much attention, discharge fumes, and are apt to be noisy," and so are not suited to television studio illumination. While this statement possibly represents a reasonable analysis of the present position of carbon arcs in this industry, it should be pointed out that this is in large part because television studio practice is still in an early stage of development, both technically and economically. Present budgets apparently cannot support studio sizes and personnel on anything approaching the scale found desirable in the more highly developed motion picture industry, although the light levels and the inherent artistic requirements seem to be substantially the same in both cases.

Whenever the present economic limitations are removed, and when, in addition, television picture quality improves to the point where more artistic lighting effects can be effectively recorded and appreciated, the carbon arc will find an important place here just as it has in motion picture studio lighting. Any added cost of lamp attention will then be properly recognized as an insignificant part of the total studio expense, while the noise and dust problems will be easily and effectively handled just as they have been in motion picture work.

Lighting Distortion in Television*

By RICHARD BLOUNT

General Electric Company, Nela Park, Cleveland 12, Ohio

Summary—Improved television pictures can be produced by (1) limiting the contrast of the original scene, (2) by selecting light sources that when combined with the camera-tube spectral sensitivity provide accurate tonal rendering, and (3) by using lighting techniques that aid in creating an illusion of three dimensions on the receiver screen.

Improper lighting technique in television may result in three forms of picture distortion: (1) Loss of detail caused by brightness contrasts that exceed the latitude of the electronic equipment. (2) Absence of depth due to improper distribution of light over the scene. (3) Rendering of colors in unnatural relative gray values caused by spectral characteristics of the light and of the camera tube.

The first type of distortion occurs when illumination levels in the scene are too uneven. Excessive illumination on some surfaces of the scene and inadequate light on others result in a picture lacking in detail because the range of brightness in the scene exceeds the latitude of the electronic equipment. This occurs, for example, when most of the light comes from overhead; upper portions of people's faces are overexposed while shaded areas, such as eyes, are underexposed.

The situation can usually be remedied by providing a general level of vertical surface illumination that is at least equal to, and preferably somewhat greater in intensity than, the horizontal surface illumination. In both cases the illumination may be supplied from broad sources, some mounted overhead and others aimed almost horizontally into the set from just high enough off the floor to allow free passage of the operating personnel and their equipment.

Some loss of detail may also be encountered even when incident-lighting levels are entirely adequate and sufficiently uniform. Difficulty arises where the reflection factors of the various scene components differ widely. Two separate materials, one dull black and

* Presented April 4, 1949, at the SMPE Convention in New York.

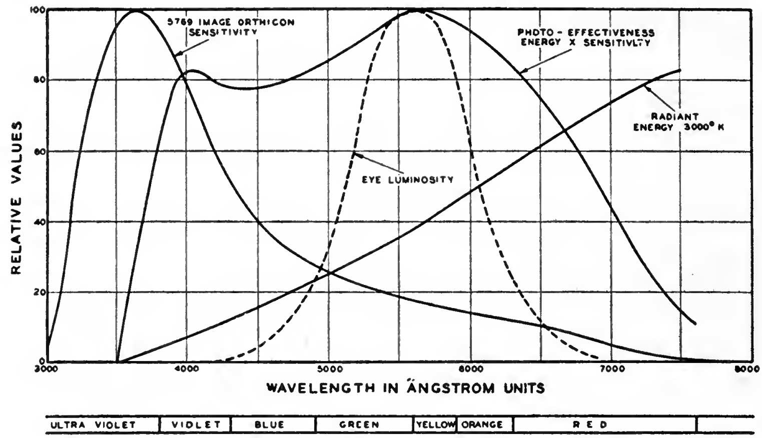


Fig. 1—Derivation of photoeffectiveness curves.

the other white, might have reflection factors of 2 and 80 per cent, respectively. With equal incident illumination, the brightness ratio[1] will be 40 to 1. Since existing equipment will correctly produce differences in brightness only up to 20 to 1, it is well to avoid using both darkest and lightest materials in a given scene unless sufficiently separated to permit compensating differences in illumination.

Television studio techniques should attempt to create on the two-dimensional receiving screen an illusion of three dimensions. The

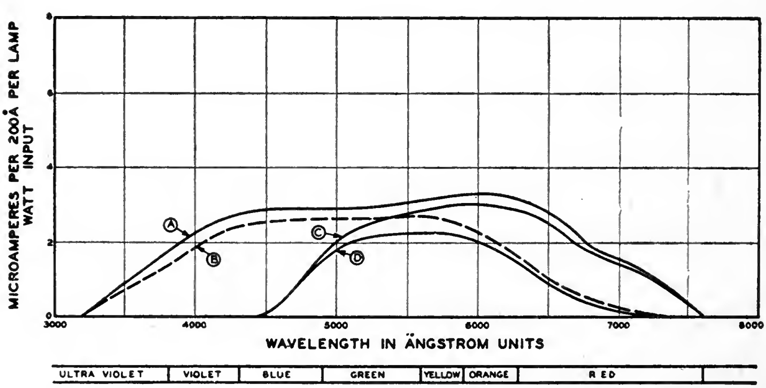
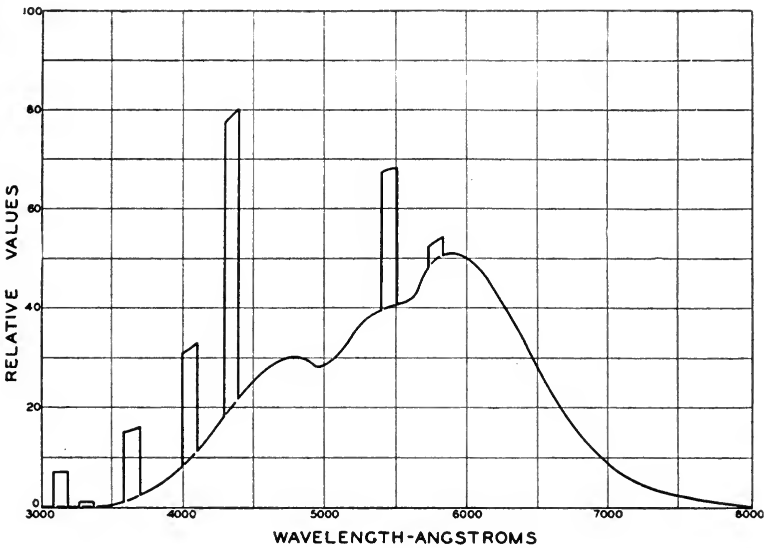
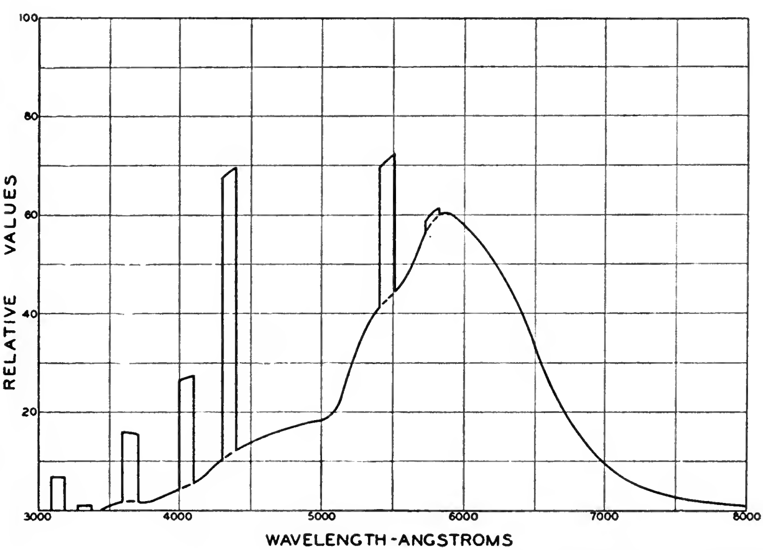


Fig. 2—Photoeffectiveness of 5769 image orthicon with 3000-degree-Kelvin tungsten sources.
(*A*) no filter. (*B*) Corning No. 9788 filter. (*C*) Wratten No. 7 filter. (*D*) Wratten No. 7 filter.



General Electric Company

Fig. 3—Spectral emission of 4500 white fluorescent lamp.



General Electric Company

Fig. 4—Spectral emission of 3500 white fluorescent lamp.

effect can best be obtained by suitable design of scenery and by proper application of light to the stage. This is accomplished by adding modeling and back lighting to the general illumination. It is the general light that provides the studio engineer with the necessary picture signal; generally it should be from broad floods, uniformly illuminating the stage and scenery so that as the cameras are directed toward various portions of the stage very limited changes in signal

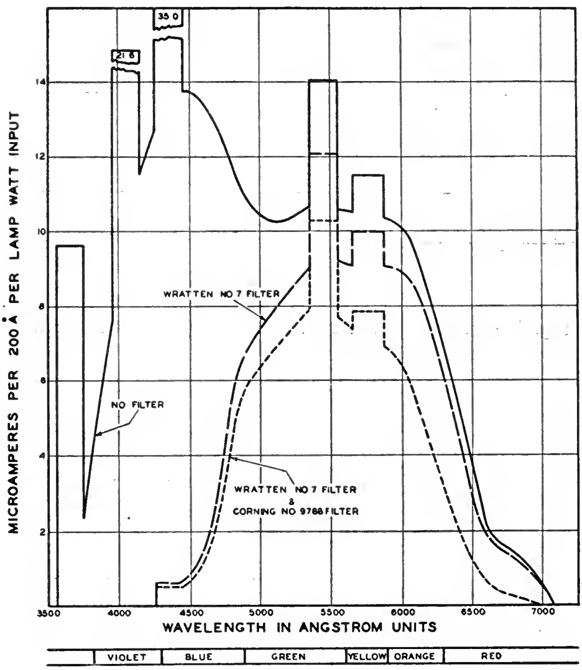


Fig. 5—Photoeffectiveness of 5769 image orthicon with 4500 white fluorescent lamps.

level occur. Modeling light for the three-dimensional effect is usually directed toward the stage at an angle to create enough unbalance so that shadows appear to give depth to faces and forms as well as to the supporting property.

Back lighting serves to separate the actors from the background by providing an outlining line of light about their heads and shoulders. It must come from overhead and slightly to the rear of the actors so that only a thin line of light is seen by the camera and direct light

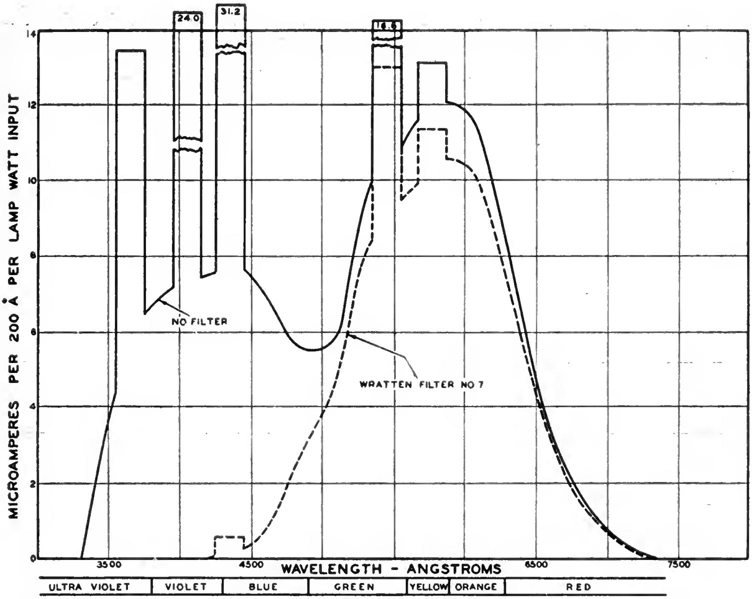


Fig. 6—Photoeffectiveness of 5769 image orthicon with 3500 white fluorescent lamps.

into the camera lens is avoided. In contrast to the general illumination, the equipment for modeling and back lighting must be accurately controllable in both beam pattern and intensity in order that light

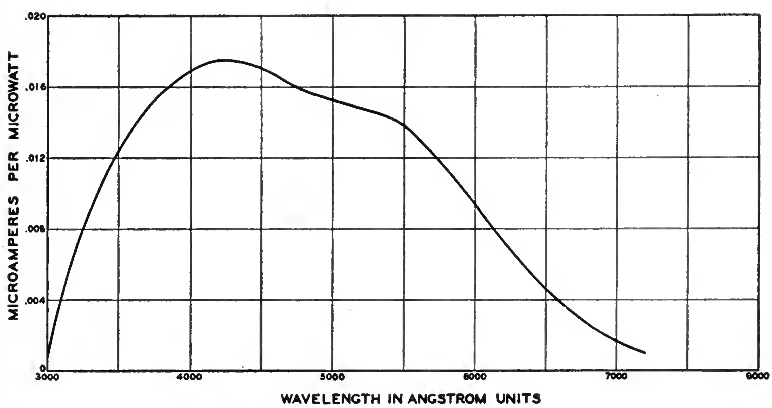


Fig. 7—Spectral sensitivity of 5820 image orthicon.

may be directed precisely toward the desired area and may be readily adjusted in relation to the level of general illumination.

Further to improve the received picture, individual colors should be reproduced in shades of gray having the relative brightness values of the original colors. This is possible only when the spectral sensitivity of the camera tube combined with the spectral energy radiated by the light source results in a response or photoeffectiveness that approximates the luminosity curve of the eye.[2]

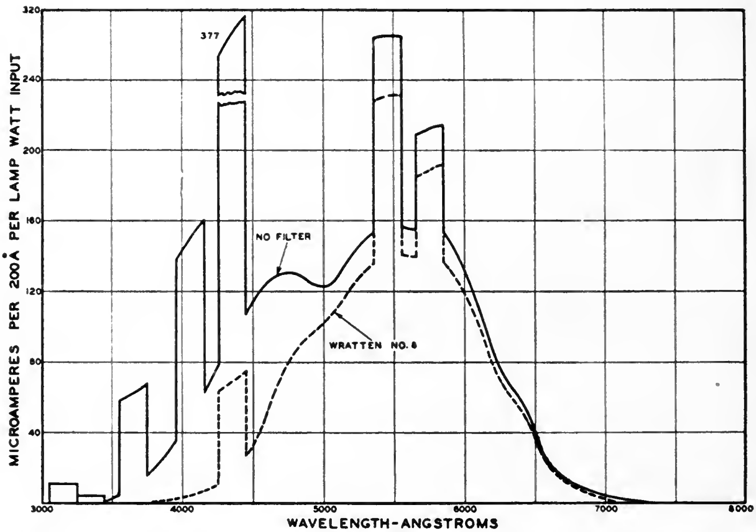


Fig. 8—Photoeffectiveness of 5820 image orthicon 4500 white fluorescent lamp.

Fig. 1 shows the photoeffectiveness curve of the 5769 image orthicon when used with a typical tungsten-filament lamp operating[3] at 3000 degrees Kelvin. For comparison the eye-response curve is shown. Note that the shape of the image-orthicon photoeffectiveness curve differs from the eye curve; distortion occurs in the picture because of excessive response in the long wavelength red and the ultraviolet regions.

Fortunately, such distortion can be eliminated easily by the use of a color-correcting filter at the camera lens. Filters[4] such as the Wratten No. 7 and the Corning No. 9788 on the camera lens provide the needed correction (see Fig. 2), with, of course, some resultant loss in signal. In Table I comparative output-signal levels are listed in

TABLE I

PHOTOEFFECTIVENESS OF IMAGE ORTHICONS WITH EQUAL WATTS OF TUNGSTEN FILAMENT AND FLUORESCENT LAMPS

Receptor	Lamp Type	Camera Lens Filters	Relative Conversion Efficiency*	Relative Signal Strength†	Color Balance: Blue 3000–5300	Color Balance: Green 5300–5900	Color Balance: Red 5900–8000
Eye	....	....	..	...	0.42	1.00	0.43
Image Orthicon No. 5769	4500 White Fluorescent	None	8.5‡	0.427	3.5	1.00	0.43
		Wratten No. 7	..	0.166	0.73	1.00	0.77
	3500 White Fluorescent	None	6.9†	0.368	2.74	1.00	0.86
		Wratten No. 7	..	0.151	0.42	1.00	0.99
	Tungsten 3000° K.	None	6	0.104	2.5	1.00	1.9
		Wratten No. 7	..	0.062	0.7	1.00	1.8
		No. 7 + 9788	..	0.038	0.8	1.00	0.97
Image Orthicon No. 5820	4500 White Fluorescent	None	43†	1.8	1.7	1.00	0.57
		Wratten No. 6	..	1.13	0.95	1.00	0.64
	3500 White Fluorescent	None	38†	1.6	1.11	1.00	0.59
		Wratten No. 6	..	1.28	0.56	1.00	0.53
	Tungsten 3000° K.	None	40	0.62	1.36	1.00	1.23
		Wratten No. 6	..	0.46	0.83	1.00	1.21

* Camera-tube microamperes per lamp lumen on photocathode.
† Camera-tube milliamperes per lamp watt.
‡ 64T6 slimline lamps at 300 milliamperes operating current.

the column headed "Relative Signal Strength," and the effectiveness of filters in reducing distortion is indicated under "Color Balance." Experience with such filters has shown a marked improvement in picture quality, especially with regard to rendering of skin tones.

Spectral-emission curves for 4500 and 3500 white fluorescent lamps are shown in Figs. 3 and 4, respectively; while Figs. 5 and 6 show the photoeffectiveness of the 5769 image orthicon with these lamps. The pertinent color balance and signal-level data are included in Table I, from which it is apparent that the 4500-degree white fluores-

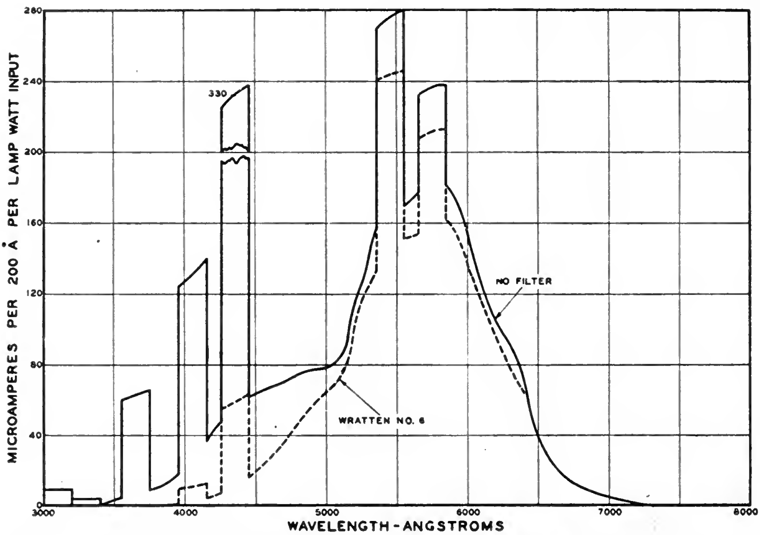


Fig. 9—Photoeffectiveness of 5820 image orthicon 3500 white fluorescent lamp.

cent lamp provides more useful energy per watt and that, when corrected with a Wratten No. 7 filter, color rendering is reasonably good.

Similar photoeffectiveness curves have been plotted for the 5820 image orthicon from the spectral-sensitivity curve in Fig. 7. Figs. 8, 9, and 10 show, respectively, photoeffectiveness for equal watts of 4500- and 3500-degree white fluorescent lamps and of tungsten-filament lamps. Table I also tabulates the signal-level and color-balance data for the camera tube and these sources. This tube is about six times more sensitive than the No. 5769, and the 3500-degree white fluorescent lamp corrected by a Wratten No. 6 filter produces a remarkable degree of color correction with only a 20 per cent loss in signal strength.

Although the 4500-degree white lamp produces more uncorrected radiation in the applicable band than does the 3500-degree, its color rendering is inferior. After correction by a Wratten No. 6 filter, it produces a lower signal level than can be obtained from a similarly corrected 3500-degree white lamp. It is apparent from Fig. 7 that little color distortion is present when tungsten-filament lamps are employed. Since fluorescent and filament lamps are usually used in combination, the effect of the No. 6 filter is shown. A comparison

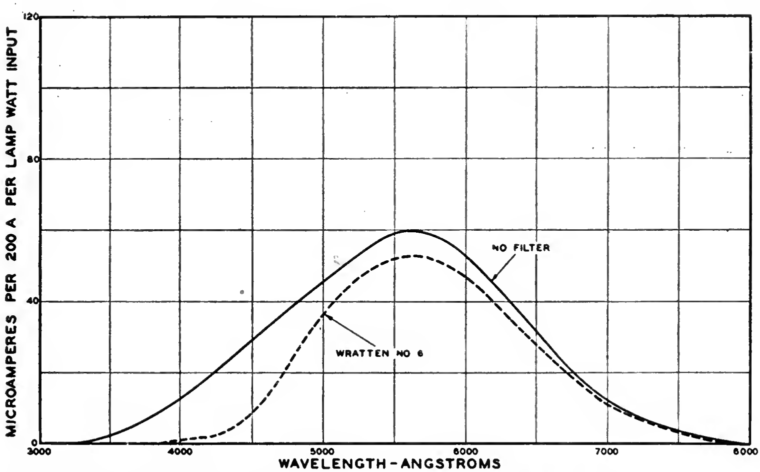


Fig. 10—Photoeffectiveness of 5820 image orthicon 3000-degree-Kelvin tungsten-filament lamp.

of the relative signal-strength figures in Table I, however, shows the advantage of using fluorescent lamps wherever possible.

CONCLUSIONS

1. The general lighting on which camera adjustments depend should provide uniform illumination of vertical surfaces of an intensity somewhat greater than the horizontal illumination from overhead.

2. Materials employed on a stage should be selected to produce brightness ratios no greater than 20 to 1.

3. Two forms of specific lighting are needed to produce an illusion of 3 dimensions on the receiving screen—modeling and back lights.

These are added to the general illumination that establishes the signal level.

4. Distortion of color rendering should be reduced by the use of filters at the camera and by the selection of light sources whose spectral-energy distribution most nearly complements the sensitivity of the camera tube and results in a combined response that approximates the luminosity curve of the eye.

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Air Cooling of Motion Picture Film for Higher Screen Illumination*

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Summary—**Screen illumination in theater projection is limited by a maximum radiant-energy flux through the projector aperture. Excessive flux heats the film beyond its safe operating temperature, producing high-intensity effects in the film with loss of image quality on the screen and possible film damage. An increase of 30 to 60 per cent in permissible flux and in attainable screen illumination can be effected if film is cooled and its position controlled by high-velocity air jets directed at the film in the aperture. The high-intensity film effects are discussed and improvements in film behavior with air cooling are described.**

INTRODUCTION

MAXIMUM SCREEN ILLUMINATION obtainable in motion picture projection has been limited by a number of practical factors. In recent years with the development of more brilliant light sources, faster optics, and improvements in mechanical design, it has become apparent that the film itself is one limiting factor, and that it does not perform satisfactorily beyond a certain maximum intensity of radiation. This limit has already been reached with the lamphouses and projectors currently offered for the first-run de luxe theaters.

Nevertheless, the realization that more light could be used to advantage has been increasing. Especially significant has been the growth in popularity of the outdoor theater, where the viewing conditions demand an unusually large screen area—by comparison with indoor standards—if the seating capacity is to be made large enough for the theater to operate profitably. This larger screen size should be accompanied by an increase in total screen light in order to keep the screen brightness at a satisfactory level. There have been other, although less pressing, reasons for increasing total screen light for indoor theaters, as well as for background projection, and for 16-mm projection. In these cases, little increase in screen size would be attempted, but an increase in the brightness level would improve comfort and convenience as well as permit more illumination of the surroundings.

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The first discussion of the problems of film behavior under the high projection intensities necessary for maximum screen light was given by Carver, Talbot, and Loomis,[1] who pointed out the in-and-out of focus phenomenon and showed its dependence upon radiation intensity. The work described in the present report is a natural sequel to this earlier discovery.

Basically, the maximum permissible radiation on film is set by a maximum film temperature. Film is heated during projection by a net absorption of energy in the photographic image, and the high-intensity projection effects result from the unknown, but fairly definite, temperature levels that the film reaches in the aperture. There are at least four ways of increasing the brightness of the projected image without increasing correspondingly the thermal misbehavior of the film:

(*1*) *Increase the Directional Effect of the Projection Screen*

A screen that is not a good diffuser can concentrate the reflected light into a beam whose angle is more nearly limited to that angle within which the audience is seated, and thus there can be an increase in apparent screen brightness without an increase either in total light upon the screen or in total radiation incident upon the film.

(*2*) *Reduce the Heating Effect of Nonvisible Radiation*

Film is subjected to an amount of infrared radiation which, in the light from a modern high-intensity carbon arc, is approximately equal to the visible energy; all of this infrared can be as effective as the visible in heating the film but contributes nothing to the brightness of the projected image. Such infrared radiation can be reduced by filters which absorb the infrared and transmit the visible; a theoretically perfect filter (removing all of the infrared and transmitting all of the visible) would permit a doubling of the permissible screen illumination without increasing the resultant heating of the film.

In addition to the heating produced by infrared radiation, there may be heating by other "useless" radiation. Any energy incident upon the film which does not contribute to the brightness of the projected image, tends needlessly to increase film temperatures; on some projectors, the shutter arrangement permits radiation to fall upon the film during the time that none is transmitted to the screen; in other equipment, the film is illuminated by a cone of light of greater aperture than the projection lens can accept. Finally, some "indirect heating" may be experienced, if the spill-over illumination intercepted by aperture baffles, and so forth, is allowed to raise the temperature of the film trap and other metal surrounding the film path.

(3) *Increase the Cooling of the Film*

Energy absorbed by the film during projection goes only partly into raising the film temperature, since some energy is reradiated from the film to cooler surroundings, and some is lost by convection to the air. If the amount of energy that the film loses can be increased, there can be an increase in the amount absorbed with no rise in film temperature. One method of increasing the rate of heat loss from the film is to impinge a high-velocity air jet upon it so that the coefficient of heat transfer from film to air is considerably increased.

(4) *Restrict the Film Motion Mechanically*

As will be described later, some of the high-intensity effects limiting the radiation intensity on film appear as an undesirable film motion during the projection interval when film is supposed to be steady in the gate. In some cases, this motion can be restricted or prevented by mechanical means, such as the glass plates used on each side of the film in some viewers, or the forces exerted by streams of air directed at the film in the projector aperture.

This report covers only the application of the latter two methods of increasing permissible screen illumination, that is, increased cooling of the film, and mechanical restriction of film motion.

PREVIOUS WORK

Air cooling of film has long been an attractive possibility for extending the satisfactory operating range in projection, and there have been many attempts to develop theater and background projectors—for both motion pictures and slides—employing air cooling. For the most part, such equipment has used a rather large volume of air at low velocity, effective in a partial cooling of the metal structure of the gate but much less effective than high-velocity air in cooling the film itself. Also it is only recently that the movement of film during the instant of projection has been known, so that in this earlier work positioning problems were imperfectly understood.

Several years ago, the Research Council,[12] in preparing its recommendations for the design of a process projector, called for air cooling as an additional safeguard for film to be used under the most severe projection conditions. Likewise, air cooling was provided by Waller[15] in the Waller Flexible Gunnery Trainer, where the radiant flux on the film is not high but the dimensional stability is extremely critical.

In the field of slide projection, Edouart[4] described air cooling in the Paramount Process Stereopticons, which have an air duct designed for minimum resistance to flow and baffles inserted to direct air onto the slides. Popovici[11] described a variation using refrigerated air. An even more critical installation was described by Tuttle[14] who discussed the cooling of slides in a glass-enclosed gate, so that the air stream could be completely directed and controlled past the slide.

There were other similar uses of air cooling, but so far as the published accounts show, none realized the high air velocities at the film surface recommended in this report, none appreciated the dual cooling and positioning functions of air on cine film, and none were successful in extending the safe projection limits to the levels reached in these experiments.

Measurement of Radiant Energy

Early in the program of studying high-intensity projection, it became apparent that a reproducible method of measuring radiant energy incident upon the film was essential. Such a basis was made possible by the work of Zavesky, Null, and Lozier,[17] who reported energy measurements on a number of typical carbon arcs, but unfortunately their methods of measurement can be duplicated only in the laboratory and require a special setup. Hatch[6] has proposed a portable meter for indicating radiant energy at the center only of the aperture in a projector head. We have built such a meter (which Zavesky, Null, and Lozier have calibrated against the more accurate measurements made in the National Carbon Company's Research Laboratory[8]) and used it for determining the level of radiation intensity in all of our experiments and for correlating a limited amount of information from the trade.

One caution should be observed in comparing our results. Zavesky, Null, and Lozier[17] report radiation output from the various arcs as that value obtained with no shutter, heat-absorbing glasses, or other absorbing elements in the beam. We have found it more convenient, on the other hand, to report what is actually incident upon the film—taking into account the reduction in energy produced by the rear shutter plus any reduction produced by draft glasses, heat-absorbing glasses, and so forth. To prevent confusion, we have chosen to call the Zavesky, Null, and Lozier figures with no shutter or absorbers "instantaneous flux"; the values measured with no shutter but with other normal absorbers (draft glasses, heat-absorbing glass, and so forth) "instantaneous net flux"; and the values including shutter plus other absorbers "mean net flux."

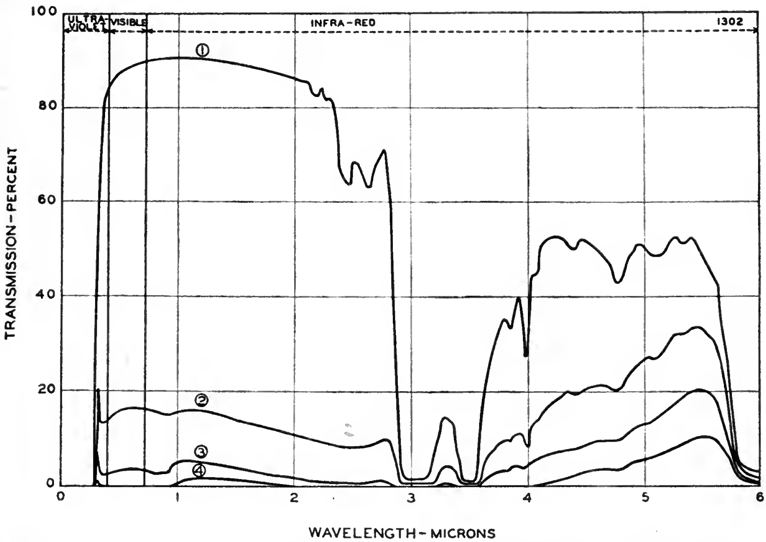

Fig. 1—Spectral transmission of Eastman nitrate fine-grain release positive, Type 1302.

The transmission in the ultraviolet, visible, and infrared of nitrate positive having successively increasing silver densities.

Curve	Image	Visual Density
1	Cleared, no silver	0.04
2	Silver, uniform flash	0.58
3	Silver, uniform flash	1.10
4	Silver, uniform flash	2.10

Our data indicate that the factor influencing film behavior in theater projection is best represented by this figure of "mean net radiant flux" upon the film.

Heating of Film

Film is heated during projection because the photographic image has a net absorption for radiation, both visible and infrared; in addition, it transmits some radiation and scatters some radiation, and, as its temperature rises above that of the surroundings, it loses energy by convection to the air and radiation to the surroundings. All of the net absorbed radiation acts to raise the film temperature, so that 1 watt of visible radiation absorbed by the film is as effective in raising film temperatures as 1 watt of infrared radiation or 1 watt of mixed radiation.

That the absorption depends upon the density of the photographic image is shown in Figs. 1 and 2, which present, respectively, the transmission of nitrate and of safety release positive. Each figure

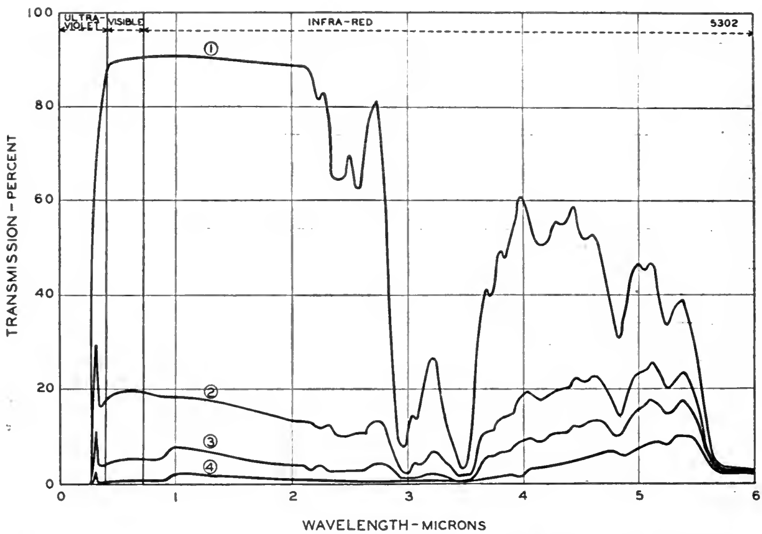

Fig. 2—Spectral transmission of Eastman safety fine-grain release positive, Type 5302.
The transmission in the ultraviolet, visible, and infrared of safety positive having successively increasing silver densities.

Curve	Image	Visual Density
1	Cleared, no silver	0.04
2	Silver, uniform flash	0.56
3	Silver, uniform flash	1.02
4	Silver, uniform flash	1.84

shows the transmission of clear film, together with that of film having increasing silver densities. It will be apparent that for our purposes nitrate and safety film can be considered equivalent.

Fig. 3 presents the distribution of energy in the crater light from a typical high-intensity carbon arc;[9] slight modifications will be introduced by the transmission properties of the optical system. It will be seen that by far the major portion of the energy is found in the range between 0.3 and 2.8 microns on the wavelength scale; referring back to Figs. 1 and 2, we note that clear film is almost completely transparent in this same range. In other words, the absorptions of film base and of film emulsion representing a transparent area in the photographic image are negligible. (The difference between actual

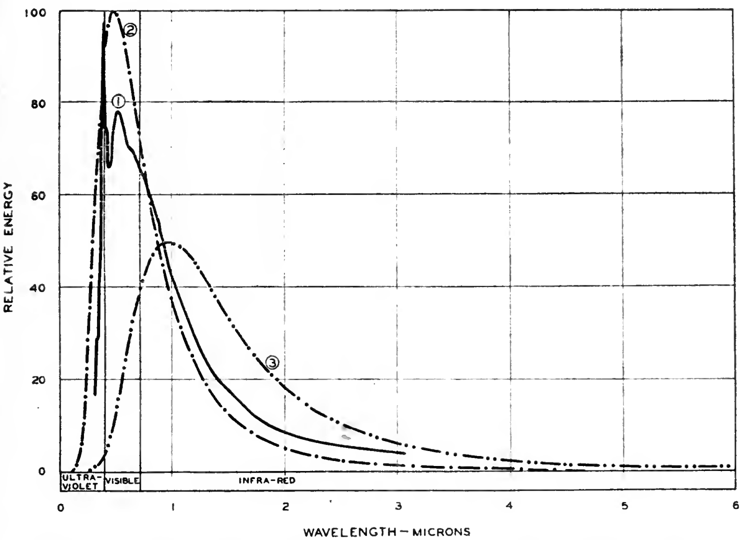

Fig. 3—Relative energy emission of selected projection light sources. The amount of energy emitted at the various wavelengths (uncorrected for absorption by condenser lens, and so forth) for arc and incandescent projection sources. The curves are drawn with equal total energies. Note that although a black-body radiator at 6000 degrees Kelvin gives an approximate color match to high-intensity arc radiation, it is not so satisfactory an approximation to total energy distribution.

Curve	Description
1	High-intensity carbon-arc crater
2	Black-body radiator at 6000 degrees Kelvin—an approximate visual match for the high-intensity arc
3	Black-body radiator at 3000 degrees Kelvin—an approximate match for the output from a tungsten projection lamp

transmission and 100 per cent transmission of the film samples measured is almost completely explained by the reflection losses at the two film-air interfaces.) It will be seen further that the production of a silver image in the emulsion layer, represented by Curves 2, 3, and 4 in Figs. 1 and 2, results in the absorption of energy in a manner that is approximately nonselective over the interval from 0.3 to 2.8 microns.

Additional evidence for believing that only the image absorbs energy is given by the behavior of dye-image films which are relatively transparent in the near-infrared region, even for relatively high absorption and density in the visible. Such dye-image films show less heating and less of the thermal effects than silver-image film does when projected at the same intensity. We have found this advantage of dye-image films to be roughly proportional to their transparency in the infrared.

What actual temperature the film reaches during projection is an interesting question that has never been answered satisfactorily. Obviously, the limitations of pulldown time, together with the limitations of the size of the film, make direct experimental measurement extremely difficult. A number of estimates have been made, however, and perhaps the best is that of Paschkis,[10] who set up an electrical analogy to the heat-transfer problem and thereby estimated the temperatures at various positions across the film thickness as a function of time during the projection cycle. The accuracy of these values theoretically is limited only by the accuracy of the necessary assumptions that must be made in setting up the problem. For example, one must assume the proportion of incident energy absorbed by the film, the location of that absorption, the thermal constants of an emulsion containing the metallic sponge of a silver image, the nature of the heat loss from the film surfaces, and so forth. The results of his estimate are presented in Fig. 4, which indicates the temperature rise in the film cross section at intervals from first exposure to temperature equalization after pulldown. The actual temperature reached by the film during the projection cycle depends first upon its initial temperature when it enters the aperture, and second upon the amount of energy absorbed. The temperature rise above the initial temperature is directly proportional to the amount of energy absorbed, as is indicated in the ordinate of Fig. 4, which is labeled $\Delta T/Q$, the temperature rise in degrees Fahrenheit for the absorption of 1 watt per square millimeter of radiant energy. It will be observed that this energy figure is not the "mean net energy" used throughout the rest of this paper, but the "instantaneous net energy" incident upon the film during the time that the beam is uninterrupted by the shutter blades.

Estimated temperature distributions in the emulsion layer—the peaks of the curves in Fig. 4—depend somewhat upon where in the emulsion cross section absorption is assumed to take place. Even these changes are small, and in the film base under any reasonable conditions, the curves are constant. If we take, for example, an instantaneous net flux of 0.80 watt per square millimeter, the approximate limit for projection without in-and-out of focus difficulties, and

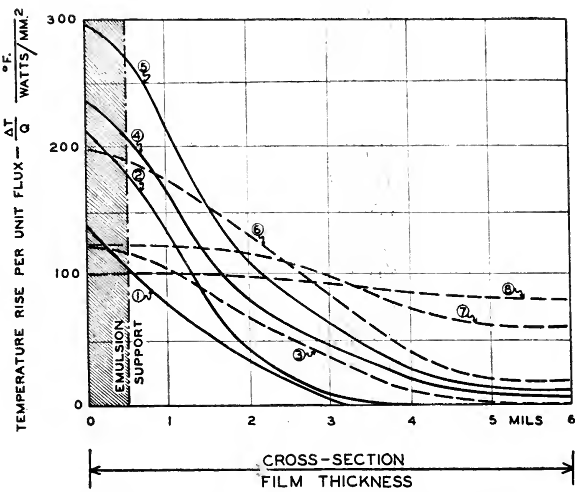

Fig. 4—Temperature rise in film during projection.
Estimated film-temperature rise for points on the film cross section as the film is heated by absorption of radiant energy in the film image. The magnitude of the temperature rise is directly proportional to the amount of radiant flux absorbed. See text for discussion of the method of estimating, and the assumptions involved.
The curves represent the temperature distribution at different times during the projection cycle, as follows:

Curve No.	Time in Milliseconds from First Exposure to Light	Description
1	6.4	Middle of first exposure
2	12.5	Start of flicker blade
3	20.8	End of flicker blade
4	26.8	Middle of second exposure
5	33.3	Start of pulldown blade
6	41.6	End of pulldown
7	83.0	End of second pulldown
8	124.0	End of third pulldown

imagine it all to be absorbed, there is a temperature rise in the emulsion of

$$\Delta T_e = (0.80)(300) = 240 \text{ degrees Fahrenheit}$$

and in the base immediately in contact with the emulsion

$$\Delta T_b = (0.80)(275) = 220 \text{ degrees Fahrenheit.}$$

For normal projection where the initial film temperature may be 80 degrees Fahrenheit, this represents a maximum emulsion surface temperature of 320 degrees Fahrenheit and a maximum base temperature of 300 degrees Fahrenheit.

We have no conclusive experimental method of determining how nearly correct these temperatures may be, but what evidence there is suggests they are not greatly in error. It is probable that film is able to perform as successfully as it does only because these peak temperatures are maintained for such short periods of time (as shown by the rapid equalization in Fig. 4), since film held continuously at these temperature levels distorts and loses essential physical qualities very rapidly.

HIGH-INTENSITY EFFECTS

When film is projected at these higher intensities, a series of phenomena occur, depending upon the particular projection intensity being studied. Many of these effects have been described by Carver, Talbot, and Loomis[1] and hence only a brief review is needed here. Listed in order of their appearance with increase in radiation intensity, these effects are summarized in Table I.

TABLE I

HIGH-INTENSITY PROJECTION OF FILM

Projection Phenomenon	Intensity Threshold Mean Net Watts/Mm²
1. Negative drift	. . .
2. Embossing	0.20–0.30
3. Change in reflected image tone	0.30
4. Focus drift	0.35–0.40
5. Image flutter	0.40
6. In-and-out of focus	0.50
7. Blistering	0.60–0.65

Of these phenomena, negative drift is an entirely normal film characteristic which is present to greater or lesser extent in all cine projection. Embossing and the change in reflected tone have never, in our experience, contributed any deleterious effect to screen quality. Focus drift is perhaps a necessary evil that must be tolerated if maximum projection intensities are to be used. Image flutter is usually visible only to a critical observer, but in-and-out of focus and blistering are two phenomena which make it impossible to obtain a satisfactory screen image; they take the control of image quality completely out of the hands of the projectionist. Accordingly, it may be said that the first four of these phenomena are necessary or at least harmless occurrences, while the fifth is borderline, and the last two must be avoided.

Some confusion has existed in the descriptions of film behavior because of the use of several names for describing the same effect. This discussion follows the terminology of Carver, Talbot, and Loomis,[2] in order to keep separate the terms that describe physical behavior of film from those that describe thermal behavior.

(*1*) *Negative Drift*

It was shown by Carver, Talbot, and Loomis[1] that film in the aperture is almost never flat and that its position bears no relationship to the curl or other physical shape it may have either entering the top of the projector gate or leaving the bottom of the gate. Film in the aperture under the influence of the light beam behaves as though the emulsion surface were expanding with reference to the base dimension, so that each frame is distorted into a pincushion shape with the emulsion surface on the convex side; since the edges are held, the center of the frame is displaced toward the arc.* This is a perfectly normal phenomenon occurring in all cine projection. High-speed pictures taken into the aperture show the center of the frame beginning to move toward the light source (which in our convention is called motion in the negative direction) from the first instant of its exposure to light. During the passage of the flicker blade, a partial recovery is effected, and with the second exposure to light the negative drift resumes and is carried to its maximum amplitude. Just how far negative the film drifts depends upon the intensity of incident radiation; the greater this intensity the greater will be the film motion.

* This conclusion assumes standard emulsion position for theater projection. If the emulsion position is reversed and the film is threaded emulsion to lens, as in some process projectors, and much 16-mm projection, it is still the emulsion surface that expands with reference to the base; accordingly the center of the frame is now displaced toward the projection lens. This paper assumes theater standard emulsion position throughout; if the results are to be applied to projection with the nonstandard emulsion position, the direction of film motion *with respect to the projector* will be reversed for negative drift, focus drift, image flutter, in-and-out of focus, and positive drift.

Under projection conditions approximating that of a first-run de luxe house, we have observed film motion of approximately 0.020 to 0.025 inch from the flat plane as a reference. With intensities in excess of what film will stand for repeated projection, we have observed a maximum negative drift of approximately 0.045 inch.

(2) Embossing

At higher levels of projection intensity (and the first-run de luxe houses have now reached this value), embossing of the film is observed. This is a permanent film deformation, resembling an incomplete recovery from the negative drift just discussed. Actually, two types of embossing are observed: (a) frame embossing, wherein the entire area of each frame appears to be raised slightly above the normal surface of the film—as a row of separate pincushions—and (b) image embossing, wherein the dark and light areas of the image are seen by reflected light to be at slightly different elevations from the nominal film surface. These two types of embossing probably begin simultaneously somewhere in the range of mean net radiation intensity 0.20 to 0.30 watt per square millimeter. Of course, at the lower intensities the embossing is minute, and can be observed only with difficulty when the film is examined under low-angle reflected light. With increasing intensities, the amount of embossing increases until it can be seen when the film is examined under normal illumination. Even when the film is severely embossed so that the center of each frame is displaced as much as 0.005 to 0.010 inch from the film plane, we have never observed any deterioration of image quality or any visible indication on the screen that this film is different from unembossed film.

(3) Change in Reflected Image Tone

Some types of film, after projection at higher intensities, show a change in reflected image tone even though the image tone by transmission is not affected. This phenomenon appears somewhere in the region of 0.30 mean net watt per square millimeter. Film thus affected shows a warmer tone when the film itself is examined by reflected light, and the tone of the frame is seen to be different from the original tone of the unprojected frame lines and film edges. No satisfactory explanation has been offered for this phenomenon; it is one of those occurrences which, though interesting, have no influence on the quality of the projected image.

(4) *Focus Drift*

As the projection intensity is increased still further, it is observed that the projectionist must now refocus occasionally during the projection of a single reel of film. This appearance of focus drift begins somewhere in the region 0.35 to 0.40 mean net watt per square millimeter. Depending upon the circumstances, there may appear to be a rather sudden change in focus with the transition from scene to scene, even though there is no splice in the film at this transition. Or it may appear that there is a gradual loss in sharpness of the projected image obtained at the start of the roll, and this must be corrected by occasional focus resharpening.

At intensities where this phenomenon occurs, we believe the only satisfactory solution is more constant attention by the projectionist. The influence of this effect can be minimized, however, by the technique of the initial focusing. Every projectionist has observed that in the setting of the projection lens there is some leeway over which the projected image remains approximately equally sharp. It is apparent that if the lens is set at the mid-point of this tolerance, slight film motion in either direction may not exceed the depth of focus of the projection lens; if, however, the lens should be focused at the limit of its tolerance, film motion in one direction will be obvious immediately as a softening of the picture detail. If the projectionist acquires the habit of setting his lens at the approximate mid-point of this depth of focus, the necessary focus corrections will be minimized.

This focus drift is apparently the result of a gradual variation in the amount of negative drift of the film at various points in the roll, induced perhaps by changes in moisture content, degree of exposure to air, and other intangible variables of film handling. When the amount of negative drift is small, variations in the amount pass unnoticed, but with the increase in magnitude of negative drift at higher intensities, some of these variations may be large enough to exceed the 0.002- to 0.004-inch tolerance in lens position for maximum screen sharpness.

(5) *Image Flutter*

Beyond the limit of radiant-flux density at which film can be projected without image difficulty, the first warning is a softening of the focus—which we have called "image flutter." The picture is still reasonably sharp upon the screen and it might well be that to the theater audience no lack of quality would be apparent. However, when we project test films which we know to be printed sharply and in which we are familiar with the best quality that can be obtained—so that any departure is obvious—we observe a softening of focus and a loss in detail that cannot be corrected by shifting the projection lens. In other words, at the point of best focus, the image quality is slightly less than optimum. This is a preliminary to in-and-out of focus, which is observed with the next increase in radiation intensity, and may be produced by the same basic phenomena. There is a sharp transition, however, since image flutter is visible only with careful examination, while in-and-out of focus is immediately obvious even to the most uncritical audience.

(6) In-and-Out of Focus

As the projection intensity is increased, a point is reached where the normal negative drift of each frame in the aperture is modified, and continued projection at higher intensities eventually replaces the negative drift with an actual positive drift or displacement of the film in the opposite direction. The appearance and degree of positive drift are a function of the radiation intensity, together with the previous projection history of the film. We have observed a maximum positive drift of about 0.045 inch. During the time when all the frames show negative drift, or the time when all frames show positive drift, a sharp steady picture can be focused upon the screen. In the transition period, however, it appears that some frames reach the point of positive drift ahead of their adjacent frames, and high-speed motion pictures show that some frames go negative, while others near by go positive. The limits of these two opposite film motions exceed the depth of focus of the projection lens and the phenomenon of in-and-out of focus is observed. Under these conditions, no one setting of the projection lens will focus all frames equally sharp, and the transition from negative to positive is so rapid and unpredictable that the projectionist has no possibility of following it. Film that is going in-and-out of focus is completely unacceptable for theater projection. We have observed that in-and-out of focus occasionally may be observed at projection intensities of 0.40 mean net watt per square millimeter; and that, beyond an intensity of 0.50 mean net watt per square millimeter, in-and-out of focus is almost certain to occur within the first five to ten days of projection in the theater. (In-and-out of focus, as well as many of the other focus effects, can be accelerated by abnormally high moisture content of the film.[1, 13])

(7) *Blistering*

With the increase in projection intensity to still higher levels, the film is observed to blister during projection. These blisters form in the film base immediately adjacent to the emulsion (where, as shown in the curves of Fig. 4, maximum base temperatures are reached). Depending upon the conditions of their formation, these blisters may be so small that the separate blisters are indistinguishable to the naked eye, or they may reach a diameter of approximately 0.005 inch. Once blisters appear, the film is useless for further projection, since the thermal isolation of the emulsion directly over the blister causes it to reach so high a temperature as to burn off and disappear. The unburned blisters show on the screen as dark spots resembling the sudden appearance of severe grain in the image, and the burned-through blisters show as white areas on the screen surrounded by obviously charred emulsion. The exact level at which blistering appears is dependent upon the type of film under consideration but for release positive, a mean net flux of 0.60 to 0.65 watt per square millimeter is required. It should be pointed out, however, that in-and-out of focus appears only after repeated projection, while blistering may be observed on the very first run. Accordingly, in an untested setup the in-and-out of focus threshold may be exceeded and even the blistering threshold passed; film projected under such conditions will blister rapidly and nevertheless require a number of projections of the blistered film before in-and-out of focus is observed. This represents an extreme case, however, and it is safe to say that tested equipment *already shown safe for in-and-out of focus* will not blister release positive.

It is apparent that the high-intensity effects which depend almost entirely upon film temperature can be modified or prevented only by preventing the film from reaching these damaging temperatures. High-intensity effects that are influenced not only by temperature but by other factors sometimes can be postponed even though the temperature threshold is exceeded.

EQUIPMENT FOR AIR COOLING

For these experiments, a radiation source capable of producing more energy than the present commercial projection lamphouses was necessary. The Peerless Hy-Candescent lamphouse was specially modified[5] to operate with water-cooled positive jaws and permit the burning of experimental trims[7] at currents and radiation intensities up to 65 per cent in excess of present commercial equipment, providing an instantaneous net flux of 1.65 watts per square millimeter and a mean net flux of 0.99 watt per square millimeter. Such trims were supplied by the National Carbon Company.

Vycor protection plates for the condensers were used, as recommended by Daily,[3] since these experimental trims burning close to the condenser tend to cause excessive pitting and spattering of the silica condenser lens. Furthermore, a $^1/_8$ inch thickness of Vycor is effective in preventing solarization and the resulting loss in transmission of the silica condenser.

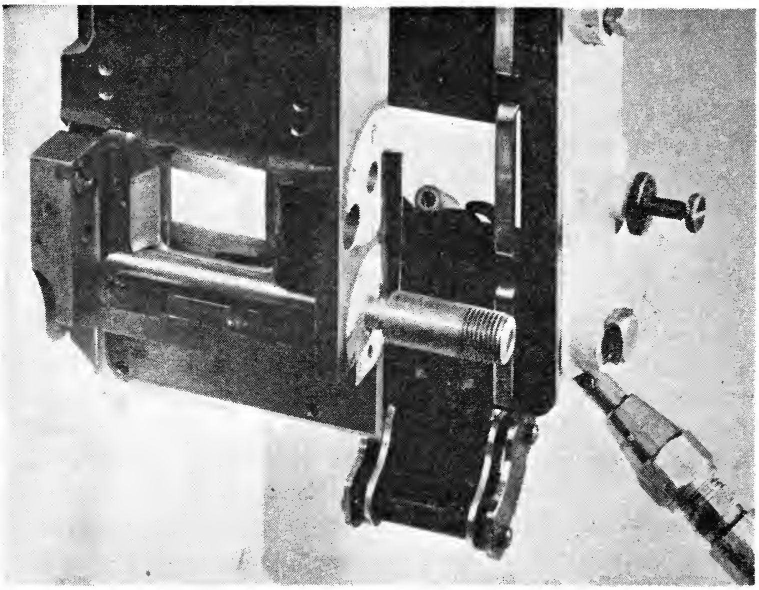

Fig. 5—Experimental film trap for air cooling.
A set of nozzles has been installed to show one of many possible methods of mounting nozzles to direct air at the emulsion side and at the base side of the film.

Our test projector is a Simplex E-7 with the gate modified as in Fig. 5 to permit the introduction of air-cooling nozzles. The projector was operated with a 60 per cent rear shutter and over-all shutter transmission to the screen of 50 per cent.

The air supply was obtained from the pressure tank of an air compressor, with the air throttled down so that it entered the nozzles at a pressure of only a few pounds per square inch. For the pressure and flow rates found necessary in the particular equipment tested, a rotary blower would have been a more satisfactory and less expensive source of low-pressure air.

A number of nozzles of different design were tested for cooling efficiency; some of these are shown in Fig. 6. These nozzles range from 0.007 to 0.14 square inch in area and were found to operate best with a

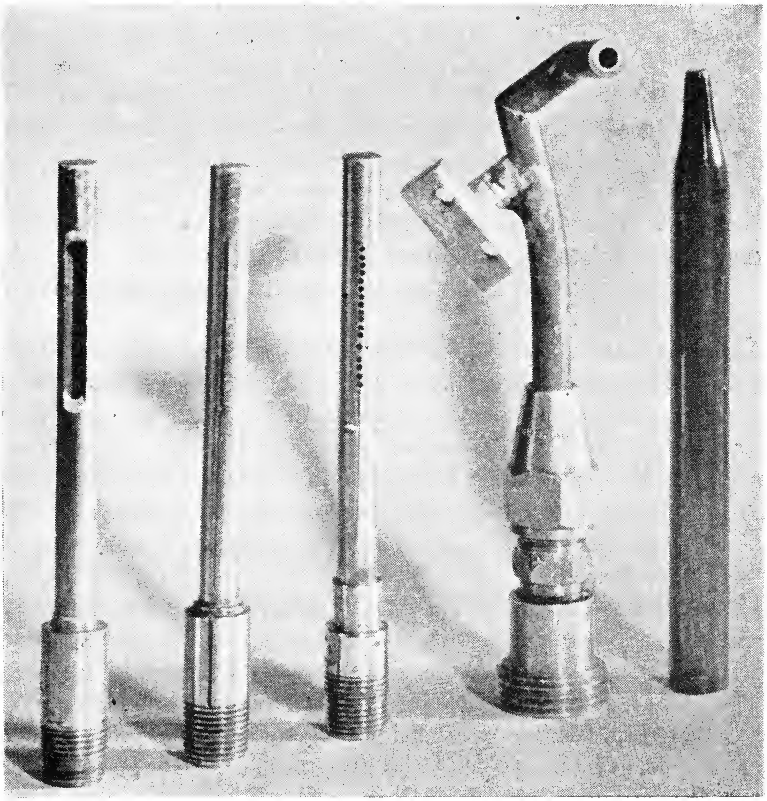

Fig. 6—Selected nozzle types for air cooling.
These nozzles are shown to indicate the variety of shapes tested, and to suggest further designs that may prove best adapted to certain equipment.

free-air velocity at the nozzles from 250 to 500 feet per second. It should be pointed out that the choice of a suitable nozzle is a compromise among cooling efficiency, ease of mounting and direction, method of construction, space available, and freedom from interference with the normal projector performance. The nozzles used in this test were chosen for their ease of installation in the Simplex E-7 projector. We feel it is undoubtedly true that more efficient nozzles with a lower noise level could be designed and built, particularly if one were free to alter the rear of the projector in order to make room for an optimum installation of the nozzles.

Cooling of Film

In order to measure how much cooling is actually obtained by air jets directed at the film in the aperture, measurements were made leading to two series of data. In the first, an approximate heat-transfer coefficient was determined for film cooled by high-velocity air; in order to make such a determination, it is necessary to know the film temperature—and as a result, measurements had to be made at very low radiation intensities such that film could be left stationary in the gate and its temperature measured with an attached thermocouple. A second set of data was obtained making use of an experimental film containing an indicator that changed visually when its temperature threshold had been exceeded.

Measurements of the approximate heat-transfer coefficient at low radiation levels (in engineering units for convenient correlation with published data on air cooling) are shown in Fig. 7. These data must be taken as indicative only, and while we expect the basic conclusions drawn from these data to apply to all methods of air cooling, the quantitative values of the heat-transfer coefficient depend greatly upon the type of nozzle used, its exact location in the gate, the angle which the air stream makes with the film, and the level of radiation intensity.

Examination of Fig. 7 and of related data indicates two important conclusions about the use of air jets for cooling: (1) The heat transfer coefficient (or the cooling efficiency) depends primarily upon air velocity and increases approximately as the 0.9 power of the velocity. (2) Cooling efficiency is only slightly affected by the volume of air used, and at constant velocity the heat-transfer coefficient increases only about as the 0.3 power of the air volume. This conclusion has been verified throughout our experimental work, and accordingly the problem of cooling film with air during projection becomes a matter of cooling with high-velocity air. That this should be true is apparent when we realize that the air immediately adjacent to the film surface is relatively stationary and sheltered from the air currents which might be set up at the back of a projector, and yet all the heat lost to the air must be conducted across this stationary layer and into the many air currents of the projection booth. By increasing the velocity of air from the jet, a scrubbing action is produced on this layer of stagnant air, reducing its thickness and reducing the insulating effect that it has in limiting the cooling of the film. The higher the air velocity the better the scrubbing action and the less stagnant air is present to impede the rapid loss of heat from the film.

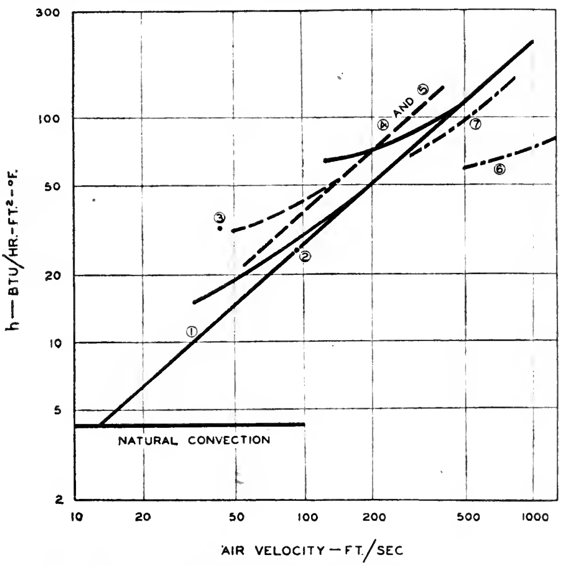

Fig. 7—Cooling cine film by high-velocity air.
Heat-transfer coefficient as a function of air velocity for several types of nozzles. (Gross coefficients not corrected for losses by radiation.) Coefficients were measured at low radiation flux densities.

	Nozzle	
Curve	Size	Description
1	0.015″ × 1.06″	Slit
2	0.052″ × 1.20″	Slit
3	0.126″ × 1.10″	Slit
4	0.077″ diameter single nozzle	
5	0.124″ diameter single nozzle	
6	0.018″ diameter row of 28 holes	
7	0.040″ diameter row of 17 holes	

In order to supplement this work on determination of heat-transfer coefficients for stationary film with actual projection data, a different method of determining film temperature became necessary. It was found possible to make an experimental film—totally unsatisfactory as release positive but adequate for test projection—which could be made to indicate when the film had exceeded a certain temperature threshold. For these experiments, such an experimental film was used, adjusted to give an indication at a temperature level approximating that reached under normal projection with present de luxe equipment. This makes it a convenient experimental tool, since if the conditions can be so arranged that this experimental film can be projected with no change, one is reasonably sure that conventional cine positive can be projected with none of the more serious high-intensity image defects. Fig. 8 shows the results of projecting this experimental positive at high intensities with the incorporation of high-velocity air

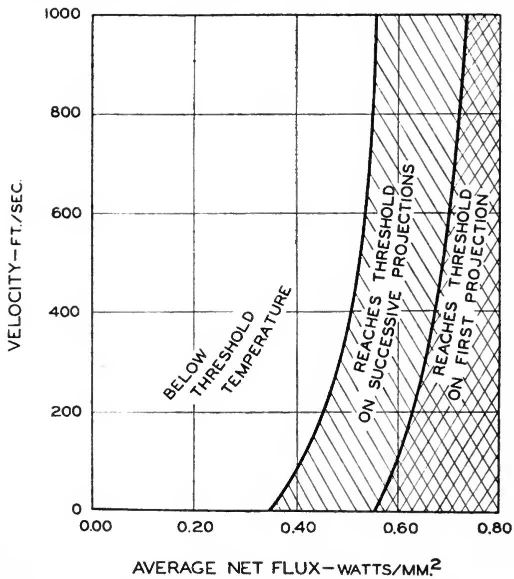

Fig. 8—Reduction in temperature of experimental film accomplished by high-velocity air.

Graph shows number of projections of a loop of experimental film before it reached an unsafe temperature, and points out how much the region of normal behavior can be extended by air cooling.

cooling. It will be seen from Fig. 8 that this experimental positive can be projected at intensities up to approximately 0.35 mean net watt per square millimeter and no change is experienced even without cooling air. To exceed this limit, however, air must be applied—and in our particular equipment, the use of air velocities at the nozzle up to 400 feet per second permits increasing the mean net radiant flux to 0.50 watt per square millimeter, or an increase of over 40 per cent, with no increase in film temperature. An increase slightly beyond this limit can be obtained by raising the air velocity still higher, although the returns are diminishing. The data of Fig. 8, therefore, show that it is possible to obtain approximately a 50 per cent increase in radiant-energy flux on the film and still maintain acceptably low film temperatures through the use of a rather simple air-cooling arrangement.

In the higher air-velocity range, the data of Figs. 7 and 8 are not entirely consistent, for one shows a continuing increase in cooling with increasing air velocity while the other shows only minor increases beyond 600 feet per minute. This is not surprising since they were obtained under widely different experimental conditions. It also may not be of great practical importance, since in our equipment the very high velocity range is accompanied by an intolerable amount of noise at the projector.

Measurement of Film Position

Before going on to discuss the problems of in-and-out of focus and the positioning of film in the aperture, the methods for determining this film position should be reviewed. In the original article by Carver, Talbot, and Loomis[1] a method of observing film position was described depending upon a gauge indicating the motion of the projection lens with respect to a fixed point on the projector mechanism. This system has been preserved essentially unchanged, with the substitution only of a dial gauge for the lever gauge originally used. This dial gauge shown in Fig. 9 indicates motion of the lens with respect to the projector frame.

Calibration to relate these values to actual film displacement from a flat plane in the gate makes use of a ground-steel gauge block with a small hole in its center, which holds thin glass-fiber cross hairs in the position that the image would occupy in film held perfectly flat in the gate. Illumination is provided by a small headlight lamp, located in crater position so that the optical system of the lamp and projector is completely filled. When the cross hairs are focused sharply on the screen, the gauge is set to zero. The convention used in designating direction of film motion from this zero, it will be remembered, is to call motion toward the light source negative and motion toward the projection lens positive. In the article it was pointed out that when the best visual focus is obtained upon the screen, the projection lens is actually focused upon the limit of film travel in the negative drift that is occurring during the projection of each successive frame. Thus, the departures from ideal flatness in the gate that are indicated by measurements of film position with this technique are the maximum values for each frame.

Such measurements of film position provide one of the best methods of following those high-intensity projection effects which depend on previous projection history. If one plots the best visual focus for succeeding projections of the same film, relatively minor trends will be found if no image trouble is encountered. A typical curve is that for condition *A* of Fig. 10. This represents normal negative drift, decreasing slightly with time; it may be accompanied by the appearance of embossing and change in reflected image tone. If intensities are

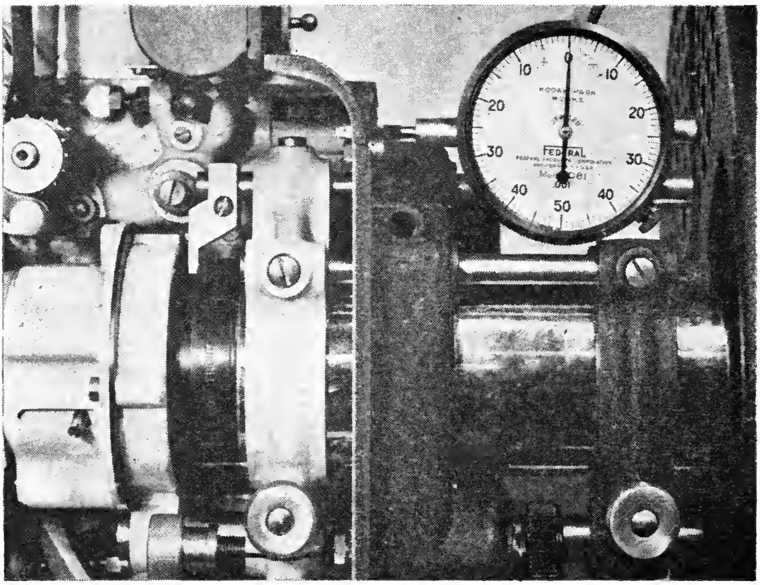

Fig. 9—Indicator for determining film position at the point of best focus. The dial gauge measures lens displacement from a fixed reference point. Calibration refers this "zero" to the plane that the image on perfectly flat film would occupy in the gate.

increased to a level that produces in-and-out of focus, however, a curve like that for condition *B* of Fig. 10 results. With successive projections, the focus position changes from negative to positive; as the zero position is approached, image flutter appears, and around zero, in-and-out of focus will be found. With successive projections, negative drift is completely replaced by positive drift, and the image quality improves.

During an accelerated laboratory test, in-and-out of focus may be encountered after 2 to 15 or more projections, and the subsequent improvement in image quality may come in from 2 to 10 projections additional. In a theater where generally longer times elapse between projections, in-and-out of focus may begin in several days to several weeks, and last correspondingly longer.

It is particularly convenient when comparing various projection conditions to study the changes in focal position during accelerated

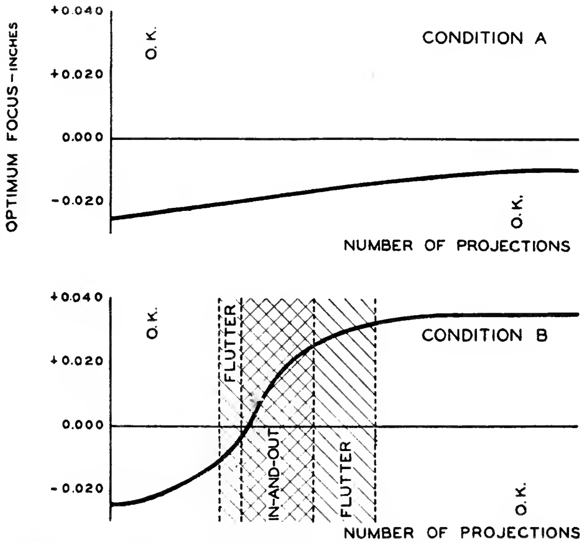

Fig. 10—Projection history of film as measured by changes in the point of best focus.

If the point of best focus is determined for each projection of the film, the resulting curves can be related to film performance. This is particularly valuable for preliminary rapid testing to predict film behavior in the trade. A slow rate of change of focus, as in condition *A*, is typical of good screen quality; a rapid rate of change of focus as in condition *B* is always accompanied by poor image quality on the screen.

laboratory tests. A rapid focus drift from negative toward positive indicates early trouble in the theater and unsatisfactory projection conditions; a slow or negligible change indicates that no serious image difficulties should be encountered.

MECHANICAL DISPLACEMENT OF FILM

It will be apparent from what has already been said about the negative drift of film in the aperture under normal intensities, and the in-and-out of focus combination of negative and positive drift at higher intensities, that film in the aperture under certain conditions can assume an equilibrium position anywhere over a range of approximately 0.100 inch. It might be assumed from this that the mechanical force of an air jet impinging on the film could contribute to positioning the film somewhere in this range, and the experimental work showed indeed that film can be moved in the aperture solely by the mechanical force of the impinging air jets. Fig. 11 presents a generalized picture of what the forces of air jets can contribute to displacement of film in

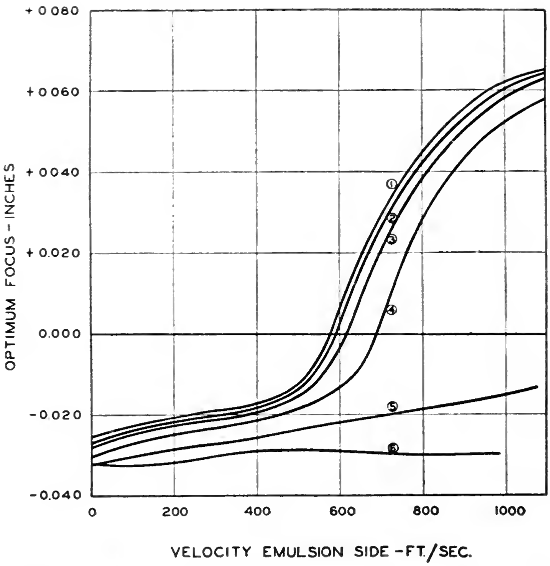

Fig. 11—Mechanical film displacement as a function of air flow from the nozzles.

The two nozzles used in this experiment made an angle of about 30 degrees to the film plane, and in this position each tended to displace film in the direction of the air flow. The curves show the behavior of freshly processed film without a previous projection history. Note that a resultant force capable of forcing film through zero and even forcing it far positive can be obtained if the emulsion-side nozzle sufficiently overpowers the base-side nozzle. Conversely, an overpowering base-side nozzle will hold film in the desirable negative deflection.

Curve	Velocity from Base-Side Nozzle, Feet per Second
1	0
2	250
3	360
4	520
5	745
6	1040

normal projection. The data for Fig. 11 were obtained during the projection of a roll of fresh film at normal intensities, where, if left to its own devices, without air impingement, the film would have taken an equilibrium position at approximately −0.026 inch. With a series of air flows directed both from the emulsion side and the base side of the film, it will be seen that this equilibrium position can be displaced to a maximum negative displacement of −0.035 inch and a maximum positive displacement of greater than +0.060 inch!

With no air on the base side and air impinging only from the emulsion side, it will be seen that near the mid-point of the air-flow range, the film was restrained from its normal negative drift to the extent that it was held nearly flat in the aperture, and that further air on the emulsion side displaced the film toward the projection lens. The action of air on the emulsion side only in pushing film toward the projection lens can be counterbalanced by air directed on the base side. It can be seen also from Fig. 11 that the high-velocity flow directed at the base side exerted enough force on the film so that, in combination with the normal forces producing negative drift, it prevented the air on the emulsion side from blowing the film toward the lens; actually, the resultant forces produced a greater amount of negative drift than would have been normal in this film. It must be realized that Fig. 11 represents *only* the effects of air forces on film which, without air, would have positioned around −0.026 inch; it does not give a definite answer about the effects of air forces on film which might be at a different stage in its projection life, and might tend of its own accord to focus nearer zero or on the positive side of the gate.

In the discussion of in-and-out of focus, it was pointed out that this phenomenon takes place when the best compromise film focus is near zero, permitting some frames to drift negatively and others to drift positively. Actually, in-and-out of focus has been produced in film under radiation conditions that normally do not result in in-and-out, by displacing the film with an air jet to bring its focal position near zero. Thus, it becomes apparent that, for in-and-out of focus, air directed only at the emulsion side has two conflicting contributions: (1) it cools the film and by lowering the film temperature delays the onset of in-and-out of focus, and (2) it forces the film more nearly toward zero and therefore hastens the beginnings of in-and-out of focus. In order to obtain the full benefit of the cooling action, it is necessary, therefore, to counterbalance the mechanical force of the air jet on the emulsion surface (where most of the film cooling must be accomplished) by directing a similar jet at the base side. The optimum procedure is to use sufficient air on the emulsion side materially to reduce film temperature, plus sufficient air on the base side to produce an unbalanced air force holding the film on the negative side of zero. The combination of these two effects is more efficient than either one alone in permitting projection at higher radiation intensities.

The mechanical force holding the film negative and preventing its going in-and-out of focus must be applied before in-and-out of focus is actually experienced. Our experiments have shown that such a counterbalancing force can be quite effective in delaying in-and-out of focus or in preventing it entirely if the projection circumstances are proper. However, it has less influence in correcting in-and-out of focus once it has occurred.

In this connection it is important to mention the relationship between film position and uniformity of focus on the screen. Most projection lenses are designed so that the image surface is not truly a plane but is a curved surface concave toward the projection lens. Therefore, film which is positioned in such a surface concave toward the projection lens can be imaged sharply over the entire picture area. Film whose curvature is greater than that of the image surface, or film that is convex toward the projection lens (and therefore contrary to the image surface) cannot be focused sharply over the entire picture area. A compromise must be taken focusing part of the image and leaving the rest unsharp. It is fortunate, therefore, that the best film performance is obtained with film restrained on the negative side of zero—since in this position it lies in a curved surface concave toward the projection lens and in best agreement with the image surface of the lens. If projection conditions are chosen that permit the film to assume a surface convex toward the projection lens—even though the steadiness and image quality are adequate—it will be found that the best definition extends over so small a portion of the entire picture area as to be unacceptable in most circumstances.

Results of Air Cooling

In the latter part of this paper we have described the results of a series of experiments aimed at increasing the safe maximum projection intensity, and permitting an increase in screen illumination without loss in image quality or damage to the film. Such an advance has been made possible through use of high-velocity air in what for simplicity has been called "air cooling," although from the discussion it has been apparent that this is actually a matter of both cooling and positioning.

These improvements have been discussed in a more or less general way so far, and a summary of what they mean in the theater may be gathered from Table II. These figures have been called "probable limits" because it will take considerable practical experience to determine what is the maximum limit for air cooling without encountering difficulties in the theater. Therefore, Table II may be said to present three levels of illumination: (A) the present maximum, calculated from the data of Zavesky, Gertiser, and Lozier,[16] (B) a readily obtainable increase, and (C) the probable maximum with air cooling alone, subject to more detailed confirmation.

TABLE II

PROBABLE LIMITS FOR SATISFACTORY FILM PROJECTION
STANDARD 35-MM THEATER PROJECTION

	(A) No Air Cooling	(B) Moderate Air Cooling	(C) Maximum Air Cooling
Output:			
Mean net radiant flux, watts/mm²	0.45*	0.58	0.74
Screen lumens			
No shutter	17,000*	22,000	27,000
50% shutter	8,500*	11,000	13,500
Per Cent Light Increase	0	29	59
Source:			
High-speed condenser-type lamp			
Positive diameter	13.6 mm		13.6 mm
Amperage	170		265
Heat-absorbing glass	1.2 mm Aklo*		None

* Heat-absorbing glass is necessary to reduce the radiant output of this trim to a value that is safe for film without air cooling. These light and energy values were measured with the glass in place.

From our experiments on air cooling, we are certain that condition (B) should be capable of realization at this time. The result would be an increase of approximately 30 per cent in available screen illumination with no increase in film difficulties or the demands made upon film. It appears from the work so far that condition (C), an increase of approximately 60 per cent, could be obtained by efficient utilization of the information we have herein presented, and we have successfully obtained such an increase with no film difficulties in excess of those normally found under condition (A). At this upper limit, however, the increase can be obtained with safety only through careful attention to the details of the cooling system.

Throughout this discussion, little mention has been made of noise from air cooling, which is quite variable, depending upon the design of the nozzles, their location in the projector, the design of the projector itself, and even the source of compressed air. In our equipment, the air necessary for condition (B) can be applied with the noise of the air itself less than the normal operating noise of the projector. The air necessary for condition (C) in our equipment produces a noise level that is on the borderline approximately equaling the projector noise. If one attempts to use air in excess of this amount, however, the noise level increases rapidly and, as pointed out previously, the increase in cooling is slight.

Additional drawbacks of this system are that a source of low-pressure air must be provided, that an additional control must be operated, that for optimum results in most cases a new projector design would be desirable (specifically planned to provide proper air nozzles, and so forth), and that at the higher ranges some safety provision must be incorporated to prevent damaging the film if the cooling air should fail during operation. We believe that the most practical application of these results will be in the provision of air cooling for new projectors designed for high-level application, and that in such design when room is provided for adequately streamlined nozzles, proper flow paths, and so forth, a result much superior to what we were able to obtain with existing equipment can be realized. In particular, such new design should make it possible to reduce still further the noise level encountered in our experiments and to reduce the required pressure and power of the compressed air. Inasmuch as the methods suggested by these experiments require consideration early in the design stages of projection equipment, the results are being reported now in order to make them available as early as possible to the designers of equipment—and for the assistance of those who must increase the performance characteristics of present equipment.

Finally, it should be pointed out that the improvement obtained through the use of air cooling is not restrictive and that to these advances may also be added the previously outlined advantages of increased directional effect of the screen and the reduction of the heating from nonvisible components through the use of heat-absorbing glass, shutter modifications, dye images, and so forth.

Conclusions

(1) Present projection practice subjects film bearing a silver image to a radiant-energy flux near the maximum that film will stand without loss of image quality and film damage because of the high-intensity projection effects.

(2) A substantial increase in screen illumination can be obtained if the film at the instant of projection is cooled and mechanically restricted by high-velocity air jets.

(3) The increase in screen illumination so obtainable should be 30 to 60 per cent beyond the present safe maximum.

(4) Optimum use of air cooling during high-intensity projection requires the provision for such cooling in the design of the projector mechanism, and of the other components of a projection system.

Acknowledgments

The study of high-intensity projection problems at the Eastman Kodak Company has been directed by Dr. E. K. Carver and Dr. C. R. Fordyce. Others have given invaluable assistance, particularly R. H. Talbot, R. S. Battey, and P. H. Preo. Dr. W. W. Lozier and his associates at the National Carbon Company have provided many helpful suggestions and supplied experimental carbons for our tests. To all of these the author expresses his appreciation and indebtedness.

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DISCUSSION

DR. NORWOOD SIMMONS: In view of the fact that in process or background projection in Hollywood wherein the camera film is integrating the positive image on the process screen during its entire stay on the screen, what is the effect of this drift of emulsion position or change of best focus? Would you say that this is evident in background work as poor resolution or lack of maximum sharpness in the final print?

DR. F. J. KOLB, JR.: It has always seemed to us that this negative drift we described must result in a lack of sharpness in background projection. The camera has no psychological mechanism such as the eye does, and the camera sees the image in all of the stages of drift from near-flat to maximum negative. Most of the time, the camera sees an out-of-focus image. Unfortunately, our experience with background projection in Rochester is quite limited, and we have no photographic verification of the lack of sharpness in a negative exposed to a process screen. We should certainly be surprised, however, if it were not an important factor in the quality of background projection.

MR. DAVID B. JOY: I believe this is probably one of the most important papers from the standpoint of projection that we have heard here for a good many years because all of us who are connected with light and its projection on the screen have realized that we have come up against an upper limit with the necessity of having to use some kind of a heat filter which at the same time absorbs an appreciable amount of light. With the way pointed by this paper, that upper limit has been raised, and it would look as though it should be a great stimulus to the theaters in getting more and better light on a screen. I assume that this method is open to anybody who wants to make a practical application of it; is it, Dr. Kolb?

DR. KOLB: We should be pleased to co-operate with anybody who is interested in making use of air cooling.

Chemical Economics of Spray Processing*

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Summary—The rates of aerial oxidation of negative and positive motion picture developers in a pilot spray-developing cabinet, employing small and large reservoirs of developer, were measured and compared with the rates for three other typical circulation systems involving varying degrees of aeration. The wastage of chemicals in the spray cabinet depended upon the volume of developer circulated. In the case of D76d developer the wastage in the spray machine could be less than that in normal systems involving average aeration providing that the volume of circulating developer was sufficiently small. In a positive developer at *p*H 10.5 the wastage was from 2 to 6 times as much as that in the normal systems, depending upon the volume of developer used.

It was found that the rate of loss of chemicals from developers of *p*H below 10.0 reached a maximum on increasing the degree of aeration. At low *p*H's the maximum was reached at a low degree of aeration, thus accounting for the possibility of making economical use of spray processing in the case of D76d. At *p*H 10.5 no maximum rate of loss was reached on increasing the aeration.

The rate of loss of the developing agents was found to vary inversely with the sulfite concentration. It was not affected by the presence of colloidal silver, or by traces of copper or dye.

A photographic developer contains reducing agents that are oxidizable not only by silver halides but also by oxygen. The developers that are almost exclusively used in the motion picture industry are alkaline solutions containing sodium sulfite, hydroquinone, and *p*-methylaminophenol sulfate (Elon). The main course of the oxidation by oxygen is well understood,[1] the ultimate products being sodium hydroxide, sodium sulfate, and the sulfonates of Elon and hydroquinone. It has been shown[2] that when solutions of this type are oxidized by silver bromide a disproportionately small quantity of Elon is oxidized to the sulfonate, as the result of a mechanism by which the methylquinoneimine is partly reduced back to

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Elon by hydroquinone. The course of oxidation by oxygen (autoxidation) is similar to that of oxidation by silver bromide, and a similar mechanism may be assumed.

I. SYSTEMS OF DEVELOPER AGITATION

Because the rate at which oxygen attacks developers is appreciable, it is customary to protect them from exposure to the atmosphere as much as possible. However, in order to achieve uniformity of treatment of the film that is being developed, it is necessary to introduce considerable turbulence in the developer solution so as to change as frequently as possible the developer actually in contact with the sensitive emulsion. Mere circulation of the developer is not usually adequate to achieve this end and systems have been described, for example, in which the developer is projected at the surface of the film from submerged jets.

On the other hand, there has teen a tendency in recent years to achieve the desired degree of agitation by methods that involve the free exposure of the developer to air. Machines have been described in which the developer is cascaded down the strands of film from a trough situated above the racks. Ives and Kunz,[3] and Crabtree and Schwingel[4] have shown that a developer can be suitably agitated by means of bubbles of air released from submerged jets and that, in spite of the aeration, the sensitometric properties of the developer can be maintained constant by proper replenishment.

Spray Development

The latest move in this direction has been to abandon altogether the idea of immersing the film in a tank of developer and, instead, to apply the developer to the loops of film by spraying it on in mid-air. Several machines based upon this principle are in use in the United States and at the time of writing this paper, similar machines are coming into use in the United Kingdom.

In these machines the degree of aeration is extreme and, at first sight, one might suppose that the rate of loss of chemicals by aerial oxidation would be too severe for the idea to be practical. While it is generally understood in the industry that the chemical consumption is increased only slightly, if at all, no comparative figures have been published. To gain a closer insight into the economics of this method of processing, a study was made to compare the performance of a pilot spray-developing cabinet with that of conventional systems, and the results of this work are set out below.

Advantages of Spray Developing

At the outset of this work it seemed that spray developing would offer several advantages:

(a) Better agitation, with greater prevention of directional effects, sprocket-hole modulation, etc.

(b) The cabinet would need to be only sprayproof as opposed to watertight. The construction of the cabinet could be light because no great hydrostatic pressures are involved.

(c) By closing off the developer supply and opening the cabinet door the loops of film are readily accessible for threading up or for mending a break.

(d) Especially in the case of positive processing, the loops can be inspected through the transparent (glass, Perspex, etc.) cabinet.

(e) The bulk of developer required to serve the spray system could be much less than that required to fill a developing tank of equivalent processing capacity.

In carrying out the work described below, the validity of claims (a), (b), (c), and (d) was not questioned. However, it emerged from the experimental work that the volume of solution used in the spray-developing system (e) has an important bearing on the cost of running. In the pilot machine that was the subject of most of the experiments, the volume of developer used was the minimum (6–7 liters) that would adequately serve the circulation system, although some experiments were made using the spray cabinet in conjunction with a large (130-liter) reservoir.

II. THE PILOT MACHINE

No special merit can be claimed for the design of the spray-developing cabinet (Fig. 1) that was constructed to carry out this work, except that it could be made from the limited materials available at the time. However, cuprous metals were carefully avoided and, with the sole exception of the pump rotor chamber, which was made of cast iron covered as far as possible by a developer-resistant chlorinated rubber paint, the developer came into contact only with inert materials: stainless steel (FMB grade), Perspex, rubber, and glass.

The cabinet was constructed of $^1/_4$-inch Perspex sheets joined together by screwing from the inside into external wooden quartering.

In this way a smooth interior was achieved as free as possible from corners. The screwheads were countersunk and covered with a rubber cement, and the internal corners of the cabinet were sealed and rounded with the same material. The small developer reservoir was constructed similarly to the cabinet. The circulation piping is

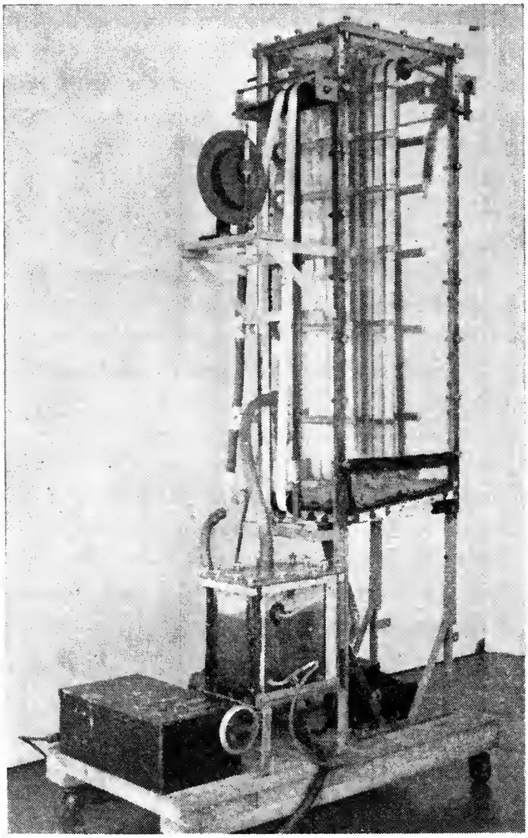

Fig. 1—Pilot spray cabinet and small reservoir.

shown diagrammatically in Fig. 2. The developer was drawn from the reservoir at A and was sent, by the $^1/_6$-horsepower pump, into the three vertical manifolds B, C, and D. Each manifold supplied six spray tubes. The spray tubes fed by B and D sprayed horizontally inward, whereas the central spray tubes fed from C sprayed horizontally in both directions. In order to make proper use of the pumping capacity, it was found necessary to avoid sharp bends in the piping, particularly where the manifolds divided.

Types of Jets

It is unfortunate that the term "spray" has come into common usage in connection with this mode of developing, because it is apt to convey the wrong impression. A spray of developer, consisting of a mist of droplets, would not be effective in scrubbing the surface of the emulsion free from used developer. For this purpose a high-velocity jet of developer is required and "jet developing" would be a more apt term.

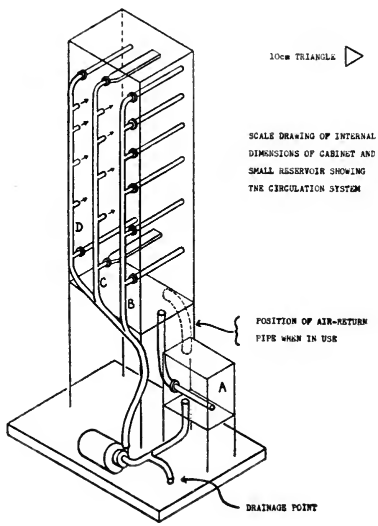

Fig. 2—Circulation system of pilot equipment.

In some commercial spray-processing machines, a splayed, flat jet is used to throw a blade of liquid. In others a coned jet is used. However, in order to maintain a high jet velocity without having recourse to a large pump, a round, 1.0-mm-diameter jet hole was adopted.

A row of 1.0-mm holes 1.0 centimeter apart was drilled along each of the single-sided spray tubes (on *B* and *D*), and two horizontally opposed rows of holes were drilled into each of the six central spray tubes (Fig. 3). When the spray tubes and the film-transport bobbins had been located in the spray cabinet, a number of the holes were resealed, leaving open only those from which the jet of developer impinged on the film.

Circulatory System

The rate of circulation, on the one occasion that it was measured, was 43.5 liters per minute (570 gallons per hour). This figure agreed well with the capacity claimed for the pump by its makers. The output from each spray was balanced by placing holed corks in the tubes feeding those spray tubes that were too well supplied in the first instance. The sizes of the holes in the cork diaphragms were found by trial and error.

The spray cabinet and the reservoir were so constructed that air could not penetrate freely in and out, save at the orifices provided for the film to enter and leave. These holes were about 5 × 1 centimeters in size and, when desired, they could be sealed by means of adhesive tape. No attempt was made to make the cabinet completely airtight. These conditions were chosen because, while complete airtightness would be troublesome to maintain in practice, it would not be inconvenient to prevent the free access of air, and one of the objects of this work was to study the changes in the enclosed air and to

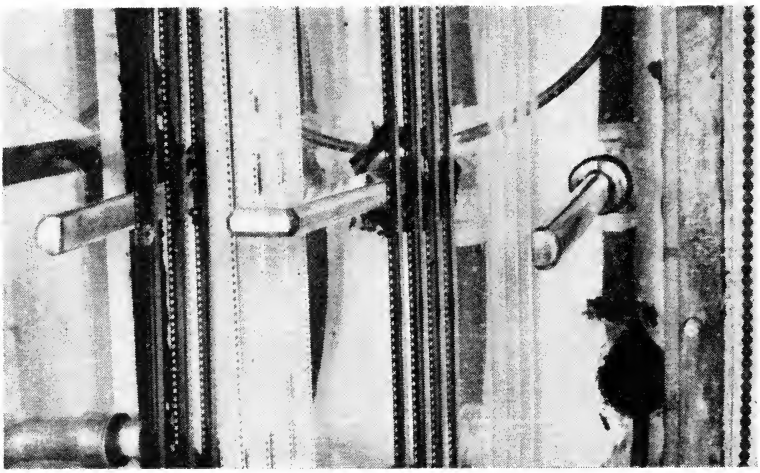

Fig. 3—View of three of the spray tubes showing the disposition of the blue-backed leader film.

find whether the use of nitrogen gas would be necessary in order to reduce the rate of oxidation of the developing agents.

After making trial runs, it became obvious that the steps taken to prevent the free entry of air were being nullified because the turbulent developer, falling down the return pipe from the cabinet to the reservoir, carried with it a large volume of air which was, of course, replaced by air leaking into the cabinet. To avoid this defect, a wide return pipe was provided for the air to return from the reservoir to the cabinet. In the description given below of the experiments on the composition of the enclosed air, this device will be referred to as the "air-return pipe."

III. OTHER SYSTEMS

Four other systems for holding and circulating the developer were examined in comparison with the spray cabinet used with a minimum quantity of developer. For convenience in referring to each, the system already described will be referred to as the *S-R Spray* (small-reservoir) system to distinguish it from the first of the following.

L-R Spray (*Large-Reservoir*)—In some commercial spray-processing machines, the spray cabinet is used in conjunction with a bulk of developer about as large as that which would be required for a total immersion machine of the same processing capacity. By using the large bulk of solution, the ease of handling and mixing a small quantity of solution (advantage (e) in the list above), is lost, but the developer is less susceptible to a rapid change in composition, and would thus be expected to show less tendency toward short-term deviations. For this reason, some of the experiments, revealed as more significant by runs on the S-R Spray system, were repeated, using a large earthenware crock as the reservoir, holding a 130-liter batch of developer. In these experiments no provision was made for returning the air carried down the developer return pipe. The L-R Spray system is shown in Fig. 4A.

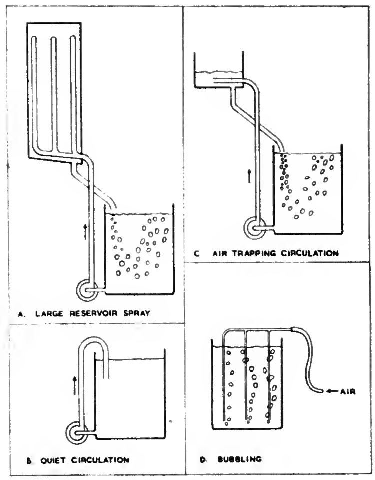

Fig. 4—Diagrams of the four alternative circulation systems. Only three of the nine jets are shown in D.

Immersion Systems

The various methods of agitating and circulating the developer in an immersion system can be divided into three groups, and the following three systems studied in this work are fairly representative.

Quiet-Circulation System—For want of a better term, the description "quiet circulation" is applied to those systems, comparatively rare in modern motion picture practice, in which bubbles of air are not trapped to any significant degree and carried below the surface into the bulk of the developer. Fig. 4B shows the arrangement used. It consisted of the large earthenware crock containing 130 liters of developer which were drawn out of the bottom and returned, below the surface so as not to entrap bubbles, at the top.

A system of this sort could, of course, be used with submerged jets without altering its characteristics toward aerial oxidation. The liquid-air interface was 16 square centimeters per liter. It should be noted, however, that if the pump gland were to leak and admit air, or if film were to be run through the tank at high speeds, carrying down air in the perforation holes into the developer, the characteristics of the system would be entirely changed and it would become similar to the air-trapping circulation system described next.

Air-Trapping Circulation System—In most processing machines, a greater or lesser amount of air is trapped and carried, as bubbles, into the bulk of the developer. In many cases, this trapping of air is an inevitable consequence of the design of the system, particularly in those installations where the developer is pumped from one tank to another and then returns by overflowing down an incompletely filled pipe, or a pipe that is so placed that air is sucked in unintentionally. In high-speed machines, the moving film carries a considerable amount of air below the surface of the developer. In any machine a leaky pump gland, or a leak on the induction side of the pump, will inject air into the developer in the form of very minute bubbles which aerate the developer very efficiently.

To simulate such conditions, the arrangement shown in Fig. 4C was used. The developer (130 liters) was pumped from the earthenware crock to a small elevated tank, and returned by passing down a 4-foot long, 1-inch bore, rubber hose, carrying with it a considerable amount of air which was impelled into the bulk of the developer in the crock.

Air-Bubbling System—To represent an air-agitated bath, 130 liters of developer in the earthenware crock were agitated by a current of air injected from nine 4-mm-diameter jets situated 56 centimeters below the surface of the developer. This arrangement was achieved by blowing compressed air down nine tubes as shown in Fig. 4D. The air flow, which was maintained constant according to a differential manometer in a fixed position in the system, was set at a level that, on the basis of general experience, seemed to provide a sufficient degree of turbulence for good processing. This rate was approximately assessed at 27 liters per minute. The rate of flow of air through each jet was balanced to the same level.

This rate of air flow was less than a quarter of that which would have been required to supply Ives and Kunz injector grids, judging from the data (for a different shape tank) given in their paper.[3] Thus, when considering the oxidation rates given below, it should be borne in mind that the air flow was comparatively low and higher rates might be met with in practice.

Experimental Conditions

The object of these experiments was to find the initial rates of oxidation of the Elon and hydroquinone from the unexhausted developer. In a continuously replenished system, the Elon and hydroquinone are maintained at a steady concentration, and the rates of

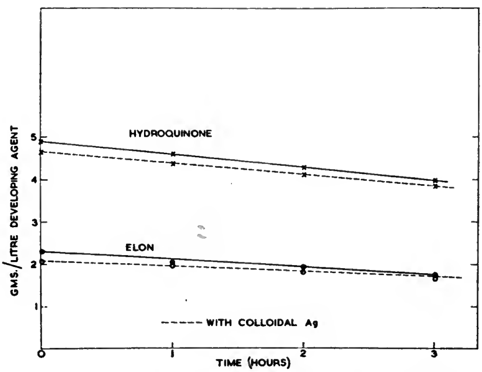

Fig. 5—Change of composition of D76d aerated in the S-R Spray system. The run with colloidal silver may be regarded as a duplicate since no marked effect could be traced to its use.

oxidation are reflected in the extra quantities of the developing agents needed in the replenisher. Because of the repeated and extended runs that would have been required to establish the correct replenishment rate in each case, the simpler course was followed of installing a fresh bath and measuring the initial rates of oxidation.

In all the runs on all five systems and in the small-scale oxidation experiments to be described later, the temperature was maintained 20 degrees, within $\pm 1/2$ degree centigrade. No account was taken of the barometric pressure because the accuracy to be expected in work of this nature was not sufficiently high to merit doing so.

The Elon and hydroquinone analyses were carried out along the lines described elsewhere.[5] Sulfite analyses were done using Stott's method.[6] The pH values were determined using an ordinary glass electrode and a high-salt buffer as described in a previous paper.[7]* Analyses of the air in the spray cabinet were made by drawing off a 50-milliliter sample of air and absorbing the oxygen in alkaline pyrogallol in a Hempel pipet. The air was sampled through a cock fitted in the back panel of the spray cabinet about 9 inches from the bottom.

Ordinary photographic grade "Kodak-Tested" chemicals were used, and tap water was employed in all the runs involving a large volume of solution.

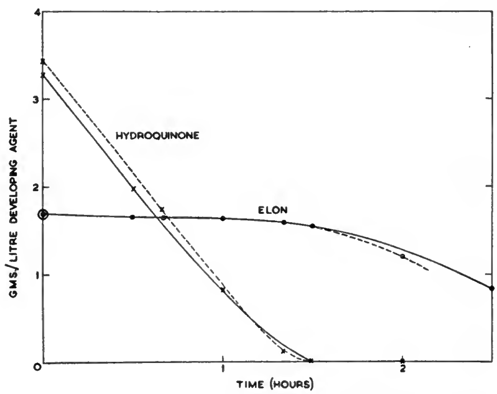

Fig. 6—Change of composition of the positive developer at pH 10.5 in two runs in the S-R Spray system.

At the outset the survey was based on D76d, as a typical negative developer, and the following positive developer:

Elon	1.72 grams
Hydroquinone	3.30 grams
Sodium sulfite	37.8 grams
Sodium carbonate	21.2 grams
Water to	1 liter

In a number of makings the pH of the D76d varied between 8.6 and 8.8. The pH of the positive developer was adjusted with sodium hydroxide to 10.5 ± 0.05. This somewhat high level was deliberately chosen so as to extend the pH range covered. Later, in the

* NOTE: The pH values obtained in this way, in the 1N NaCl buffer using an AgCl/0.1 N KCl reference electrode, read 0.3 unit higher than the values that would be obtained using a saturated calomel electrode in any buffer.

light of the results obtained, it was thought necessary to repeat some of the more significant runs with the positive developer adjusted with bisulfite to pH 10.0.

Oxidation Rates in the Five Systems

Since it was thought possible, that the presence of colloidal silver might influence the rate of oxidation, most of the runs were repeated after adding about 0.014 gram of colloidal silver suspended in a gelatin sol, per liter of developer. When, as will be discussed later, it was established that it did not affect the rate of oxidation, its use was discontinued. Figs. 5, 6, and 7 illustrate typical exhaustion runs and

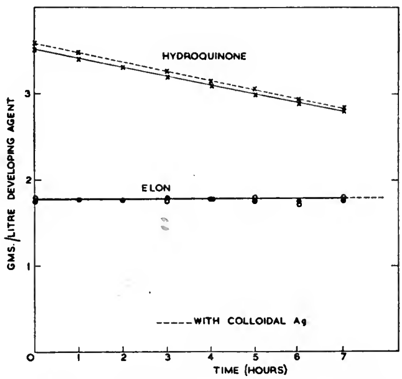

Fig. 7—Change of composition of the positive developer at pH 10.5 in the air-bubbling system.

give some idea of the fair degree of reproducibility that was obtained in the rates of oxidation. The runs with colloidal silver may be taken as duplicates of those without. For lack of space, full plots of all the runs will not be given; instead, the initial rates of oxidation in terms of grams per liter per hour are given in Table I. Because of its apparent lack of effect, a number of the runs shown in Table I have no counterpart with colloidal silver.

Before discussing the results in detail, it is necessary to comment upon the rather wide deviations that are shown in Table I in the initial concentrations of Elon and hydroquinone. These deviations, which do not materially affect the results, arose from the fact that, in order to expedite this somewhat lengthy work, the baths were made up slightly overstrength, with respect to the developing agents, to allow

TABLE I

Developer	System	Vol. of Developer Liters	Initial Concentration Elon	Initial Concentration HQ	Rate of Oxidation Per Hour per Liter Elon	Rate of Oxidation Per Hour per Liter HQ
D76d	S-R Spray	7.2	2.30	4.88	0.17	0.30
	L-R Spray	121	1.95	4.94	0.11	0.27
		130	2.01	5.15	0.11	0.27
	Quiet	130	2.24	5.57	0	0
	Air-trapping	130	2.06	5.45	0.02	0.074
	Air-bubbling	130	2.10	5.33	0.035	0.08
D76d +Ag	S-R Spray	7.2	2.08	4.66	0.12	0.26
	L-R Spray	.....	....	....	.....	.....
	Quiet	130	2.06	5.5	0.02	0
	Air-trapping	130	2.06	5.42	0.02	0.074
	Air-bubbling	130	1.92	5.33	0.03	0.063
Positive developer *p*H 10.0	S-R Spray	7	1.64	3.01	0.08	1.78
	L-R Spray	130	1.83	3.39	0.014	0.305
Positive developer *p*H 10.5	S-R Spray	6.3	1.70	3.35	0.08	2.6
	L-R Spray	118	1.76	3.48	0.01	0.50
	Quiet	130	2.04	3.77	0	0.008
	Air-trapping	130	2.18	3.88	0	0.076
	Air-bubbling	130	1.77	3.51	0	0.099
Positive developer *p*H 10.5 + Ag	S-R Spray	6.3	1.60	3.26	0.07	2.88
	L-R Spray	.....	....	....	.....	.....
	Quiet	130	2.00	3.76	0	0
	Air-trapping	130	2.08	3.83	0	0.113
	Air-bubbling	130	1.79	3.58	0	0.106

for some oxidation in mixing and for some dilution by water remaining in the systems from the washing after the previous run. After installing the bath in any one of the systems, it was circulated for a few minutes to ensure uniformity, the *p*H was checked, and then the first sample was drawn for analysis. The run commenced immediately, since most of them were of long duration, and were well advanced before the first analysis was complete. Thus there was no convenient opportunity to adjust each bath to exactly the same initial concentrations of Elon and hydroquinone before starting the run.

Whereas in the first runs the volume of developer used in the S-R Spray system was 6.3 liters, it was found convenient later to use 7 liters of developer.

IV. EXPERIMENTAL RESULTS

Table II shows the rates of loss of Elon and hydroquinone in grams per hour from each system after the figures have been adjusted to relate to standardized conditions of initial volume and developing-agent concentration. The standard volumes are taken as 7.0 and 130 liters and the rates are adjusted (to 2.0 grams Elon, 5.0 grams hydroquinone, and 1.72 grams Elon, 3.30 grams hydroquinone) on the assumption that they should be proportional to the initial concentration, the *p*H being constant.

TABLE II

RATES CORRECTED TO STANDARD VOLUMES AND CONCENTRATIONS

Developer	System	Standard Volume, Liters	Rate of Loss of Developing Agent from the System: Elon	HQ
D76d	S-R Spray	7.0	1.0	2.2
	L-R Spray	130	14.3	34.1
	Quiet	130	0	0
	Air-trapping	130	2.8	8.8
	Air-bubbling	130	4.3	9.8
D76d +Ag	S-R Spray	7.0	0.8	2.0
	L-R Spray	130	...	...
	Quiet	130	0	0
	Air-trapping	130	2.8	8.9
	Air-bubbling	130	4.1	7.7
Positive developer *p*H 10.0	S-R Spray	7.0	0.6	13.7
	L-R Spray	130	1.8	37.2
Positive developer *p*H 10.5	S-R Spray	7.0	0.6	18.0
	L-R Spray	130	1.3	62.2
	Quiet	130	0	0.9
	Air-trapping	130	0	8.5
	Air-bubbling	130	0	12.3
Positive developer *p*H 10.5 + Ag	S-R Spray	7.0	0.5	20.4
	L-R Spray	130	....	....
	Quiet	130	0	0
	Air-trapping	130	0	12.7
	Air-bubbling	130	0	12.9

		Elon	Hydroquinone
Standard concentrations	Negative developer	2.00 grams	5.00 grams
	Positive developer	1.72 grams	3.30 grams

Running Cost

In order to illustrate the relative cost in developing agents of running the various systems, without processing film, the values from Table II are shown pictorially in Fig. 8, *1.0 gram of Elon being taken as equal in cost to 2.0 grams of hydroquinone.**

At *p*H 8.7, in the case of D76d, the loss of developing agent is negligible in the quiet circulation system. The cost of running the S-R Spray system is about one third of that for the air-trapping and about one fourth of that for the air-bubbling system. The cost of running the L-R Spray system is far greater than any of the others.

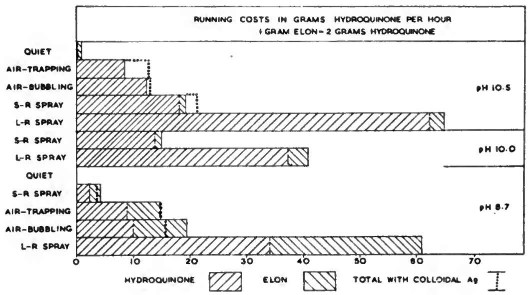

Fig. 8—Diagrammatic representation of the data given in Table II. The values refer only to the cost of chemicals wasted by aerial oxidation.

At *p*H 10.5 both the spray systems are more costly to run than the other systems. The quiet-circulation system loses an insignificant quantity of developing agent. The air-trapping and air-bubbling systems cost about two thirds as much as the S-R Spray system, and about one sixth as much as the L-R Spray system.

At *p*H 10.0 the cost of running the two spray systems is roughly two thirds of the cost at *p*H 10.5.

The presence of colloidal silver made no significant difference to the cost of running, and in the diagram the best value for a particular system is probably the mean between the figures shown for the rates with and without the colloidal silver.

The minimum cost of running a bath depends upon the amount of silver that is to be reduced to form the image. Evans[8] quotes figures for the silver content of 1000 feet of motion picture positive image;

* Based on prices in Great Britain.

an average (for fine-grain positive), taken on the basis of his estimates, would be 10 grams. The reduction of this quantity of silver would require about 5 grams of hydroquinone. Any of the systems studied in this work would process nearly 1000 feet of motion picture positive film per hour, so the minimum average rate of loss of hydroquinone would be 5 grams per hour. However, experience has shown that most systems require at least 5 liters of bromide-free replenisher per 1000 feet in order to keep the soluble bromide concentration of the bath down to a reasonable level of about 2 grams of potassium bromide per liter. This quantity of replenisher is sufficient to replace the carry-over of developer and to occasion some overflow, or "bleed."

Thus in practice, excluding loss by aerial oxidation, each of the five systems might be expected to cost (in grams of hydroquinone):

	Concentration in Developer, Grams per Liter	Cost (in Grams of Hydroquinone) per 5 Liters
Elon	1.72	$5 \times 2 \times 1.72 = 17.2$ grams
Hydroquinone	3.30	$5 \times 3.30 = 16.5$ grams
plus		
Cost of developing the image		= 5 grams
Total		= 38.7 grams

or in round numbers, about 40 grams of developing agent in terms of hydroquinone equivalents, when processing positives. For negatives the figure would be somewhat greater:

$$5[(2 \times 2.0) + 5.0] + 2.5 = 47.5$$

or in round numbers, 50 grams of developing agent in terms of hydroquinone equivalents if it is assumed that the average weight of image silver per 1000 feet of negative film is half of that found on prints.

Some loss of developing agent is occasioned by adsorption in the film even if unexposed film is processed and no development occurs.[9] No special allowance for this loss is made here in view of the approximate nature of the calculation and the enhancement of the values in the rounding-off.

If these figures of 40 and 50 grams hydroquinone equivalents per hour are compared with the autoxidation figures in Fig. 8, it will be seen that in most cases the appropriate autoxidation loss is less than half of them. Only the L-R Spray system shows autoxidation losses which are equal to, or greater than, the development loss figure.

Effect of Colloidal Silver on Autoxidation Rates

No definite change in the rate of oxidation of developing agents in the runs on the five systems could be associated with the addition of colloidal silver.

Volmer[10] observed that the addition of colloidal silver accelerated the darkening of alkaline developing-agent solutions on aeration. Weissberger and Thomas[11] examined the effect of colloidal silver on the rate of absorption of oxygen by sulfite-free solutions of developing agents. Their experiments on Elon and hydroquinone, made at rather low *p*H levels (between *p*H 7 and 8), showed that colloidal silver slightly accelerated the absorption of oxygen by hydroquinone.

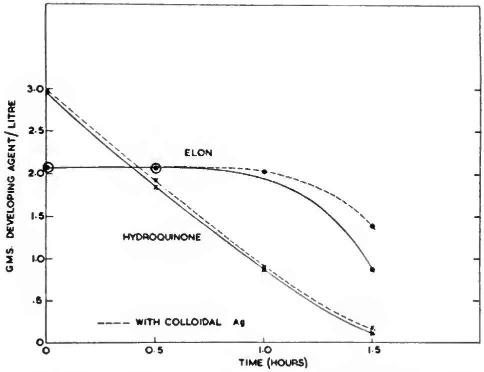

Fig. 9—Course of autoxidation when 1-liter samples of the positive developer at *p*H 10.5 were aerated together, one containing colloidal silver.

Colloidal silver had almost no effect on the initial rate of absorption by Elon, but the partially oxidized Elon solution absorbed oxygen much more slowly in its presence. An experiment on *p*-aminophenol at *p*H 9.2, a level closer to those used in the present work, showed a marked increase in the initial autoxidation rate when colloidal silver was added, though, as in the case of Elon, the partially oxidized solution absorbed oxygen much more slowly in the presence of the silver.

To check the influence of colloidal silver on the rate of autoxidation of developers more precisely than it was possible to do on the pilot systems, experiments were made on 1-liter samples of the positive developer (*p*H 10.5). Compressed air, at a constant rate of flow, was moistened and then bubbled through two 1-liter cylinders arranged in tandem, separated by an empty flask which acted as a spray trap.

One liter of developer was placed in each cylinder and 0.02 gram of colloidal silver was added to one of them. To ensure uniformity of treatment, the air flow was set at a high rate so that its composition would be but little changed on emerging from the first developer cylinder, and the two cylinders were interchanged every 15 minutes. The cylinders were stood during the run in a tank of water at 20 degrees centigrade.

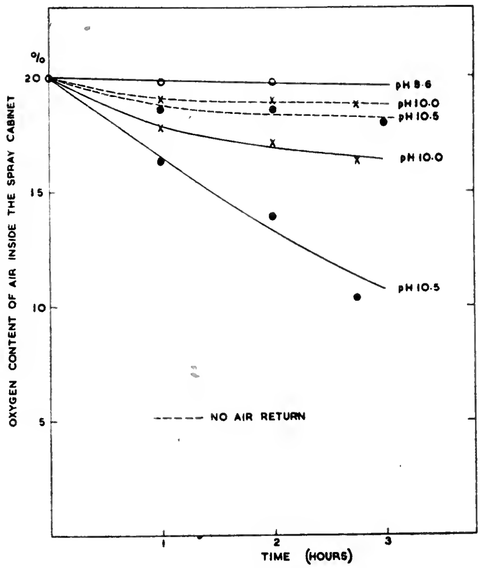

Fig. 10—The course of the oxygen depletion in the spray cabinet. The broken lines refer to runs in which the air-return pipe was closed.

The results, in Fig. 9, show that colloidal silver had no effect on the rate of autoxidation of hydroquinone, or on the almost zero rate of autoxidation of the Elon while hydroquinone was present in appreciable quantity. However, when the hydroquinone was almost entirely oxidized, the rate of oxidation of the Elon was inhibited by the presence of colloidal silver. The results agree with those of Thomas and Weissberger.

Composition of Air in Spray Cabinet

Using D76d developer, tests were made to find whether reducing the oxygen content of the air in the cabinet would have a marked influence on the rate of autoxidation. On circulating D76d in the S-R Spray system, with the air-return tube in position, it was found that the oxygen content of the air did not deviate much from that of normal air (top curve, Fig. 10). On flushing the cabinet with cylinder nitrogen the oxygen content of the air was reduced from the normal 20 per cent to 4 per cent and maintained at this level by a nitrogen flow of 2 liters per minute. The rate of autoxidation of the developing agents was the same at this low oxygen level as it was in normal air. The reason for this emerged later, and will be described below.

In carrying out runs with the positive developers, the solutions were replenished, because of their much more rapid rate of autoxidation, in order to maintain them at substantially constant composition, especially in respect to developing-agent concentration and *p*H. Fig. 10 shows the change in oxygen content of the air in 3-hour runs. When the air-return tube was in position, the oxygen content fell toward equilibrium at about 15 per cent at *p*H 10.0. At *p*H 10.5 the oxygen content reached 10 per cent, and was still descending rapidly. When the air-return tube was closed the reduction in oxygen content was much less. At *p*H 10 the equilibrium value would appear to be at about 18 per cent, and perhaps 17 per cent at *p*H 10.5.

These values would be markedly affected in practice if a compressed-air knife were used in the developing cabinet to prevent carry-over of developer. The imperfect correlation between the relative rates of developer oxidation and rates of oxygen depletion, probably due to changes in the degree of closure of the cabinet, makes it necessary to regard the curves in Fig. 10 as being of illustrative significance only.

Influence of Degree of Aeration on Rate of Autoxidation

On considering the fact that, in view of the high degree of aeration produced in the spray cabinet, some of the rates of loss of developing agents are lower than might be expected, and the fact that reducing the oxygen content of the air to 4 per cent had no influence on the rate of autoxidation of D76d, it seemed likely that the degree of aeration involved was sufficient to supply the developer with oxygen faster than the oxygen could be removed by reaction with the reducing agents. Thus, under the conditions of spray processing, the rate-determining factor would no longer be the degree of exposure of the solution to air. This hypothesis was checked experimentally and was found to be in keeping with the experimental results.

Fifty milliliters of the developer under test were placed in a tube 52 centimeters long and of 2.0 centimeters internal diameter. Compressed air, metered by a Rotameter flowmeter, was moistened by bubbling it through a flask of water packed with marble chips, and was injected at the bottom of the oxidation tube through a 0.71-mm-diameter jet. The pressure of the air at the flowmeter was measured by a mercury manometer. The oxidation tube was placed in a water jacket which was set at 20 degrees before each run. Unless otherwise stated, each sample of developer was aerated for 30 minutes. Only the hydroquinone content of the developer was determined, since the relation between the rates of Elon and hydroquinone oxidation, at a given *p*H, did not seem likely to vary with the general rate of oxidation.

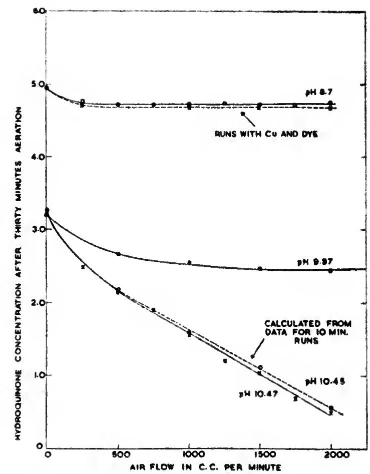

Fig. 11—The course of the autoxidation of 50-milliliter samples of the developers, as the degree of aeration was increased.

The results for the negative and positive developers are shown in Fig. 11. They are not corrected for the change in pressure of the air (7.5 centimeters mercury at 2000 cubic centimeters per minute) at the measuring point. At *p*H 8.7 the rate of autoxidation of hydroquinone reached a maximum at an air-flow rate of less than 250 cubic centimeters per minute. Increasing the air flow up to 2000 cubic centimeters per minute produced no increase in the rate of loss of hydroquinone. The addition of tolusafranine (1 drop of a 1 per cent solution in 50 milliliters of developer) was made in another run, the dye being used as a substitute for the sensitizing dyes, likely to be picked up by a negative developer, which might affect the rate of oxidation. The results, shown by the broken line, indicated no significant change. Neither did the addition of one drop of a 1 per cent copper (sulfate) solution affect the results.

At *p*H 10.0 (9.97 in Fig. 11) the positive developer showed what was substantially the same mode of behavior, the practical limit to the rate of oxidation of hydroquinone being reached at an air flow of about 1500 cubic centimeters per minute, although very little further increase in autoxidation rate occurred beyond the 1000-cubic-centimeter-per-minute stage. At pH 10.5 (10.45 in Fig. 11), however, the rate of autoxidation appeared to reach no limit within practical rates of air flow and increased steadily up to the maximum measurable air-flow rate of 2000 cubic centimeters per minute. On increasing the rate of air flow to the maximum that could be tolerated without blowing the developer out of the oxidation tube (about 5000 cubic centimeters per minute), it was found that the hydroquinone was completely oxidized in the 30-minute run. The experiment was repeated, this time reducing the time of aeration to 10 minutes, and the results, *after multiplying the actual hydroquinone losses by 3*, are shown by the broken line and agree very well with the results obtained previously.

From these results it may be concluded that at pH levels up to 10.0 (at 20 degrees centigrade) the rate of oxidation of the developing agents will increase on increasing the degree of aeration until the concentration of oxygen in solution is sufficiently high to ensure that the autoxidation of the developing agents can take place at the maximum rate permissible under the given conditions of temperature, pH, and sulfite concentration. Increasing the degree of aeration beyond this point has no further influence on the autoxidation rate.

Factors Influencing Autoxidation

Further study of this point might show that the factor setting the level of the maximum rate of autoxidation is the solubility of oxygen in the developer, the maximum being reached at the degree of aeration that is sufficient to maintain the developer saturated with oxygen. Some experiments were made in the hope that this point might readily be cleared up, but the results were ambiguous. Briefly, it was found that adding quantities of potassium chloride up to 200 grams per liter to the following developer:

Elon	2.0 grams
Hydroquinone	5.0 grams
Sodium sulfite, anhydrous	20.0 grams
Borax	2.0 grams
Water to	1 liter
pH adjusted with sodium bisulfite to	8.7

reduced the percentage of hydroquinone oxidized in a 15-minute run from 5 per cent to 4 per cent (air flow of 1250 cubic centimeters per minute). This evidence tended to favor the oxygen-saturation theory. On the other hand, additions of potassium chloride to the following developer:

Elon	1.72 grams
Hydroquinone	3.3 grams
Sodium sulfite, anhydrous	20.0 grams
Sodium Carbonate	21.2 grams
Water to	1 liter
*p*H adjusted to	10.0

up to 100 grams per liter seemed to cause an initial increase in the rate of autoxidation of the hydroquinone. Increasing the potassium chloride concentration up to 200 grams per liter caused the autoxidation rate to fall back to its initial value. Similar results were obtained when potassium nitrate was used to load the developer. If it is assumed that loading the developer in this way does reduce the solubility of oxygen, then these results for the positive-type developers favor the view that under these circumstances it is not the solubility of oxygen but some other factor that sets the maximum rate of autoxidation on increasing the degree of aeration. To deal with this matter satisfactorily it will be necessary to measure the solubility of oxygen in the developer solutions.

The fact that, at *p*H 10.5, no maximum rate of autoxidation was found on increasing the degree of aeration, and the fact that the slope of the curve is much steeper than it is at *p*H levels up to 10.0, indicate that the *p*H of the developer should not be raised above 10.0* in systems involving considerable aeration.

Influence of Sulfite Concentration on Rate of Oxidation

The effect of varying the sulfite concentration was studied in the case of the positive developer at *p*H 10. No special study of the negative developers was made in this connection because a very high sulfite concentration is maintained in them for reasons other than the prevention of autoxidation. However, it will be seen from the results in the previous sections that, at an air flow of 1250 cubic centimeters per minute, 5 per cent of the hydroquinone was oxidized in 30 minutes when the sulfite concentration was 100 grams per liter. The same percentage loss of hydroquinone occurred in 15 minutes when the sulfite concentration was 20 grams per liter. Thus the rate of oxidation was halved on increasing the sulfite concentration from 20 to 100 grams per liter.

* See note on page 674.

To examine the effect of varying the sulfite concentration at *p*H 10.0, a range of solutions was prepared by mixing solutions A and B in varying proportions:

	A	B
Elon	1.72 grams	1.72 grams
Hydroquinone	3.30 grams	3.30 grams
Sodium sulfite, hydrated, analytical reagent	10.0 grams	200.0 grams
Sodium carbonate, anhydrous	21.2 grams	21.2 grams
Water to make	1 liter	1 liter
*p*H adjusted to — Ordinary electrode	....	10.00
*p*H adjusted to — ALKI electrode	9.94	9.98

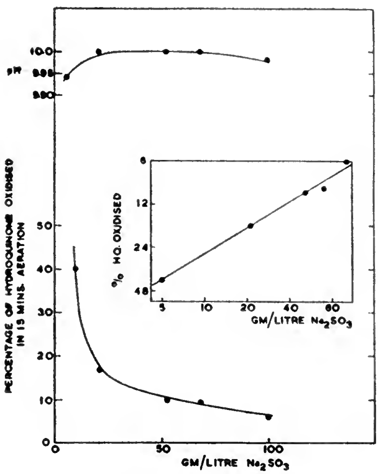

Fig. 12—The influence of sulfite concentration on the rate of autoxidation of hydroquinone from the Elon-hydroquinone developers.

Because of the wide range in sodium ion concentration, it was deemed unsafe to level the *p*H values using the ordinary glass electrode. Solution B was brought to *p*H 10.00 using the ordinary glass electrode; the *p*H value of the solution as given by an ALKI (high *p*H) electrode was 9.98. The *p*H of solution A and the *p*H values of the intermediate solutions were then measured with the ALKI electrode. All the *p*H readings fell within the range of 9.94 to 10.00, which may be taken to mean that the *p*H's of the intermediate solutions were probably intermediate between those of the extreme solutions.

Fifty-milliliter samples of these solutions were aerated at 20 degrees centigrade, using an air flow of 1250 cubic centimeters per minute. The percentage losses of hydroquinone, plotted in Fig. 12, agree with the results of James and Weissberger,[12] who found that the initial rate of autoxidation of hydroquinone was inversely proportional to the sulfite concentration. The log-log plot, inset in Fig. 12, shows a reasonably linear relationship over a sulfite concentration range of 20:1.

The conclusion to be drawn from these results is that 40 grams per liter of sulfite is about the optimum concentration for positive developers in highly aerated systems. To halve this rate of loss of developing agents by autoxidation it would be necessary to raise the sulfite concentration to about 100 grams per liter, a concentration that probably would cause considerable development fog and decrease the maximum gamma obtainable. Whether or not any economy can be effected by increasing the sulfite to this level depends, of course, upon the relative cost of sulfite and hydroquinone. The ratio between the prices of these products fluctuates from time to time and varies considerably from one country to another. To illustrate this problem, the case of the L-R Spray system will be considered, with the developer at *p*H 10.

It is assumed, as before, that this machine will process 1000 feet of film per hour. The autoxidation cost in terms of hydroquinone is shown by Fig. 8 to be 41 grams per hour. In this time, 5 liters of replenisher would be required and this replenisher would contain the extra 41 grams of developing agent plus, among other things, the sulfite. Analysis showed that in the system in question, the loss of sulfite was roughly equal to the two moles per mole of hydroquinone that theory, based on the evidence of Tausch, would require. Thus the concentration of the sulfite in the developer, by influencing the rate of autoxidation of the developing agent, affects, in turn, its own rate of loss.

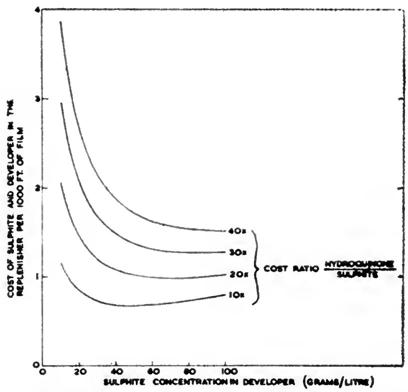

Fig. 13—These curves, showing the cost of sodium sulfite and developing agent in the positive bath replenisher, indicate that unless sodium sulfite (anhydrous) costs much less than $^1/_{40}$ of an equal weight of hydroquinone, it is not worth while increasing its concentration above 60 to 70 grams per liter.

Using the linear relationship between the sulfite concentration and the rate of loss of developing agent given in Fig. 12, the total cost, in arbitrary units, of sulfite and developing agent per hour, is shown in Fig. 13 for four different hydroquinone-sulfite price ratios. The absolute levels of these curves will depend upon the absolute prices of these chemicals. It will be seen that increasing the sulfite concentration in the bath from 38 to 100 grams per liter, to halve the rate of loss of developing agents, would only save money if the hydroquinone-sulfite price ratio is 40:1 or more. At a ratio of 30:1 the most economical sulfite concentration would be reached at 80 grams per liter. At a ratio of 20:1 the most economical sulfite concentration in the bath would be 60 grams per liter. At a ratio of 10:1 the most economical concentration of sulfite would be 45 grams per liter.

Although the numerical values in the above example were chosen to illustrate the case of the L-R Spray machine, the shape of the curves and the general conclusion are probably valid for any case involving the aerial oxidation of an Elon-hydroquinone developer at *p*H 10 and at 20 degrees centigrade when the hydroquinone-Elon ratio is sufficiently high for the hydroquinone to be predominantly lost.

V. CONCLUSION

Practical experience by the motion picture processing laboratories shows that a spray or jet-applied developer can be maintained over a considerable period by suitable replenishment. The present work indicates that the cost of the chemicals wasted by aerial oxidation depends upon the volume of developer used in the installation. If the minimum volume of developer is used, e.g., about one twentieth of the volume that would be required in a normal total-immersion system of the same production capacity, then it is *cheaper* to use a spray system with a negative developer at *p*H 9. This arises from the fact, now presented, that the autoxidation rate in a developer of this type reaches a maximum value at a comparatively low degree of aeration. When the volume of the developer in a spray system is about one sixth of the volume in an equivalent total-immersion machine, having a fair degree of aeration, the two systems will cost about the same to replenish. At equal volumes, aerial oxidation in the spray system will waste 3 to 4 times as much developing agent and sulfite as in any normal system.

At the other end of the range, at *p*H 10.5, a spray-developing machine will cost about twice as much in developing agent and sulfite wastage as any normal machine, and, at equal volumes, it can cost over six times as much.

An interesting point emerging from this work is the very small, or negligible, rate of aerial oxidation in a system where, in spite of a vigorous stirring of the solution, no bubbles of air were carried below the surface.

The figures quoted so far relate to the relative wastages by aerial oxidation. Put in another way, it may be said that in the case of negative developers the use of a small-reservoir spray system may result in some saving of chemicals, while a large-reservoir spray would just about double the *total* cost of developing agent consumed. In the case of positive developers at *p*H 10 the use of a small-reservoir system might increase the *total* cost of developing-agent consumption by about 10 per cent, whereas the large-reservoir system might increase the cost by about 70 per cent. Thus the possibility of making economical use of spray processing would seem to depend upon the extent to which the volume of circulating developer can be reduced without losing control over the rate of change of the composition of the bath. The theoretically ideal condition would be that in which the volume of circulating developer is reduced to zero, for in this case the "replenisher" itself (presumably of constant composition) is sprayed on to the film and then runs to waste. This advance awaits only a suitable application technique.

In the case of negative developers, there is little to be gained by using nitrogen or an airtight system, unless the oxygen content of the air can be brought much lower than 4 per cent. If nitrogen were used, the cost of doing this would be prohibitive. Although reducing the oxygen content of the air, especially in the case of positive developers, could be achieved by making the cabinet airtight, the trouble of doing this and the instability that would be introduced on opening the cabinet doors and admitting oxygen make the device scarcely worth while.

Some advantage might be gained in a spray system using a large reservoir of developer, if the air bubbles trapped in the returning developer could be separated before they are carried back into the bulk of the solution in the reservoir. This separation could, perhaps, be coupled with a removal of dissolved gelatin by allowing the foam to be removed from the system at this point.

Acknowledgment

The author would like to acknowledge the assistance rendered by Miss S. J. Moorcraft and Messrs. A. F. C. Hirst and J. Smith in constructing the apparatus and carrying out the many hundreds of analyses involved.

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Lead-Sulfide Photoconductive Cells in Sound Reproducers*

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Summary—**A number of experiments have been performed on the behavior of lead-sulfide photoconductive cells, as applied to sound reproduction. These include measurements of sensitivity or signal output under a wide variety of conditions in a standard 16-mm sound projector. Data have been procured with silver, silver sulfide, dye image, and iron-toned sound tracks. Measurements have also been made on the frequency response and variation of signal output with exciter-lamp color temperature.**

Introduction

The lead-sulfide photoconductive cell was introduced to the motion picture industry by Cashman[1] in 1947. More recently, Anderson and Pakswer[2] published a detailed comparison of the lead-sulfide cell with the *S1* and *S4* photoemissive types. A subcommittee of the SMPE Sound Committee is now studying the cell. There is evidence of widespread interest in the development, but to date the cell has not been widely accepted for motion picture sound reproduction. A report has been issued by the Motion Picture Research Council[3] which concludes that "this tube shows excellent promise but indicates a need for further development."

One difficulty has been that there are not enough data at hand taken from the point of view of the equipment manufacturer to enable a real evaluation of its worth. Furthermore, not all of the data which are available (published data, advertising, and private communications from development groups) are consistent and meaningful. In addition the tube manufacturers, at least in the initial stages of development, have had considerable difficulty in obtaining uniformity of characteristics in production runs. On the other hand, there are many clear-cut advantages in the use of the lead-sulfide cell for sound reproduction. This paper will present data taken in 16-mm sound projectors which it is hoped will help to clear up some of the questions involved.

* Presented April 8, 1949, at the SMPE Convention in New York.

Review

A brief review of the salient features of the cell is probably in order. The photoelectric action is internal (as opposed to the external photoeffect or photoemission). An excess of free electrons in the thin layer of active material results in an increased electrical conductivity. Cells of this type may be used as receptors in circuits much the same as those used with photoemissive tubes; the signal voltage is developed across a resistance in series with the cell, and polarizing voltages of 45 to 90 volts are commonly used. The voltage sensitivity is high; in some cases, up to 30 decibels increase in output signal may be realized over a vacuum photoemissive tube. The frequency response seems to be adequate; Cashman mentions a loss of the order of 7 decibels at 10 kilocycles per second. The spectral response is concentrated in the infrared[1] with a peak at 2 to 2.5 microns, and cutoff at approximately 3.5 microns. The response, however, can be varied considerably,[2] by varying the amount of oxide in the active material. The noise level is very low, and attainable signal-to-noise ratios are very high. Furthermore, the absolute noise output decreases when the cell is illuminated, in contrast to the behavior of photoemissive tubes, in which the noise voltage is proportional to the square root of the mean photocurrent. Finally, the effect is apparently quite linear with light intensity, at least within certain limits. This point will be discussed in more detail later.

Theory of a Signal Circuit Using a Photoconductive Cell

Additional understanding of the use of a photoconductive cell may be gained by a rather elementary mathematical approach. Consider a light-sensitive area like that shown cross-hatched in Fig. 1. The following symbols will be used in the treatment:

L = distance between electrodes
X = width of electrodes
τ = thickness of photoconductive coating
ρ_0 = specific resistance of the coating
g_0 = $1/\rho_0$ = specific conductance of the coating
G = conductance of the tube
R = $1/G$ = resistance of the tube
I = light intensity (flux per unit area on sensitive surface)
ω = angular frequency of alternating-current light excitation
R_0 = load resistance in signal circuit, Fig. 2
E = supply voltage to signal circuit
E_0 = signal voltage
e_0 = alternating-current component of signal voltage

We may write, for the conductance G of the area between the electrodes, or the resistance R

$$G = g_0 \tau(X/L) \tag{1a}$$

and

$$R = \rho_0 (L/\tau X). \tag{1b}$$

Equation (1b) is the more familiar form of the fundamental resistance equation, but (1a) and (1b) are completely equivalent. If the specific conductance g_0 is not constant over the whole area, it may be shown that

$$G = \overline{g_0}\tau(X/L), \tag{2}$$

where $\overline{g_0}$ is the average value,

$$1/LX \int \int g_0(X,L)\; dX\; dL.$$

The only assumption we shall make about the photoconductive effect is that the specific conductance g_0 is related to light intensity I by an equation of the form

$$g_0 = A + kI.$$

If the light intensity is not uniform over the surface, it may still be shown that

$$\overline{g_0} = A + k\bar{I},$$

where $\bar{I}$ is the average intensity over the sensitive area. The constant A results from the fact that the dark resistance of the cell is finite. Accordingly,

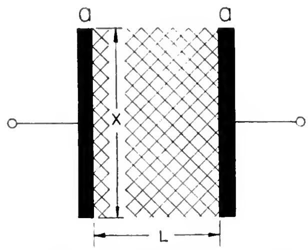

Fig. 1—Schematic representation of photoconductive surface (cross-hatched area) with electrodes a, a.

$$G = (A + k\bar{I})(\tau X/L). \tag{3}$$

First note that the conductance does not depend upon the size of the sensitive area but only on the shape factor X/L and the thickness of the layer. Second, the response depends upon the average intensity and not on the total flux. For a given total light flux, the response is inversely porportional to the sensitive area. Since the noise currents are inversely proportional to the square root of the sensitive area,[1] the attainable signal-to-noise ratio is also inversely proportional to the square root of the sensitive area.

Next consider a photoconductive cell used in a circuit like that shown in Fig. 2. Assume that the average light intensity I is sinusoidally varying as a function of time,

$$\bar{I} = B + C \cos \omega t. \tag{4}$$

Then

$$G = (A + kB)\frac{\tau X}{L} + \frac{kC\tau X}{L}\cos\omega t$$

which can be simplified to

$$G = a(1 + m\cos\omega t) \text{ if } a = (A + kB)(\tau X/L) \text{ and } m = \frac{kC}{A + kB}. \quad (5)$$

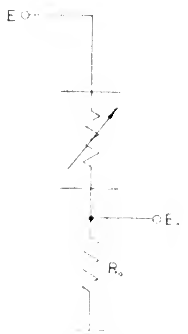

Fig. 2—Simple signal circuit using photoconductive cell as detector; signal voltage is developed across the resistor R_0.

The voltage developed across the load resistance R_0 is just

$$E_0 = E\frac{aR_0\,(1 + m\cos\omega t)}{1 + aR_0(1 + m\cos\omega t)}. \quad (6)$$

When this expression is expanded in a series of powers of $\cos\omega t$, and coefficients collected, we find the fundamental component of the alternating-current signal,

$$e_0\ (\text{fundamental}) = \frac{aR_0}{(1 + aR_0)^2}E\,m\cos\omega t. \quad (7)$$

This expression has a maximum value for a $R_0 = 1$, or

$$R_0\ (\max) = \frac{L}{(A + kB)\tau X}. \quad (8)$$

This points up the fact that maximum alternating-current signal output is obtained when the load resistance is matched to that value of the cell resistance corresponding to the mean light level, and not necessarily to the dark resistance of the cell. Subject to the matching condition expressed by (8), the signal voltage can be expressed as

$$E_0 = \frac{E}{2}\left(1 + \frac{m}{2}\cos\omega t - \frac{m^2}{4}\cos^2\omega t + \frac{m^3}{8}\cos^3\omega t\ \ldots\right). \quad (9)$$

The literature is rather vague on the matter of linearity. Cashman states that the effect is linear up to intensities of 30 to 40 foot-candles. Anderson and Pakswer say that linearity is obtained "up to light levels of about 0.01 lumen" but say nothing of the area, and the limit presumably is determined by intensity and not by total flux. Neither paper makes it clear whether the "effect" referred to is fundamental (i.e., change of conductivity) or simply the signal voltage developed across a load resistor. Even though the fundamental effect were ideally linear, one would expect a nonlinearity in the voltage output because as the signal voltage is developed it reduces the voltage across the sensitive element (i.e., the cell is not ideally a constant-current device). This is borne out by the appearance in (9) of distortion terms of the second and higher order. Equation (9) can be expanded and rearranged to give the harmonic components:

$$e_0 = \frac{E\,m}{4}\left(\cos\omega t - \frac{m}{4}\cos 2\omega t + \frac{m^2}{16}\cos 3\omega t \ldots\right). \tag{10}$$

To give a rough practical example, if the polarizing voltage E were 100 volts, and the light modulation sufficient to give an alternating-current fundamental component of 1 volt peak amplitude, then the

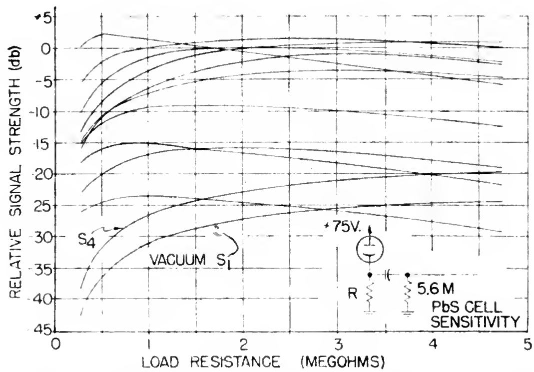

Fig. 3—Signal output (in decibels relative to an arbitrary zero) versus direct-current load resistance for a number of lead-sulfide cells; the same curve is plotted for an *S1* and *S4* vacuum phototube to serve as a reference.

second-harmonic term would be 1 per cent. If the peak amplitude of the fundamental is n per cent of the polarizing voltage, one may expect second-harmonic distortion of n per cent. In all practical cases, distortion terms higher than the second order are negligible.

SENSITIVITY

A number of tests have been made to determine the sensitivity of the cells under practical test conditions. Fig. 3 is a plot of the signal output from a large number of photoconductive cells and from two photoemissive tubes, plotted against the value of the load resistance. The conditions of the test were the same for all cells, but at a load resistance of 1 megohm, there are variations in output of nearly 30 decibels. The data were taken in a 16-mm projector using the Motion Picture Academy 400-Cycle Signal Level test film. The exciter-lamp color temperature was approximately 3100 degrees Kelvin. The curves illustrate the desirability of matching the load resistance to the resistance of the photoconductive cell. A total of about 20 lead-sulfide cells has been tested, from five different manufacturers. The sensitive areas ranged from $^1/_8 \times {}^1/_8$ inch to $^1/_4 \times {}^1/_4$ inch. This alone can account theoretically for a range of output up to 12 decibels, since the size of the light spot was just about correct for the smallest surface. However, it is worthy of note that some of the cells which give the largest output are not those with the $^1/_8$- $\times$ $^1/_8$-inch area, but $^1/_8$- $\times$ $^1/_4$-inch. The variations from cell to cell are undeniably large. This situation seems to be improving, however, and it is encouraging that five cells recently received from one manufacturer fell within a 10-decibel sensitivity range. All manufacturers report encouraging results in their attempts to reduce variations from cell to cell, and any single cell seems to be quite stable and long-lived.

Exciter-Lamp Color Temperature

Fig. 4, curve *A*, shows the results of measurements made on lead-sulfide cells to determine the effect of exciter-lamp color temperature on signal output. The data were taken with several different exciter lamps in a 16-mm projector, using the Motion Picture Academy 400-Cycle Signal Level test film as a signal source. The exciter-lamp voltage and current were measured, and the brightness temperature of each lamp as a function of voltage was independently measured by a Leeds and Northrup optical pyrometer. Corrections to the measured brightness temperature were computed from data for tungsten given on page 1993 of the "Handbook of Chemistry and Physics," Chemical Rubber Publishing Co., Cleveland, Ohio, 24th edition, 1940. The absolute values of color temperature are probably not very precise. However, they are precise enough to show that, as one might expect from the spectral response of the cells, the lead-sulfide cell is much less sensitive to exciter-lamp color temperature than either the *S1* or *S4* phototube.[4]

Curve *B* in the same figure is a plot of the total radiated power from a tungsten lamp as a function of color temperature, determined by thermopile measurements. Since curve *A* was taken simply by varying the voltage on an exciter lamp in a given optical system, the data represent the response obtained from a *constant area of the light source.*

Curve *C* shows the variation of photosignal with light-source color temperature at *constant total radiated power.* It was obtained by dividing, point by point, the ordinates of curve *A* by the ordinates of curve *B*. These data indicate that the greatest transducer efficiency for the combination of a lead-sulfide cell and a silver sound track would be obtained with a light-source color temperature a little higher than

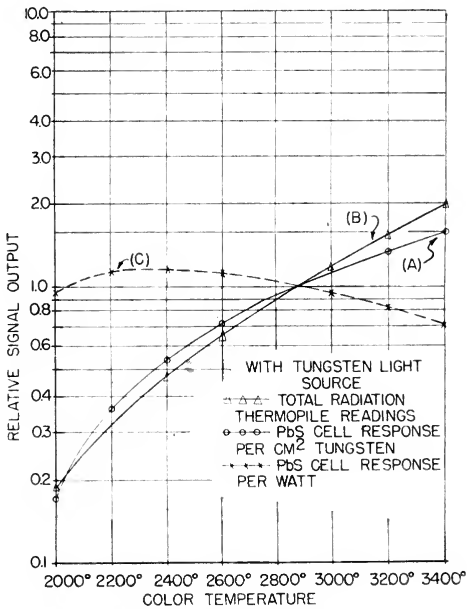

Fig. 4—Behavior of a lead-sulfide cell as a function of exciter-lamp color temperature; curve (*B*), plotted as a reference, gives the total radiation from a tungsten source per unit area. All curves are normalized to 2870 degrees Kelvin.

2000 degrees Kelvin. This efficiency can only be realized, however, if exciter lamps are designed which will operate at this color temperature. Furthermore, since the energy flux through the scanning aperture varies with color temperature as shown by curve *B* in Fig. 4, the loss in power which would result from reducing the color temperature could only be recovered by utilizing a larger area of radiating surface. There is no good reason (except, perhaps, lamp life) for operating presently available exciter lamps at other than their rated voltage and color temperature, no matter what type of photosensitive element is used as a transducer in the sound system.

Since the lead-sulfide-cell output is less sensitive than the *S1* and *S4* surfaces to light-source color temperature, one would expect it to be less sensitive to alternating-current ripple in the lamp power supply. Fig. 5 shows the hum-to-signal ratios obtainable with the lead-sulfide cell used with a number of different lamps when the lamp power is pure 60-cycle alternating current. The figures do represent an improvement over the *S1* and *S4* tubes, and the low-resistance filaments are almost good enough. These are high-power lamps, however, with large envelopes, and not suitable for use in 16-mm equipment.

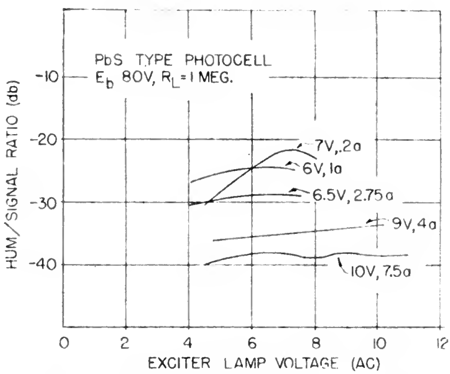

Fig. 5—Hum-to-signal ratio obtained with the lead-sulfide cell and a number of standard exciter lamps. The lamp excitation was raw 60-cycle alternating current.

The use of an indirectly heated exciter lamp has been prominently mentioned. Tests have been made of experimental lamps of this sort used with lead-sulfide cells, and signal-to-hum ratios of greater than 90 decibels have been obtained with raw alternating-current voltage on the lamp. However, the color temperature of these lamps is quite low; consequently the total radiated power and the signal output are also low.

The considerations affecting the choice of an exciter lamp for use with the lead-sulfide cell may be summed up as follows: The advantages claimed for the cell have included increased signal output and a very much simplified exciter-lamp supply. Upon close scrutiny it appears doubtful that these two advantages can be realized simultaneously without considerable optical redesign, and even then the signal output may be limited by optical considerations.

FREQUENCY RESPONSE

There are notable discrepancies in the available data on the frequency response of the cells.[1, 2, 5] Figures quoted for the high-frequency attenuation have ranged from 2 decibels at 10 kilocycles per second to 10 decibels at 7 kilocycles per second. Therefore, it seemed worth while to take frequency-response measurements on a variety of cells from different manufacturers, all under the same experimental conditions. Data were taken in two different 16-mm projectors on

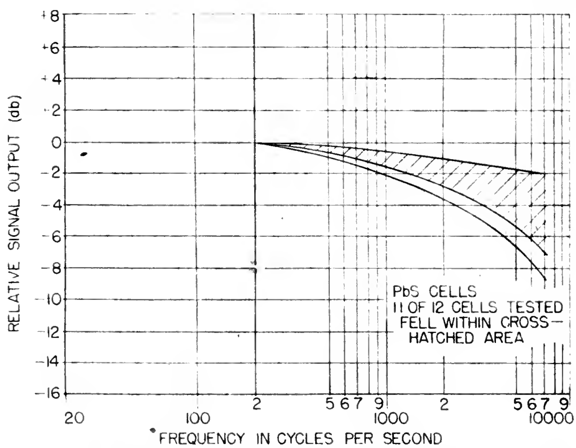

Fig. 6—The frequency-response curves obtained with twelve samples of lead-sulfide cells.

12 lead-sulfide cells from three sources. In each of these projectors the effective scanning-slit width at the film is about one-half mil. The standard multifrequency test film was used as a variable-frequency source, and the over-all system frequency response was equalized by high-frequency emphasis in the amplifier, to the point where it was approximately flat with a vacuum photoelectric tube. The color temperature of the light source in both projectors was quite high—about 3000 degrees Kelvin. This is mentioned here as a reference for future work, inasmuch as there is some indication that the frequency response improves with increasing color temperature. The data on this point are not consistent, however, and the effect, if it exists, is so small that the accuracy of our measurements does not warrant any definite statement. The results are plotted in Fig. 6.

For the great majority of the cells, the measured frequency defect ranged from 2 to 7 decibels at 7000 cycles per second. One cell showed a high-frequency drop of 8.4 decibels at 7000 cycles per second.

Some additional comments are pertinent. There is no apparent correlation between sensitivity and frequency response. Such a correlation has been suggested by one of the groups working in this field,[5] but our results do not confirm it. As a matter of fact, the cells which show the highest sensitivity lie at both extremes of the frequency response curve. Another theory has been advanced[5] to the effect that a direct-current light bias tends to improve the frequency response of the photoconductive cells. Again, our results fail to confirm this supposition. In one of the projectors used, a direct-current bias of the order of 3 to 5 foot-candles was present, but there is no appreciable difference between results obtained in the two projectors.

[AUTHOR'S NOTE: Considerable clarification of the data on frequency response has been possible since this paper was presented at the SMPE Convention. For this, I am indebted to Mr. John A. Maurer. At the conclusion of the paper, he asked if the sound optics had been refocused for infrared when lead-sulfide cells were substituted for the *S4* vacuum phototube used as a reference. I answered that they had been refocused. Subsequently, it was found that in the case of one set of measurements this had been done, but in a second set this was not the case. When measurements were retaken with sound optics properly focused for all cells, the gross inconsistencies with which I was plagued at the time of the Convention were removed.]

USE WITH COLOR FILM

One question which has been raised very frequently relates to the use of the lead-sulfide cell with dye-image sound tracks. The modulation of the light beam in a sound optical system depends upon absorption of light by the track material. As pointed out by Görisch and Görlich,[6] if the track material does not absorb completely in the wavelength region to which the phototube is sensitive, the signal output is decreased, and the noise level (caused by dirt, scratches, and so forth) increased. The net signal output from an optical sound system employing a photosensitive receptor is actually in the general case a very complicated story, depending upon the characteristics of the light source, film base, track material, and the detector. A subsequent paper will treat this situation more thoroughly than is possible here, where our main interest lies in the characteristics of this one particular type of cell.

No direct measurements have been made, or at least none have been published, of the transmission of the composite dye track in the wavelength region beyond 1 micron. Transmission curves have been published[7] for the region below 1 micron. In the near infrared, all gelatin dyes are known to be transparent. It is not surprising, then, that there has been concern over the use of the lead-sulfide cell with this track. On the other hand, it is practically impossible to secure samples of the track on the open market, and there is a strong indication that the film companies do not consider their present dye-image tracks commercially feasible. However, the collection of data on the use of this cell with color film of all types was considered important.

There are four types of sound track in use at the present time with color film: (1) Metallic silver. In this case the sound is printed first, then the emulsion is cleared, and the color picture printed by the regular three-layer process. (2) Silver sulfide, which may be applied by a rather complicated edge treatment after the picture is printed. (3) Ferri-ferrocyanide, which is the cyan layer of the two-color processes. (4) Dye image, as it is called, which is usually a composite of the three layers in the familiar tripack color film.

It is extremely difficult to make accurate comparative alternating-current measurements of the performance of any phototube with different types of sound track, since standard recordings are available only in the case of the silver track. One is faced with the problem of comparing the level from a few bars of music, for example, with that from the 400-cycle test loop! It is possible, however, to make direct-current measurements which theoretically give the information one is after. Such measurements consist essentially in measuring the effective total percentage transmission of the sound-track material. Consider an area of the track equal to the area covered by the scanning beam in a projector. The peak-to-peak alternating signal current (corresponding to 100 per cent area modulation) is equal to the difference between the direct photocurrent obtained with clear base, and that obtained with an equal area of the printed track material, superimposed on the base. Direct photocurrent measurements of this type are appealingly simple and accurate. The results are shown in Fig. 7. The solid lines represent the signal output relative to an arbitrary reference level, as computed from direct-current measurements. The isolated points represent some rough alternating-current measurements made as a check, with the output from the 400-cycle silver-track test loop taken as a reference. As was expected, the output from a metallic silver sound track is considerably greater than that from other types of track with the lead-sulfide cell, although the silver-sulfide track is nearly as effective. There is a considerable loss of signal (16 to 18 decibels) in the case of the composite dye

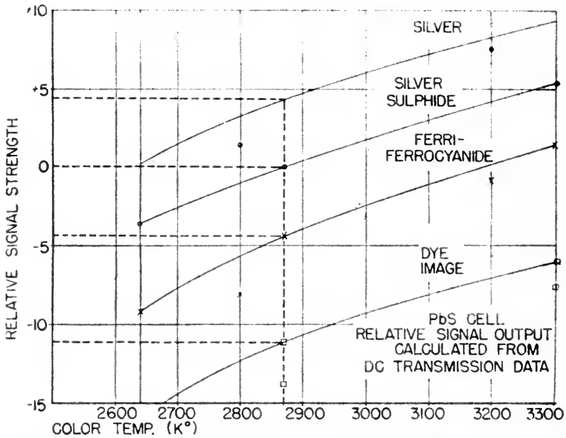

Fig. 7—The relative performance of four different types of sound track with the lead-sulfide cell; these figures are calculated from transmission measurements made using the lead-sulfide cell as a receptor.

track. Note that the dependence on the color temperature of the exciter lamp is approximately the same for all the tracks.

Conclusion

It is still not wise to make any sweeping statements about the probable future of the lead-sulfide cell. However, it would be worth while to outline some of the advantages and disadvantages connected with its use, on the basis of present knowledge. There are several clear-cut advantages:

(1) An increase in signal output of 15 to 30 decibels over ordinary phototubes for a given optical system and exciter-lamp color temperature.

(2) Increased signal-to-noise ratio, with silver sound tracks.

(3) Maximum sensitivity at fairly low values of load resistance—1 megohm or less. Hence, circuit capacitance is not such a problem.

(4) The possibility of a simplified exciter-lamp power supply, or even operation of the lamp directly from the alternating-current line.

(5) Stability and long life for any given cell.

Some possible disadvantages:

(1) Reduced signal-to-film -noise ratio from all types of dye sound tracks now available.

(2) Greater variations from cell to cell, particularly as regards sensitivity, than with present production of photoemissive cells. Selected cells may be available, however,

(3) A high-frequency response curve which is not quite as good as that of gas photoemissive tubes.

The poor behavior with presently available dye track is potentially the most serious of these disadvantages; its real seriousness can only be measured when the commercial intentions of the film companies with regard to the use of this track become better defined than they are at present.

ACKNOWLEDGMENT

I wish to express my thanks to Mr. S. Hayes and Mr. R. J. Schreiner of this Laboratory, who took most of the data presented here, and my appreciation to Dr. F. B. Berger for many valuable discussions on the subject.

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(6) R. Görisch and P. Görlich, "Reproduction of color film sound records," *J. Soc. Mot. Pict. Eng.*, vol. 43, pp. 206–213; September, 1944.

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DISCUSSION

MR. J. A. MAURER: If I understood you correctly, you stated that the response is not so much proportional to the total amount of light striking the cell as it is to the average intensity of the light striking the cell.

MR. RICHARD W. LEE: That is correct. If you have a given total amount of light, it pays you to condense it into the smallest possible spot and use the smallest possible surface which can just be covered by that spot.

MR. MAURER: Does that not imply that in the case of the lead-sulfide cell it becomes almost imperative to have the projector so designed that the light flux on the cell changes in intensity only and not in area, in order to get undistorted response?

MR. LEE: That would depend on whether the sensitivity, that is, conductivity versus light flux, is constant over the area or not. If it is constant over the area, then I think it would still hold true that the output would be dependent only upon the average intensity. Even if the size of the spot varied, if the sensitivity were uniform over the surface, I think you would still get linear response.

MR. MAURER: The second point relates to your frequency-characteristic measurements. The optical systems that are generally used in 16-mm projectors are made up entirely of simple glass lenses uncorrected in any way for chromatic aberration. Did you refocus the optical system when you started to use the lead-sulfide cells? I think the shift from the range normally used to the infrared where these cells respond would be significant.

MR. LEE: Yes, we shifted the focus, I think with a 7000-cycle track.

DR. JOHN G. FRAYNE: In view of the wide disparity in response and in frequency characteristic of these cells, why is anybody interested in using them at this time?

MR. LEE: It is difficult to answer that question in a very straightforward way. I think one reason for the wide disparity in results which have been obtained, quite frankly, is that a very large number of small manufacturers entered this field practically as soon as the lead-sulfide cells were announced. It is possible at the present time to obtain from some manufacturers cells which are quite consistent so far as signal sensitivity is concerned at least. So far as frequency response goes, I do not know.

DR. FRAYNE: So the reason is mainly economic then, is that right?

MR. LEE: Frankly, I do not know. I have been somewhat puzzled myself that the cell has not received wider acceptance than it has.

MR. E. W. D'ARCY: There is a very practical reason behind using the cells. We have been experimenting with them now for almost two and one-half years, and we secure with no trouble whatever a 60-decibel signal-to-noise level with them. That is the most practical reason we use them.

In addition to that, with the sulfide cell we are able to terminate the cell itself into a load resistance of somewhere around 200,000 ohms, which just about eliminates cable problems and eliminates the necessity of transformers or preamplifiers for normal coupling arrangements. That sets aside the economies of the thing almost completely.

QUESTION: Would you care to comment upon your experience as far as variability from cell to cell is concerned?

MR. LEE: They are exceptionally variable from manufacturer to manufacturer. There is a great deal of magic in making the cells. I think there are suppliers who are quite reliable and from whom cells with quite reproducible characteristics can be obtained.

MR. R. T. VAN NIMAN: The SMPE Sound Committee has a Phototube Subcommittee, of which I happen to be the Chairman, and we have been investigating this whole matter of sulfide phototubes for over a year now. I have purposely held up making any official report on it because of the existing confusion. We hope at the fall convention in Hollywood, to have some rather comprehensive report summarizing all the experiences.

MR. D'ARCY: The point you brought out about color film and the impossibility of securing adequate test material, even 400-cycle level film from the various color manufacturers, is a very real one. We tried to do that on a research project for the Navy and had absolutely no luck. We therefore had to disregard the producers of film who were so uninterested in their product or promoting it as not to make available to us their particular subject matter for our tests. If the Society could, through its intervention, secure such film, it would be very valuable.

MR. LEE: It would be a tremendous advantage for this kind of work.

MR. VAN NIMAN: The committee is working on that right now.

MR. EDWARD S. SEELEY: Variability of level leaves me somewhat puzzled: the stress placed on it. For quite a number of years, the variation in sensitivity of conventional gas cells made by what we thought was the most responsible manufacturer, was 10 decibels by their own manufacturing tolerances. They could not guarantee them any better than that. As time has gone on, manufacturers have adopted methods of selection, because there was a large number of those cells used and there was a demand for more uniformity. So today, after many years of use of gas cells, we have reasonable uniformity provided you buy the right type. If you just buy any old type from any old manufacturer, I will guarantee that you will get a bigger variation than you showed for the lead-sulfide cell.

MR. LEE: That is quite possible.

MR. VAN NIMAN: After twenty years of making these cells, the procedure, as I understand it now, is to make a batch of cells, sort out the best ones, and sell them for $18.75, and the next ones you sell to the motion picture industry and the ones that have no response whatever, you sell for $1.50 to photocell experimenters.

MR. JOHN VOLKMANN: Did you notice any correlation between your response curves and the sensitivity? In other words, does the frequency characteristic, the fall off of highs, appear to be greater for the cells that showed the least amount of sensitivity?

MR. LEE: No, I had received some indication that there should be some correlation from a couple of cell manufacturers who felt that the cells which showed the highest response tended to show a poorer frequency response. Through the whole range of thirty or thirty-five cells which have been measured from a number of different manufacturers, I cannot construct any correlation.

DR. FRAYNE: I would like to ask if anybody in this audience has made any measurements on the effect of gamma, that is, on the contrast of black-and-white sound track, by switching over from standard cells to this cell. If the transmission is different in the infrared from, say, the 7500 to 8000 region, there will be a distinct change in gamma. That will mean the processing for a photoemissive tube will not be correct for a sulfide cell.

To add to the importance of this, I remember in the old days when we switched over from the old potassium blue sensitive cell, there was a change in gamma of around 15 to 20 per cent which had to be corrected. I wonder if anybody has any data of what happens to gamma when you go to the lead-sulfide cell.

MR. LEE: I have made some preliminary direct-current measurements, and although the lead-sulfide cell is best with silver sound tracks as they are recorded, say, for the Motion Picture Academy test reels, yet that sound track, I will put it this way, does not give one hundred per cent absorption of the wavelengths to which this cell is sensitive. The absorption of the track is down perhaps something of the order of 2 decibels from what you would get with 100 per cent absorption.

DR. FRAYNE: Have you made any intermodulation tests?

MR. LEE: No, I have not.

MR. D'ARCY: We have made distortion tests using the 400-cycle film, but I do not think that would mean anything with reference to your gamma.

DR. FRAYNE: I think that is a very important thing and should be studied.

MR. LEE: There is an effect pointed out, I think, by Drew and Johnson of the Radio Corporation of America in a paper a couple of years ago where they were making measurements on the dye tracks, where they noted that with the *S1* phototube which is sensitive to the near infrared, the lowest layer of the composite track, which does most of the infrared modulation, is actually the poorest so far as printing conditions are concerned. There is practically no cross-modulation cancellation in that printing process, and the distortion level is very high. That effect, I would expect, would be very much worse in the case of the lead-sulfide.

DR. FRAYNE: I would strongly recommend to the manufacturers of the equipment who are going to put these cells in their machines, that before they take the irrevocable step, they study the projected effect of the cell's response on gamma of the sound track.

MR. LEE: That is right. The way I feel about it is that at present there are enough variables in this situation that I do not feel like saying that the lead-sulfide cell is a good cell for 16-mm projection or other types or that it is not. It shows a great deal of promise, but there are a lot of complications, particularly this matter of the track.

MR. D'ARCY: Would Dr. Frayne be willing to suggest a method of doing that with the sulfide cell to your satisfaction?

DR. FRAYNE: This is not the time and place, but it can be worked out, and I would be very happy to co-operate with the committee. It is a long and detailed process, but can be done. It has been done in the past when we switched over from one cell to the other. In fact, if you read Dr. McKenzie's famous pamphlet on "Toe and Straightline Records" it will give you a clue as to procedure. Of course, we have had intermodulation measurements since then, too. I am quite positive that film can be processed for correct reproduction over lead-sulfide cells, but the question is, how does a film processed for optimum playing on a lead-sulfide cell compare to one with optimum processing for the other cell; is there a wide discrepancy? We have not any information, and yet it is very vital.

MR. LEE: There is another thing pointed out by Anderson and Pakswer in their paper, printed in the January, 1949, issue of the JOURNAL, namely, that it is possible to throw the spectral response of the lead-sulfide cell around considerably. What effect the various spectral-response curves which they print there have, what effect doing that has upon the quality of the reproduction in other respects, I do not know, and they gave no information there, but it may be that a compromise is possible.

Section Meetings

Atlantic Coast

On October 26, 1949, approximately 196 members and guests heard Col. R. H. Ranger, of Rangertone Inc., describe and demonstrate his new quarter-inch magnetic-tape recorder. This equipment, by utilizing a unique method of synchronizing, provides motion picture and television producers facilities for producing high-quality lip-synchronization on quarter-inch magnetic tape.

A 60-cycle tone, laid down by a special head running parallel to the edges of the tape forms the basis for the synchronizing unit. There were demonstrations of the equipment, recording and playing back.

The Eastman Kodak Kodachrome Processing Laboratory, Flushing, L.I., was host to the Atlantic Coast Section on November 16, 1949.

Mr. Phil Smith, manager of the plant, had arranged an exceptionally well-planned and comprehensive tour schedule, which covered all of the aspects of the processing of commercial and amateur Kodachrome.

The guide conductors explained the major points of the various operations and the foremen of the various areas were on hand to answer the many questions posed by over 275 members and guests.

Ed Schmidt, *Sec.-Treas.*

Central

The September 22, 1949, meeting was in the form of an open house visit to the Eastman Kodak Company's color film laboratory at 1712 So. Prairie Ave., Chicago. As groups of 15 were assembled, they were escorted on the tour by members of the Eastman laboratory staff. About 250 members, guests, and students attended this affair.

The 16-mm Kodachrome developing machines, the color-control laboratory, and the chemical mixing room were shown, as well as the assembly of 35-mm Kodachrome transparencies in the ready mounts.

"The New Amprosound Repeater," by C. P. Goetz, Director of Industrial Sales, Ampro Corp., Chicago, was presented at the October 20, 1949, meeting. This paper describes a new self-contained 16-mm sound projection unit with a built-in screen. Features of unusual interest are the latex screen, a six-element wide-angle *f*/2.4 projection lens, and the continuous reel of new design. The machine was demonstrated during the talk by H. H. Wilson of the Ampro Corp.

"Color Phenomena," by Isay Bolinkin, University of Cincinnati, Cincinnati, was the next paper on the program. This lecture and more than twenty experiments performed to explain color phenomena were presented before the Society in Santa Monica in the Spring of 1948.

George W. Colburn, *Sec.-Treas.*

Reference Data for Radio Engineers, Third Edition

Published (1949) by The Federal Telephone and Radio Corporation, 67 Broad St., New York 4, N. Y. 640 pages + 29-page index. 800 charts and tables. $5^1/_2 \times 8^1/_2$ inches. Price, $3.75.

"Reference Data for Radio Engineers" is a handy reference book confined primarily to electrical, physical, and mathematical data related to the science and application of electronics. It is certainly not intended to be a text and it has not yet reached the bulk and complexity of the typical handbook. The editors have displayed considerable wisdom in choosing what and how much material should be included.

The first edition in 1943 contained 180 pages with no index; the second edition issued in 1946 contained 322 pages plus index; and the current edition has been expanded to 640 pages plus index. The acceptance that previous editions of this book have had, and particularly the frequency with which the new and expanded editions have been issued, is testimony enough of its value.

In the third edition, material has been added to subjects previously included such as mathematical formulas, antenna data, and transmission-line formulas. New material has been included on subjects formerly classified such as radar and servomechanism fundamentals and on subjects which have recently assumed increasing importance such as pulse modulation, spurious frequency responses, amplitude-modulation, frequency-modulation, and television broadcast standards, and others.

H. J. Schlafly
Twentieth Century-Fox Film Corporation
New York 19, N. Y

Photoelectricity and Its Application, by V. K. Zworykin and E. G. Ramberg

Published (1949) by John Wiley and Sons, 440 Fourth Avenue, New York 16, N. Y. 478 pages + 16-page index + xii pages. 352 illustrations. $6 \times 9^1/_4$ inches. Price, $7.50.

The increasingly numerous and important applications of photocells in the scientific and industrial fields have called for a comprehensive and authoritative text on the theory and production of these devices, their various types and performances, and their applications in such fields as photographic and optical measurements, sound reproduction, still or moving image transmission, communications in general, telemetering and object detection, as well as a number of more specialized applications.

The authors of the above book have provided just such a text as specified. Their descriptions are well chosen and clear, and of unusually complete and diversified nature. Indeed, the wealth of presented information makes their text practically encyclopedic. The numerous illustrations are pertinent. Mathematical derivations, and even end equations, are minimized.

The book is clearly intended for engineers specializing in motion picture and television technologies, for engineers concentrating on the supervision or control of industrial or related processes by photocells, for designers and constructors of photocells, and for scientists in many fields who plan to use photocells and their associated circuits as detection or measurement tools. The division of chapters, and the mode of presentation of the material within chapters, are well adapted to the needs of such workers.

Despite the volume of material in the book, skillful classification and adequate author and subject indexes enable the ready location of most material dealing with specific topics. It may be added that the long and successful research experience of the authors is probably responsible for their forward-looking treatment of various topics, including a stimulating outline of the possible future uses of photocells. Their analyses at times touch the prophetic—with corresponding encouragement to the professional reader.

Alfred N. Goldsmith
Consulting Engineer
New York 17, N.Y.

The Information Film, by Gloria Waldron

Published (1949) by the Columbia University Press, Morningside Heights, New York 27, N.Y. 267 pages + 13-page index + xviii pages. 14 illustrations. $5^3/_4$ by $8^3/_4$ inches. Price, $3.75.

The notion seems to have grown up, particularly among teachers and librarians, that books are something more than media for circulating information and entertainment, and, conversely, movies, radio, and television, which serve these identical functions, are, somehow, not to be mentioned in the same respectable breath. This interesting item of academic mythology draws considerable sustenance from the dull and dreary hyphenation, *audio-visual*, a term which unfortunately has become a formidable element in the promotional vocabulary of non-theatrical film enthusiasts. Between the bibliophiles and the cinemaphiles a sort of self-interest cleavage has developed and, if anything, grows wider and less justified from day to day.

Gloria Waldron, with the assistance of Cecile Starr, in her report of the Public Library Inquiry on *The Information Film*, has done a great service in the destruction of prejudices for and against movies and books among the library profession.

Underlying this comprehensive report is the sensible idea that public libraries and public librarians exist for the somewhat simple purpose of housing and circulating information to the public. There is apparently no doubt in Miss Waldron's mind that books are not synonymous with information. Once the major premise on the function of the public library is admitted, we need only fill in the minor premises regarding the media through which information is circulated in this century in order to draw the conclusion that public libraries should, in order to discharge their function, circulate information films to the public.

But a great many people do not think except in times of personal crisis. It then becomes necessary to take people mentally by the hand and walk with them through the diverse paths of operational detail, carefully explaining and persuading at each step.

The Information Film is exactly that sort of operational and persuasive guide service for public librarians. Miss Waldron makes few assumptions regarding the film literacy of her audience. As a result, she has compiled what is perhaps the most definitive book thus far produced on the non-theatrical film. It is both comprehensive and practical.

Charles F. Hoban, Jr.
The Catholic University of America
Washington, D.C.

George Eastman House

The George Eastman House, Inc., a public educational institute of photography in Rochester, New York, was opened on November 9, 1949. Distinguished visitors from the world of photography and related arts and sciences were in attendance. Addresses were given at the opening ceremonies in the afternoon by several notables including Mr. Earl I. Sponable, president, Society of Motion Picture Engineers; Dr. D. A. Spencer, past-president, Royal Photographic Society of Great Britain; Dr. M. Abribat, representing the Société Française de Photographie; Captain E. J. Steichen, Museum of Modern Art; Mr. C. G. Clarke, president, American Society of Cinematographers; Dr. J. G. Mulder, president, Photographic Society of America, and Colonel G. W. Goddard, United States Air Forces.

The principal speakers for the evening session held in the Eastman Theater were Dr. C. E. K. Mees, vice-president of Eastman Kodak Company; Dr. A. Valentine, president of the University of Rochester; Admiral Richard E. Byrd, and Miss Mary Pickford.

The purpose of the Institute will be to demonstrate the technique of photography and illustrate its historical development, to show the manifold part it plays in nearly every branch of human activity, and to facilitate research in various fields of photography.

In two rooms on the second floor of Eastman House are shown several exhibits relating to the beginning of motion pictures. The historical motion picture collection which has been assembled for many years includes equipment, films, and related materials from the collections of Gabriel Cromer and François Dublier. Toys illustrating the "persistence of vision" principle include the Zoetrope, the Phenakistoscope, and Reynaud's Projection Praxinoscope. Several of these can be operated by the visitor who will see first hand the simulated motion created by them. Negatives, prints, apparatus, and notebooks of Muybridge are shown.

Projectors and cameras made by early pioneer experimenters can be operated by the visitor. Models of equipment include a Lumière camera-projector, Demeny, De Bedts, Grimoin-Sanson, Prestwich, and Boulé cameras. One of the original Armat projectors made in 1895 is on display.

A Mutograph camera and a Cineclair projector are included. Posters and still photographs of early performances are displayed. Cameras, printers, and projectors of the period 1900–1920 can be seen.

Other rooms in the House will have exhibits of amateur motion picture equipment for 8-, 9.5-, 16-, and 28-mm film for home and school use. Several 16-mm projectors are set up in a number of rooms for showing motion pictures that tell the story of specific exhibits.

— New Products —

Further information concerning the material described below can be obtained by writing direct to the manufacturers. As in the case of technical papers, publication of these news items does not constitute endorsement of the manufacturer's statements nor of his products.

Recordall has recently been released by the **Miles Reproducer Company, Inc., 812 Broadway, New York 3, New York.** This new type of recorder weighs 15 pounds and is applicable for use in the office, laboratory, home, car, plane, train, or school.

It employs a permanent jewel to record or to play back continuously up to $3^1/_2$ hours (up to 24 hours on custom-built models) on each face of an endless plastic band of safety film known as Sonaband. The Sonaband is self-aligning and can be removed or replaced at the end of $3^1/_2$ hours within two seconds. Each Sonaband holds over a mile of soundtrack, which is indexed and permanent requiring no erasing or shaving.

Recording on a Recordall is possible without a supervising attendant since the machine is automatically voice-powered, whereby the vibrations of the voice coming through the microphone or telephone instantly start the machine and the cessation of sound automatically causes the machine to stop within 4 to 6 seconds.

Meetings of Other Societies

December—

American Association for the Advancement of Science	December 26 through December 31 New York, New York

March, 1950—

Institute of Radio Engineers National Convention	March 6 through March 9 New York, New York
Optical Society of America Winter Meeting	March 9 through March 11, 1950 New York, New York

—*New Products*—

Further information concerning the material described below can be obtained by writing direct to the manufacturers. As in the case of technical papers, publication of these news items does not constitute endorsement of the manufacturer's statements nor of his products.

Ticograph

A positive check on admissions is now available to theater owners through the Ticograph, an automatic ticket checker recently placed on the market by **Theatre Control Corporation, 319 Orleans Street, Detroit, Michigan.** This machine does the checking so that the owner or circuit supervisor need only record the information it supplies.

Standard theater admission tickets are imprinted with a special "Criss-Cross Design" so that each ticket is edge-marked with dots, the locations of which vary with the numerical progression of the tickets. As the Ticograph stacks the stubs in a transparent container, the edge-marking on the stubs forms a definite visible pattern making a single ticket far out of normal sequence conspicuous. Missing, resold, or unauthorized tickets can be spotted immediately.

A series of interlocking controls in the Ticograph are of special interest. For example: only a conventional admission ticket will operate it. When the stub containers have been removed or when unauthorized containers have been inserted, the Ticograph refuses to take tickets. When a container should be replaced, a signal light flashes. Ticograph continues to take tickets until the container is replaced with an empty one. If this is not attended to in due time, however, the machine will begin rejecting additional tickets until the filled container is replaced.

The Ticograph collects, counts, cuts, checks, and records the sequence of every admission ticket, and then stacks the stubs into sealed tamperproof containers in the exact order of their collection. The cross-checks are so designed that any irregularity in the handling of admission tickets is reported.

SMPE Officers and Committees: The names of Society Officers and of Committee Chairmen and Members are published annually in the April issue of the JOURNAL. Changes and corrections to these listings are published in the September JOURNAL.

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