B. E. STECHBART

3328

Journal of the Society of Motion Picture Engineers

VOLUME 51 JULY 1948 NUMBER 1

Subscription to nonmembers, $10.00 per annum; to members, $6.25 per annum, included in their annual membership dues; single copies, $1.25. Order from the Society's general office. A discount of ten per cent is allowed to accredited agencies on orders for subscriptions and single copies. Published monthly at Easton, Pa., by the Society of Motion Picture Engineers, Inc. Publication Office, 20th & Northampton Sts., Easton, Pa. General and Editorial Office, 342 Madison Ave., New York 17, N. Y. Entered as second-class matter January 15, 1930, at the Post Office at Easton, Pa., under the Act of March 3, 1879.

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Brightness and Illumination Requirements*

By H. L. LOGAN

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Summary—This paper analyzes the problem presented by the continuous lighting of motion picture theater auditoriums; gives data on screen brightness with various types of film running; relates auditorium brightness to average screen brightness with film running; proposes a specific arrangement of brightnesses from screen background to theater lobby; and suggests a practical method by which this arrangement of brightnesses may be attained with standard lighting equipment.

The continuous lighting of motion picture theaters is a rather special problem. The tentative and controversial rules suggested in Report No. 1 on "Brightness and Brightness Ratios" of the Illuminating Engineering Society do not seem to apply, as they are for spaces in which critical seeing tasks occur, and in which the object of regard is a detail seen at close range.

The screen is the object of regard in a motion picture theater and is seen at an average minimum distance[1] of 22.5 feet. This distance is greater than the minimum at which the ciliary muscles tense in order to bring an object into focus.[2] That is, the observers' lenses are in a relaxed state at all screen-viewing distances in the average motion picture theater, which is characteristic of distant, rather than close-range vision.

The three-to-one rule[3] would be impossible to apply in any event as diffusion from the interior of the house would put an overlay of light on the screen that would greatly reduce contrasts. Mimimum screen brightnesses, with film running, as measured by the writer (see Table I), ran as low as $^1/_{27}$ of the average brightness. Still lower brightnesses were frequently encountered but they were below the range of the instrument used and could not be accurately measured. The author estimates that minimum brightnesses of $^1/_{50}$ of the average brightness are common.

* Presented April 21, 1948, at the Atlantic Coast Section in New York.

If the interior of the house was lighted to a brightness of one third the average screen brightness (with film running), and in such a way that no direct light could reach the screen, the screen could still receive an overlay of light by diffusion from the house surfaces that would approach one third of the average screen brightness. In this case details that had a brightness less one third of the average screen brightness would tend to be washed out, and brighter contrasts would be diluted.

TABLE I

MEAN BRIGHTNESS MEASUREMENTS OF MOVING PICTURE SCREENS

	Brightness In Foot-Lamberts			
	Screen	With Film Running		
Film	Blank	Minimum	Average	Maximum
Black-and-white news	15.0	0.35	1.08	2.50
Black-and-white feature	15.0	0.04	1.09	5.10
Black-and-white news	13.6	0.26	1.42	4.20
Cine-color short	15.0	0.53	1.40	2.70
Technicolor feature	10.1	0.18	1.27	5.63
Technicolor travelog	15.0	1.20	2.40	3.70
Self-colored animated cartoon	10.1	0.36	1.65	4.73
Self-colored animated cartoon	15.0	0.53	2.80	5.90

Such washing out and dilution of screen detail would not be acceptable and so the subject must be approached from another angle. It is for this reason that the author undertook to measure screen brightnesses with film running. Until such brightnesses were known, engineers would be guessing at permissible brightnesses in the rest of the observer's field of view, as such brightnesses obviously had to be considerably less than screen brightnesses in order not to wash out screen detail with an overlay of diffused light originating from the walls, ceiling, and floor of the illuminated auditorium.

Measurements of screen brightnesses with film running were not possible until the development of the instrument shown in Fig. 1. This instrument has a specially shaped mirror that picks up the same field of view as an observer. The mirror is viewed by a photosensitive electronic cell and the results read on a milliammeter. When the instrument is so located with respect to the screen that the screen sensibly fills the field of the instrument, and no other light approaches from any other part of the instrument field, the needle deviation is a measure of the total light coming from the screen at any instant. The instrument is equipped with filters to correct the response of the electronic cell to that of the standard observer, the action of the instrument being independent of human judgment, and automatic.

The instrument measures "steradian foot-lamberts," which can be converted into other units when the distance of the instrument from the source of light is known, or when there is some reference condition to tie to, such as the brightness of the blank screen (which was sepa-

Fig. 1—Logan fluxmeter.

rately measured by two observers with two different Luckiesh-Taylor Brightness Meters in this investigation).

The writer has adopted the average screen brightness with film running as the basic reference criterion in the design of motion picture theater lighting. Previous investigators, having no way of arriving at instantaneous average brightness for entire screen with film running, have used stills and measured the "white" and the "blacks" which they have then used as reference values.[4, 5] The eye may spend as

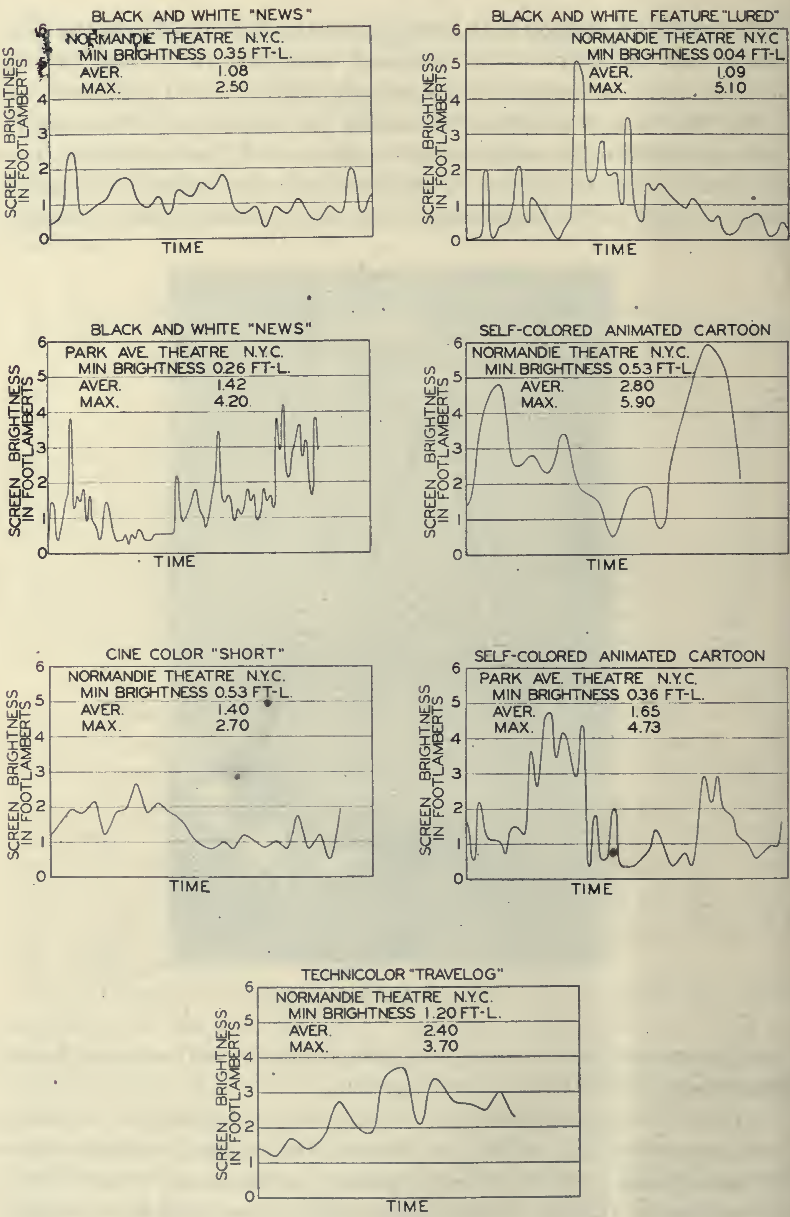

FIG. 2—Sequence of brightness changes for various types of film.

little as $^5/_{100}$ second on a fixation point, and its fixation pauses normally average $^{15}/_{100}$ second.[6] Motion picture film is moved along at a rate that is based on this fact and its complement, the persistence of vision. As a result the eyes in screen viewing seldom have an opportunity to rest on a fixation point long enough to adapt to it. The author believes that with the rapidly fluctuating brightness of the screen with picture running, the eyes have no choice but to adapt to the mean screen brightness. See Fig. 2 for sequence of brightness variations on screen as a whole, for films measured.

If we adopt the lowest mean brightness, as measured in this investigation, that is likely to be met, namely that of black-and-white newsreels, as our reference value, we start with 1 foot-lambert for the screen in action. We can allow one tenth of that,[7] so long as it is very uniformly distributed, as the steady brightness of the walls, ceiling, and floor of the auditorium. That is, these surfaces may have a brightness of 0.1 foot-lambert. This brightness should be carried right up to the edge of the screen. Fabir Birren reports to the writer that when the space between screen and proscenium arch was lighted in experiments in the Walt Disney studios the illusion of great depth was created in the pictures. This area should be lighted so as to appear as a pale gray mist. The lighting preferably should be absolutely uniform, but if that cannot be accomplished because of job conditions, then the brightness should be least near the screen, and rise to the brightness of $^1/_{10}$ foot-lambert of the auditorium walls. This is not much light but it is close to what the Park

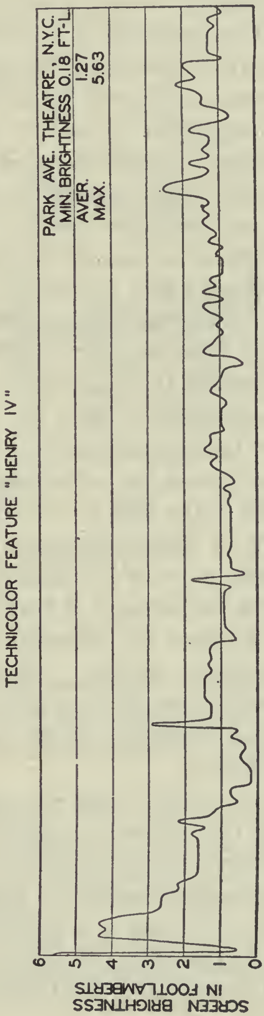

Fig. 2 (*continued*)—Sequence of brightness changes for various types of film.

Avenue Theater, New York City, provides for full house lighting with no picture running, for example. Measurements in this modern theater with house lighting on full gave the following:

	Foot-Lamberts
Walls	0.120
Balcony face	0.085
Ceiling	0.070

Offhand, it would seem that the house lights in this theater therefore could be operated at all times with great improvement to the ease, comfort, and safety of the patrons. Perhaps the principal reason why this may not be true, is that the auditorium is largely lighted by coves. It is impossible to control the action of coves. The wall area in the immediate neighborhood of these coves has a brightness of 10 foot-lamberts. This means that the cove running around the proscenium arch, for example, which is one of the main sources of light in this auditorium, is nearly ten times the brightness of the screen when a black-and-white newsreel is running; and 500 times the minimum screen brightness that can be expected. Jones[5] found that a brightness of 3 foot-lamberts was the highest that could be tolerated toward the front of the auditorium.

In addition to this, the ceiling roundels that helped provide the house lighting had a brightness of 600 foot-lamberts. This is not so important as the cove brightness because these roundels are not included in the field of view of most people on the auditorium floor and would be disturbing principally to occupants of the balcony. The significant point is that the brightness of these ceiling roundels is a function of the size of lamp used, and the latter is larger than necessary because the reflection factors of the various surfaces reached by the light are too low. If higher reflection factors for floor walls, and if the backs of seats were used, the lamps could be reduced in proportion, and the brightness of the roundels could be dropped to more reasonable figures.

It is evident that in order to attain satisfactory house lighting while the screen is in action, the distribution of light must be very carefully controlled, as the brightness level of 0.1 foot-lambert must be the actual maximum brightness at any point within 30 degrees of the line of sight of a patron watching the screen (see Fig. 3). This control not only will involve the careful selection of location of the light sources, but also the careful choice of materials for walls, ceiling, and floor, to reflect the proper quantity of light efficiently, and so permit the use of small lamps in order to have equipment of very low brightness.

This problem will ease somewhat as screen brightnesses become higher. If, for example, colored films replace black-and-white entirely, house lighting can about double, as indicated by the figures in the last column of Table II.

That there is a need for house lighting is evident. Patrons of moving picture theaters are coming and going constantly. The lack of

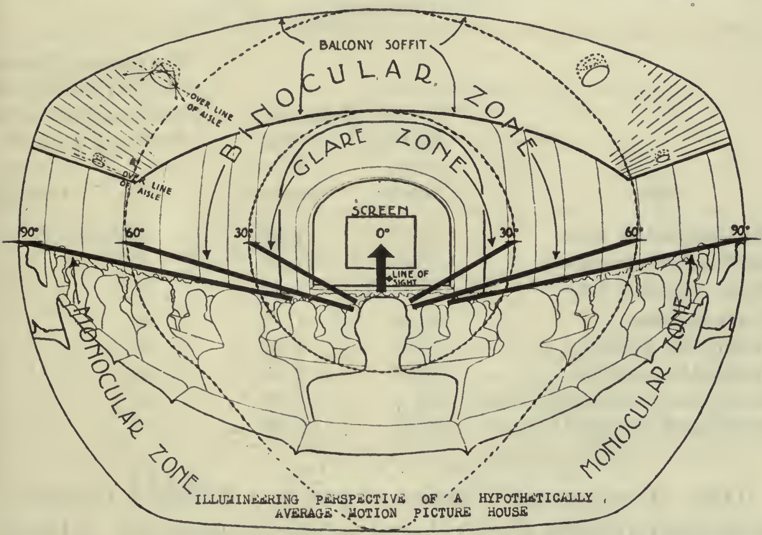

Fig. 3—All that is included in the field of view of a patron seated in the standard observer's position.

light handicaps safe movement and causes inconvenience, not only to the patrons who are moving in and out of seats, but to those with whom they interfere because they cannot see sufficiently well to move with the least disturbance.

Illumination levels in moving picture theaters with the house lights out are somewhere between starlight and moonlight, and much closer to the former than the latter. Under these conditions accidents will average seven times the theoretical minimum rate.[8] There is no possibility that accidents can be reduced to the theoretical minimum rate in the foreseeable future as a general brightness of the field of view of 6 foot-lamberts would be required, or sixty times the maximum that present screen brightnesses will permit. However, the adoption of a general brightness level of 0.1 foot-lambert would tend to reduce accidents by about 43 per cent over present experience, which would be a worth-while gain.

Second, the lack of sufficient general light invites undesirable conduct on the part of some members of the audience, particularly children and young people.

TABLE II

COMPARISONS OF AVERAGE BRIGHTNESS MEASUREMENTS OF MOTION PICTURE SCREENS

	Average Brightness in Foot-Lamberts		Brightness of Screen with Film Running as a Percentage of Blank Screen Brightness	
Film	Screen Blank	Film Running	Net	Group Average
Black-and-white news	15.0	1.08	7	
Black-and-white feature	15.0	1.09	7	8
Black-and-white news	13.6	1.42	10	
Cine-color short	15.0	1.40	9	
Technicolor feature	10.1	1.27	13	
Technicolor travelog	15.0	2.40	16	15
Self-colored animated cartoon	10.1	1.65	16	
Self-colored animated cartoon	15.0	2.80	19	

Third, it reduces the comfort of patrons. Vision is tolerable in most moving picture theaters but all authorities agree that, with a few notable exceptions, it is far from comfortable Television manufacturers have been faced with this comfort factor and have found it necessary to raise television screen brightness so that the screen can be viewed in domestic interiors with house lights on.

Last, house lighting inspires and aids better "housekeeping," which patrons find inviting.

A brightness of 0.1 foot-lambert is too low for people to adapt to quickly when coming from outdoors, unless a long foyer is available in which the lighting can drop steadily as the people move along. However, some improvement in the situation can be brought about in any case if the brightness of the foyer surfaces at the theater end is set at 2 foot-lamberts. This should be succeeded by a brightness of 1 foot-lambert for the surfaces of the extreme rear of the auditorium behind

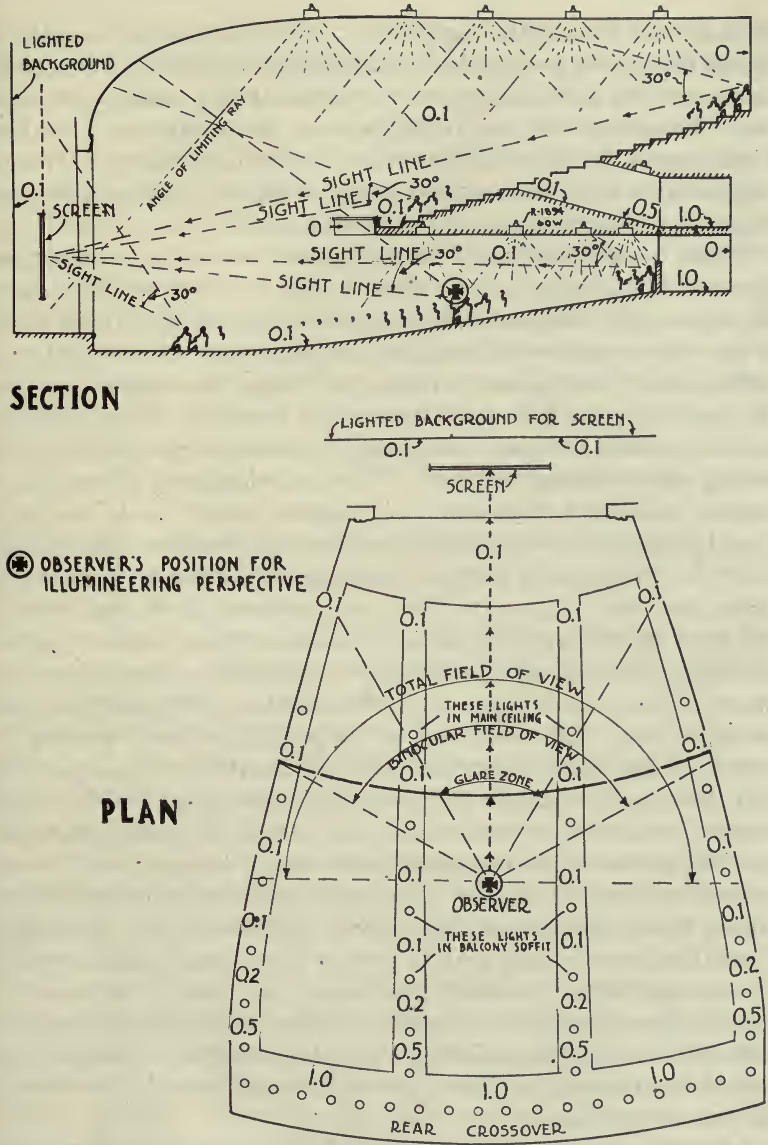

Fig. 4—Section gives sight lines of closest and farthest observer, and of observer in standard position. It also shows the 30-degree angle with sight lines and that no luminous part of any lighting unit comes within 30 degrees of sight line of any observer. Finally, it shows that no direct light from a lighting unit can reach the screen. Figures 0.1, etc., show recommended brightness levels in foot-lamberts.

the last row of seats (the crossover). This 1 foot-lambert brightness should drop to 0.5 foot-lambert on the aisle floors within 10 feet of the rear end of the aisle, and to the prevailing 0.1 foot-lambert within 20 feet. From then on, up to the front of the auditorium, the floor brightness of the aisles should remain at 0.1 foot-lambert. This arrangement of brightnesses is illustrated in Fig. 4, with a suggested arrangement of lighting outlets to accomplish it.

Higher house brightnesses would be possible if motion picture theaters were designed to permit them. This might sometimes require the screen to be louvered or hooded (after the fashion of traffic lights, or the miniature screens used for sales promotion in camera stores). Offhand this would appear to reduce the number of seats by narrowing the angle of view, but this would not be necessary as the principal louvering would be against the ceiling to prevent direct light from the ceiling lights striking the screen. The actual amount of hooding required could also be reduced by sinking the lights into the ceiling, so that the depth of the coffer acted as a louver against the screen (see Figs. 3 and 4). This would have the advantage of hiding the main ceiling lights from the balcony patrons. An examination of Figs. 3 and 4 will show that such ceiling lights in the main ceiling cannot come into the field of view of any patron on the main floor as long as none are placed in the forward 30 per cent of the ceiling. This prohibition also prevents stray light from any of the ceiling sources reaching the screen. Figs. 3 and 4 also show that the lights in the main ceiling, and those in the balcony soffit, when recessed in properly designed coffers, are hidden from most patrons. In the few cases where the lens can become visible it is at the upper edge of a patron's field of view where it is farthest from the line of sight, and the least effective in reducing visual efficiency and comfort. The sides of the light coffers should be painted a dark gray to prevent them being bright enough to disturb patrons. Concealed downlights also could be used. In many theaters the use of lens units in coffers, or downlights, would be sufficient, in combination with the fact that screens are usually placed 6 to 10 feet behind the proscenium arch, to make special louvering of the screen unnecessary.

In addition to this it would be desirable to give all surfaces that are parallel to and face the screen, such as the balcony face and rear wall of the theater, a low reflecting finish (about 20 per cent), to make their contribution to screen brightness neglibible. Surfaces parallel to, but that face away from the screen, such as the backs of the seats, should be given a reflection factor about equal to floor, or 30 per cent. Finally, the walls and ceiling should be sloped away from the screen as far as possible and given a ribbed surface. One side of each rib should face away from the screen and be given a reflection factor of 50 per cent. The other side of the rib that would face in the general direction of the screen could be dark gray with a 10 per cent reflection factor. This permits light to be accepted by these surfaces without its getting back to the screen. Floor coverings should have a reflection factor of 30 per cent and ceiling lights should begin no closer to the screen than about one third the depth of the house. They would be arranged over the remaining two thirds of the ceiling over the aisles so that the aisles would get the benefit of the principal illumination and no patron could be directly under a light to receive a high light on back of head and shoulders that might be disturbing to others. This would usually also light up the walls owing to the side aisles running along the walls. Where there are no side aisles the lights should also run in such relation to the walls as to light them uniformly.

Similar lights should be repeated under the balcony over the aisles, and along the back crossover.

Illumination on the ceiling would come from diffusion from the walls and floor. If ceiling was finished white it would acquire a brightness about equal to moonlight.

It would be desirable to raise this brightness to $^1/_{10}$ of a foot-lambert but most attempts to do this raise more problems than they solve. Where the scale of the interior permits, as in Radio City Music Hall, it can be done by a similar series of well-designed stepped coves. This is impractical in the average motion picture auditorium, and it is better to let the ceiling remain dark than to run into the great brightness variations that accompany most attempts at ceiling illumination.

It is easier to meet the visual requirements of continuous motion picture theater lighting with incandescent lamps than with fluorescent, as the extraordinary degree of control required is difficult with fluorescent. Fluorescent can be used for the decorative and intermission lighting. Further, the incandescent equipment can be dimmed easily so that after the computed installation is made, the exact point at which the house lighting no longer handicaps the screen can be determined by experiment.

In conclusion, the brightness level of 0.1 foot-lambert suggested in this paper for house lighting (about three times full moonlight), would call for an illumination level of from 0.3 to 0.4 foot-candle, on the basis of the reflection factors recommended This can be secured, from 60-watt, incandescent lamps on about 15-foot centers average, in controlled, coffered, direct-lighting equipment. Where the brightness level is to rise, as at the rear stretch of the aisles, and the rear crossover, the lights should be spaced proportionately closer. If these incandescent lamps were used behind a Controlens the glass surface could have an off-axis brightness of as low as 60 foot-lamberts, instead of 600 which is present practice. Even this low equipment brightness of 60 foot-lamberts would not come into the normal field of view, owing to the coffer shielding, as previously explained.

Now that the nature of the problem is understood, designers can be depended upon to come forth with a variety of layouts and equipment that will meet the conditions.

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Light Modulation by P-Type Crystals*

By GEORGE D. GOTSCHALL

Brush Development Company, Cleveland, Ohio

Summary—**A means of modulating a light beam with a flat response which greatly exceeds the audio range is described utilizing the linear electrooptic effect in P-type** crystals. The unit uses parallel polarized light and although it requires relatively high voltages, it draws essentially no current and has no moving parts. From the basic aspects it seems very promising for an efficient yet sturdy variable-density recording system.**

Intensity modulation of a light beam may be accomplished in one of three or more ways: (1) mechanical shutter or diaphragm, (2) modulation of intensity of the light source proper, or (3) phase retardation of polarized light passing through an electrooptic medium. The first two methods are quite well known, but the third, although not new in principle, is relatively new in application. The quadratic electrooptic effect, also known as the Kerr effect, has been known to scientists for some time, especially in such polar liquids as nitrobenzene. However, the effect is small, voltages are extremely high, the light beam is restricted in width, and the cell is liquid in form. The effect to be described herein is the so-called linear electrooptic effect which is a property characteristic of piezoelectric crystals and which overcomes the Kerr-cell disadvantages wholly or in part. The basic symmetry relationships of the linear electrooptic effect were first discussed by Pockels,[1] who made detailed measurements on quartz, sodium chlorate, tourmaline, and Rochelle salt. This work is still basic for our knowledge of the electrooptic effect in crystals, although during the last fifteen years several German scientists have published articles on this phenomenon with emphasis on the application of zinc sulfide.

* Presented November 19, 1947, at the Atlantic Coast Section Meeting in New York.

** The term "P-type" has been given to a group of isomorphic crystals which include the primary phosphates and arsonates of ammonium, potassium, or rubidium.

The requirements which a crystal must meet in order to be suitable electrooptically are many, and as a result only a few crystalline substances are satisfactory. Extensive research at the Brush Development Company led to the discovery of a substantial electrooptic effect in ammonium dihydrogen phosphate crystals as well as other crystals of the primary phosphate family, termed P-type. It was recognized that the symmetry relationships in this crystal family were particularly favorable for the occurrence of a sizable parallel electrooptic effect, i. e., with the light beam parallel to the electric field. Among the outstanding features of these crystals are the facts they can be artificially grown to large sizes, have excellent transmission characteristics, satisfactory physical properties, and possess the highest electrooptic constants.

To explain briefly the nature of the parallel electrooptic effect, first consider the mechanics of light transmission through a trans-

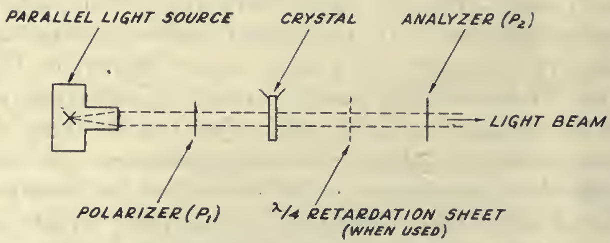

Fig. 1—Simple electrooptic system.

parent substance. Transparent media are composed of atoms or molecules carrying electric charges or dipoles. The refraction (or velocity) of light is then determined by the disposition and electromagnetic interaction of these particles with the electric-field component of the incident light wave. The application of an electric field to the transparent medium will produce displacement or deformation of the particles and thereby influence the refractive properties of the material. In the case of the P-type crystals, a certain cut and alignment allows light to pass with equal velocities for all planes of polarization. However, the application of an electric field reduces the phase velocity in one specific plane of polarization and increases it in a perpendicular plane of polarization, thus introducing a phase difference in the two components. The parallel electrooptic effect may then be described as a linear change of the refractive indexes (or phase velocities) for a given applied electric field. This change is at best in the order of one part per million for a field of one kilovolt per centimeter, but even this minute change is satisfactory for a device based on phase shifts.

To explain the behavior a bit more fully, let us consider a simple system (Fig. 1) where we polarize a parallel light beam so that the vibration direction is parallel to one of the crystalline axes, X or Y, (mutually perpendicular to the Z or optic axis in P-type crystals). This light beam can be resolved into two vector components along secondary axes $\hat{X}$ and $\hat{Y}$ (also called mechanical axes) (Fig. 2). In

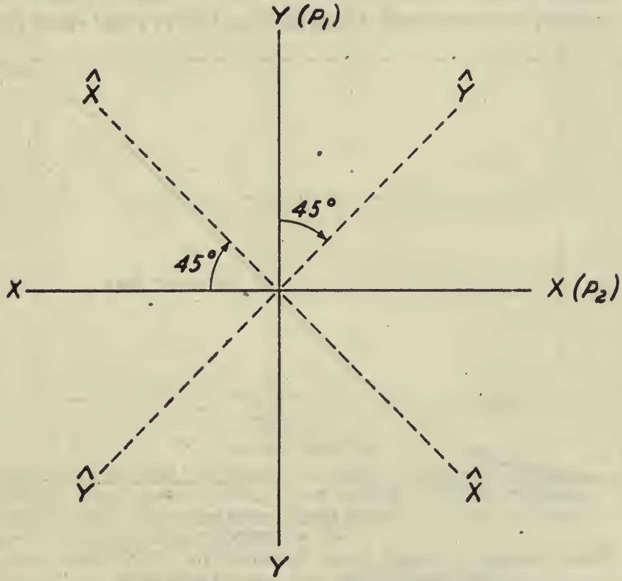

Fig. 2—Z-O Plate of "PN" crystal showing position of polaroids and secondary axis.

this figure, the polarizer (P_1) is shown as parallel to the Y axis and the analyzer. (P_2) parallel to the X axis. Initial conditions will permit no light to pass, for we have the analyzer at 90 degrees to the polarized beam. However, under the influence of an electric field, the velocity of the vector components along $\hat{X}$ and $\hat{Y}$ are changed, one being increased and the other decreased, the effect on each depending on the polarity of the voltage. This results in incomplete extinction of the light, which will now be visible through (P_2). The electrooptic effect will be maximum for the light polarized parallel to one of the crystalline axes, X or Y (as shown in the above diagram) and minimum for light polarized parallel to one of the secondary axes, $\hat{X}$ or $\hat{Y}$.

For a field of one kilovolt per centimeter, the difference in the two refractive indexes was found to be 2.9×10^{-6}, or equivalent to a phase difference of about $\pi/20$ radians per centimeter for green light. The intensity of the light passed is found to be proportional to the sine squared of half the angular phase difference. For a "PN"* (ammonium dihydrogen phosphate) crystal as discussed we will get maximum transmission for a retardation of one half wavelength which requires approximately 9000 volts for green light (Fig. 3). For the system as described, thickness of the crystal does not enter,

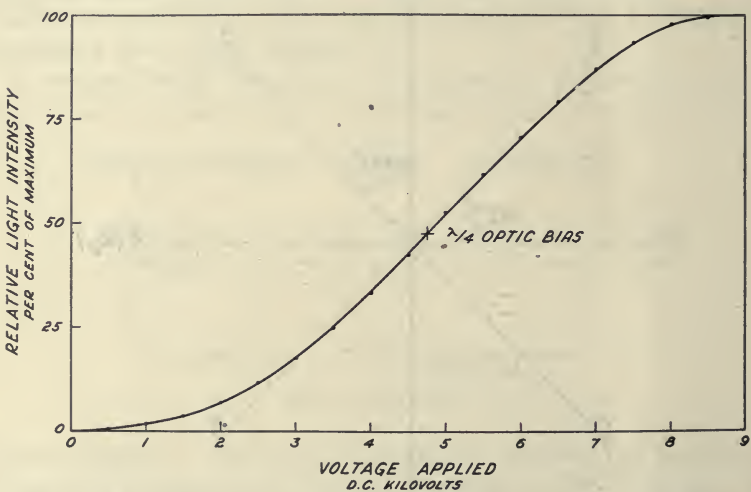

Fig. 3—Light intensity versus direct kilovolts for "PN"-Nesa unit using green parallel light and crossed polaroids.

as doubling the thickness for a given voltage will result in half the change of refractive index but twice the light path.

The value of the change in refractive index as given above for "PN" is the total electrooptic effect which is composed of the "clamped" electrooptic effect and the "indirect" electrooptic effect. This latter effect is created by the piezoelectric deformation of the crystal lattice which causes a refractive index change through the elastooptic effect. In the P-type crystals these effects are of the same sign, and recent experimental data have shown the division in "PN" to be 58 per cent "clamped" and 42 per cent "indirect."

* Copyright, Brush Development Company, Cleveland, Ohio.

Theoretically, the "clamped" electrooptic effect is frequency-independent practically to the infrared region because displacements in the order of only intermolecular distances are involved. The "indirect" effect has resonant frequencies dependent upon the physical dimensions. It is to be expected then that this effect would become negligible above the range of natural resonant frequencies of the crystal. The frequency curve is shown in Fig. 4 and it is to be noted that the slight increase in response at the high end is due to approaching resonant frequency. Mechanical damping will eliminate this rising characteristic. The linearity of modulated output versus modulation voltage is shown as Fig. 5.

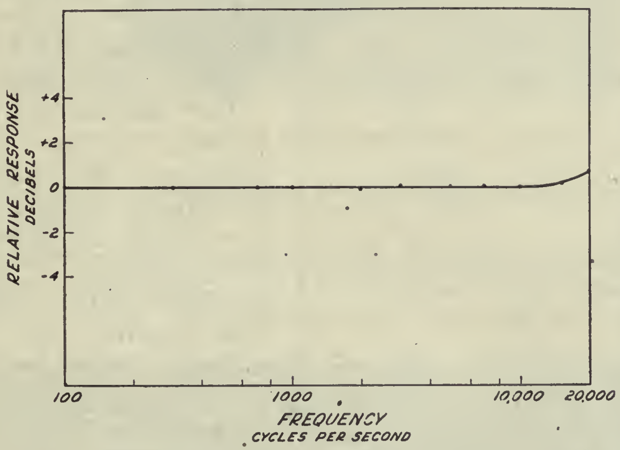

Fig. 4—Frequency response of light modulator using a 150-volt, root-mean-square, sine wave. White, parallel, direct-current light source was used with λ/4 plate inserted between the crossed polaroids.

When using the unit as a light-beam modulator, it is usually desirable to use an optical bias of a quarter-wave retardation. As shown in Fig. 3, this transfers the initial operating point from the origin to point X with no voltage applied. Operating from this point of the curve it can be seen that we get maximum modulation and minimum distortion for a given applied audio voltage. In most of the frequency experiments, a modulating voltage of 150 volts, root-mean-square (425 volts peak-to-peak) was used with very satisfactory results.

A convenient size of crystal for experimentation was found to be

2 inches square and about $^1/_{16}$ inch thick. After polishing to an optical finish, transparent conducting electrodes, Nesa,* are attached by means of a special transparent conducting cement. The Nesa electrodes are $1^3/_{16}$ inches square, thus providing a nice margin of crystal to act as high-voltage insulation. This margin is treated to prevent damage by moisture and consequent leakage or voltage flashover. The unit easily accommodates a 1-inch diameter parallel light beam. The static capacity of such a unit is under 100 micromicrofarads, diminishing rapidly in the resonant frequency region. The direct-current shunt resistance is in the order of 150 to 350 megohms.

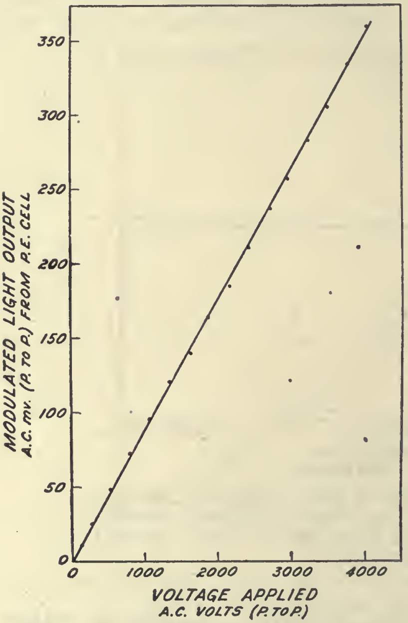

Fig. 5—Linearity of modulator using "PN" crystal driven at 1000 cycles. Direct-current parallel light with λ/4 plate inserted.

The transmission of the over-all system depends chiefly upon the transmission of the polarizing material and the transparent electrodes as the transmission of "PN" is practically 100 per cent from 2000 angstrom units to 1.5 microns. The transmission of a recently completed unit composed of "PN" crystal and two Nesa electrodes cemented onto place was about 75 per cent whereas the Polaroid** had 28 to 32 per cent transmission when it ideally should be 50 per cent. This results in an over-all maximum transmission value of about 15 per cent for half-wave retardation which is more than enough to activate a photoelectric cell or expose film.

The dark-to-light ratio depends upon many factors mentioned above plus alignment and beam parallelism and color. However, dark-to-light ratios as high as 300 to 1 have been obtained with the application of 9 direct kilovolts. Alignment of the crystal with

* Made by the Pittsburgh Plate Glass Co., Pittsburgh, Pa.
** Made by the Polaroid Corporation, Cambridge, Mass.

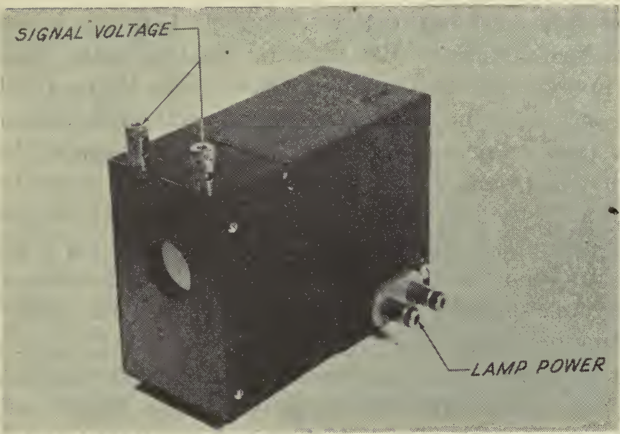

Fig. 6—Assembled view of experimental light modulator.

relation to the light beam is very critical and is done with the assistance of a projection lens.

A complete system including the light source and lens system was constructed in a housing $2^1/_2 \times 4 \times 5^1/_2$ inches. As a light source, a 10-watt Western Union concentrated arc lamp[2] was used and

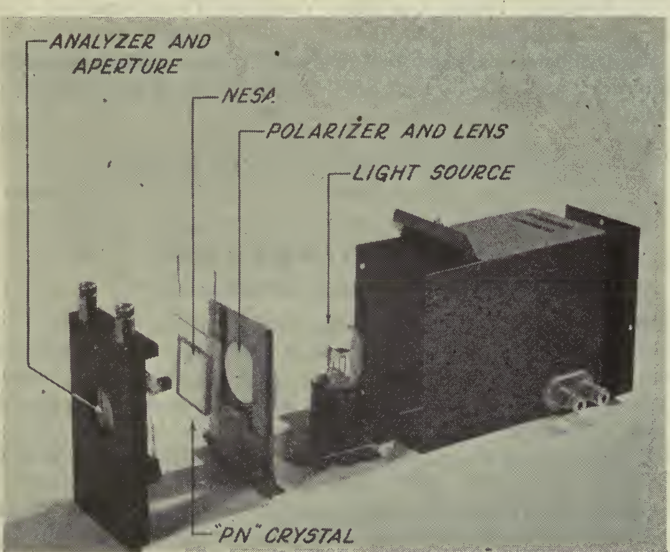

Fig. 7—Exploded view of experimental light modulator.

operated from two heavy-duty 45-volt B batteries in series. A portable high-voltage supply was first used to strike the arc, and later to apply voltage to the crystal unit. Since the lamp will remain lit at reduced current, a stand-by switch reduces the current by 80 per cent except when actually in use. A photograph of this unit is shown in Figs. 6 and 7. Although the point light source is convenient in size, in the laboratory suitable parallelism was obtained from an inexpensive Central Scientific light source having a 6-volt, 18-ampere tungsten filament. Direct current from a bank of storage batteries was supplied for frequency measurements while 60-cycle alternating current was used for all other tests.

The unit as described has a flat response in excess of audio requirements, has an excellent dark-to-light ratio, is simple and sturdy, has no moving parts, has a high impedance input, and has good transmission characteristics for application to variable-density sound-on-film recording. The adaptation is very simple as light emanating from the aperture of the modulator as shown in Fig. 7 is parallel, and a cylindrical lens could then focus this circular beam of modulated light into a small slit on the sound track.

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FORTY YEARS AGO

Talking Pictures in Rochester

This is the way the press agent describes the animated pictures: "To hear the voice, to catch every sound and the intonation of every word and see the people in life size moving before your eyes, and yet realize there is not a single person there—it seems like some phantom of the brain, an hallucination, and one is almost tempted to rush to the stage and grapple with the ghostly actors as one is moved to cry out in the vividness of a dream. Such is the wonderful spell that is cast over the spectator on his first view of the marvelous talking, singing, dancing moving pictures which Manager Parry of the National will introduce for the first time in Rochester to-morrow afternoon."

—*The Moving Picture World, May 30, 1908*

Portable 16-Mm Sound Projector*

By H. H. WILSON

Ampro Corporation, Chicago, Illinois

Summary—Some of the problems encountered in the design and production of a quality 16-mm sound projector designed to meet the requirements of the school, church, and industrial fields, are analyzed. Screen illumination, sound reproduction, operational controls, film handling and film protection, noise factors, styling, maintenance, and weight limitations will be discussed. Manufacturing problems and their solution on the basis of mass production will be considered.

The projector described was designed to meet the requirements of the school, church, and industrial fields. First, the general conditions under which the equipment will be used; second, the consumers' requirements; and third, the actual design and manufacture of a projector to meet these requirements will be described.

The Application—The school, church, and certain phases of in dustrial applications can be considered as a group so far as the design of this type of equipment is concerned because of the technical similarity of their applications of the equipment. In most cases the projector will be used to project sound films before small audiences although occasionally it will be used before audiences of 500 to 600 people.

Classrooms usually have hard-surfaced walls and frequently cannot be completely darkened. Industrial showings may be made in many types of rooms ranging in size and acoustical properties from the private office to the product display room.

Consumer Requirements—Since we have considered the general conditions under which this equipment will be used, let us now turn to a more detailed analysis of what will be required in the projector in order to make it most useful as an audio-visual tool.

The distance from the last row of seats to the front of the typical classroom is about 25 feet; therefore the screen width should be approximately 4 feet (a 39- × 52-inch screen is commonly used). This screen has an area of 14 square feet, consequently, at least 165 lumens will be required to provide adequate screen illumination.

* Presented April 25, 1947, at the SMPE Convention in Chicago.

Only a few watts of audio power would be required for the classroom, but additional power will be required for larger rooms. Increased power can be obtained at a reasonable cost, so it was considered advisable to provide an amplifier having 10 to 15 watts' output. Sound quality should be as good as space, weight, and cost factors will permit.

The projector frequently will be operated by elementary or high-school pupils; therefore, the controls should be as few and as accessible as possible. It will be necessary to provide for both sound and silent speeds, reverse operation, and the projection of a single frame. Simplicity of threading is required as well as maximum film protection.

Due to the excessive area of hard-surfaced walls, the mechanism must be very quiet in operation or the attention of the audience will be distracted from the subject matter being presented.

Naturally, audio-visual equipment will be used only for those applications where either it can do a better teaching job or a more economical one than can be accomplished by other means; consequently both the initial cost of the equipment and the maintenance cost must be kept as low as is practicable. The design of the projector should be such as to provide maximum film protection because first, the cost of procuring or replacing prints is a factor in the cost of a visual-education program, and second, the teaching film differs from the entertainment film in that the contents of the teaching film does not become obsolete for many years; consequently, film wear is the principal cause for retirement of a print.

For ease of carrying and storage it is desirable that the unit be as small and compact as possible and that neither the projector nor speaker case, when packed, weigh more than 50 pounds.

General Design—In the design of the Premier-20 projector great effort was made to meet the consumer's requirements. The complete design cannot be said to be entirely new; those units, which past experience indicated to be satisfactory, were retained in this model, some units have been redesigned, and the methods of manufacturing other units have been revised in order to maintain closer tolerances and thereby improve their performance.

Light Source and Optics—The projector was designed to use projection lamps of the medium prefocused base type. A 750-watt, 25-hour lamp is standard equipment although a 1000-watt lamp may be used. The lamp socket is mounted in such a manner that the lamp can be moved either vertically or horizontally. This type of mounting provides two advantages, one, positive alignment of the lamp filament with the optical axis can be obtained, and two, the lamp position can be adjusted in order to correct for the shifting of the filament which may result from use.

The reflector and condensing lenses are mounted on the right-hand cover of the projector and the holder is properly positioned on the cover at the time of assembly. The cover assembly and its optical components may be removed for cleaning and replaced without disturbing their alignment with the aperture.

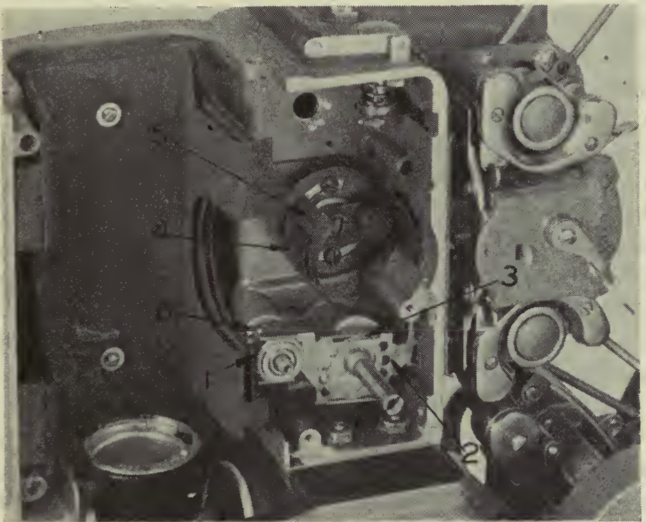

Fig. 1—Intermittent and shutter.

The projection-lens mount is solidly attached to the mechanism head by means of a dowel and screws in order to maintain positive alignment of the lens with the aperture plate. Coarse focusing of the projection lens is obtained by sliding the lens in the holder; fine focusing by rotation of the threaded lens barrel. The lens is locked in position by means of a cam-and-spring assembly which clamps the lens in position without producing any tendency of the lens to shift in the holder. A coated $f/1.6$ lens of 2-inch focal length is standard equipment. Lenses of other focal lengths also may be used.

Intermittent and Shutter—(Fig. 1) The intermittent unit consists of three cams and a shuttle. Two of the cams make up the lateral cam assembly (*6*) which causes the teeth of the claw to engage the perforations and also holds the shuttle (*2*) and claw in the retracted position while the shuttle makes an idle stroke. The purpose of the idle stroke is to allow the vertical cam (*3*) to be revolved at 2880 revolutions per minute (at sound speed) thereby providing a comparatively short film-transport time without the use of a vertical cam having such a small working angle that the life of the intermittent might be seriously affected. The film-transport time is 4.68 milliseconds, therefore, approximately $^1/_8$ of the complete projection cycle is required for film advance. Each lateral cam is ground individually and then paired with the mating cam by selective assembly. The vertical cam is rough-ground, then attached to the camshaft, and finish-ground in order to maintain the throw within close limits.

The action between the claw and the film perforations is quite similar to that of a rack-and-pinion mechanism. The radius of the pinion (distance from shuttle pivot (*1*) to film plane) is quite long and the tooth form has been corrected in order to eliminate any tendency of the claw teeth to drag across the edges of the perforations during the entrance or retraction periods. This type of movement is very quiet and produces very little film slap; it also has the advantage that when used in conjunction with the gate mechanism, which will be described, it will not damage the perforations if the lower loop is lost, and the loop can be reset without stopping the projector.

The two-blade barrel-type shutter (*4*) revolves at 2160 revolutions per minute at sound speed and provides three interceptions of the light beam per frame. The shutter is attached to an adjusting disk so that exact timing with the intermittent can be obtained. The shutter is driven by means of a quill through which the safety-shutter shaft passes. The safety shutter (*5*) consists of a single curved blade having a radius shorter than the intercepting shutter and pivoted on the axis of the intercepting shutter. The single hole pierced in the safety shutter acts as an optical stop and maintains a low aperture temperature when still pictures are being projected. The safety shutter is actuated by means of a centrifugal clutch mechanism which is built into the shutter-gear assembly.

Framer and Film Gate—Framing is accomplished by the vertical movement of the framer plate which slides in a milled channel directly behind the aperture plate (Fig. 2). In assembly the aperture plate is aligned with the aperture in the framer plate and is attached to the mechanism head by means of six screws. The right-hand edge of the aperture plate is used for film-positioning and springs located on the opposite edge of the plate hold the film against the right-hand edge.

The pressure shoe (*1*) is attached to the pressure-shoe carrier (*2*) which slides in ways milled in the carrier yoke (*3*). The carrier yoke is pivoted near the front of the projection-lens mount and is locked to the lens mount by means of a latch (*4*) located near the rear of the lens mount. Moving the gate lever to its forward position moves the pressure-shoe carrier and the pressure shoe away from the

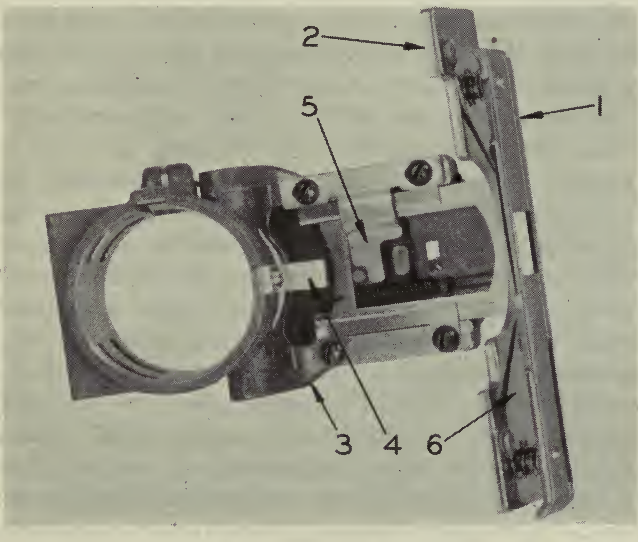

Fig. 2—Lens-mount assembly.

aperture plate and simultaneously opens the sprocket shoes. Pressing the gate latch toward the aperture releases the carrier yoke so that the yoke and pressure shoe can be swung outward approximately 90 degrees. This makes both the pressure shoe and the aperture plate readily accessible for cleaning.

Pressure is applied to the pressure shoe by means of two coil springs of conical form. Control of the shoe pressure is obtained by movement of the carrier stop (*5*). The contact surface of the shoe is $3^1/_8$ inches in length; this results in a low pressure per unit of area; consequently, if the lower loop is lost, both the film and the shoe are pushed away from the aperture by the claw and the film is not damaged. Lateral alignment of the pressure shoe is obtained by moving the mounting plates (*6*) by means of which the shoe is attached to the carrier.

Bearings, Lubrication, and Gearing—All shafts in the mechanism are parallel; consequently, the bearing bosses can be reamed in a single fixture thereby simplifying the manufacturing procedure and maintaining a high degree of precision. "Oilite" bearings are used for all shafts and are burnished to size after they are pressed into the mechanism casting.

All moving parts of the mechanism receive oil from a central oil well. Oil is distributed to various parts by means of oil tubes which are sealed into the oil well and bearing bosses. The shuttle and bearings that are not parts of the mechanism housing receive oil through oil passages drilled axially in the shafts and holes drilled radially in the shafts at the proper points.

The gearing is of the helical type. All transmission members lie within four parallel planes which are closely spaced. This type of design produces a very compact transmission assembly in which end thrusts can be kept low, a high degree of precision can be maintained, and gear noise and vibration can be reduced to a minimum.

Motor and Drive Unit—The drive motor is of the universal type. A Lee governor is used to control both the sound and silent speeds. The speed-selector switch and reversing switch are attached to the motor by short leads and are located on the amplifier-housing wall adjacent to the motor. The complete motor assembly can be removed by disconnecting two leads from the terminal board on the motor, removing the motor-retaining parts, the switch-retaining nuts and the fan.

The main drive system consists of a flat, neoprene-impregnated, fabric drive belt running on pulleys having synthetic rubber facings. The driven pulley is mounted on an "Oilite" bearing and also serves as the driving member of a single-plate automotive-type clutch. The clutch mechanism is actuated by means of a knob on the right-hand cover of the projector. The purpose of the clutch is to disengage the projector mechanism from the motor in order to project single frames.

Ventilation—A radial-blade centrifugal fan is mounted on the motor-armature shaft. The fan is $3^1/_8$ inches in diameter and operates at the motor speed of 5200 revolutions per minute when the projector is running at sound speed. Air is drawn across the amplifier and motor and into the fan intake thereby providing ventilation for the amplifier and motor. A fan-scroll reversing vane is used to maintain substantially the same air delivery regardless of the direction of fan rotation (*1*).

Feed and Take-up Mechanisms—The feed-reel arm is permanently attached to the mechanism housing and is pivoted in order that it may be swung back over the top of the mechanism when the projector is placed in the case. When the projector is operated in reverse a ball-type clutch contained within the spindle cup automatically engages and the spindle is driven in a counterclockwise direction by means of a spring belt. High-speed rewinding is accomplished by engaging a dog-type clutch located on the left-hand side of the mechanism. A pulley formed as an integral part of the clutch, by means of a spring belt, drives a pulley attached to the left-hand end of the reel spindle. Two thousand feet of film can be rewound in two minutes.

The take-up-reel arm also is pivoted in order that it may be swung up in front of the mechanism housing when the projector is placed in the case. The take-up spindle is connected to the spindle-drive pulley through a ball-type clutch which automatically disconnects the spindle from the pulley when the projector is operated in reverse. For rewinding, the take-up belt is shifted to a loose pulley by means of a manually operated belt shifter.

Soundhead—The soundhead is assembled as a separate unit and is attached to both the mechanism housing and the amplifier housing. Direct scanning is accomplished on a rotary sound drum mounted on ball bearings and stabilized by means of a flywheel. Loop vibration is controlled by passing the film between the pressure and tension rollers. The pressure-roller arm is pivoted and its travel controlled in such a manner that it can be used to reset the lower loop without stopping the projector.

Amplifier and Speaker—The three-stage amplifier consists of a 6J7 voltage amplifier, a 6J5 driver, and push-pull 6V6 output stage. The output is 15 watts with less than 5 per cent distortion. The standard output impedance is 15 ohms; a simple adapter (available as an accessory) makes necessary connections to the 7.5-ohm tap of the output transformer for operation of two speakers. A 6V6 is used as a radio-frequency oscillator to provide 6 volts at 1 ampere for the exciter lamp.

The volume control for sound on film controls the intensity of the exciter lamp; a potentiometer in the grid circuit of the 6J7 controls the volume of the microphone or phonograph. A slotted-shaft type of control, located in the rear control panel, controls the polarizing voltage applied to the phototube. The tone control is of the inverse-feedback type.

Plug and receptacle connectors are located in the rear control panel for connecting a converter or inverter if required. The standard

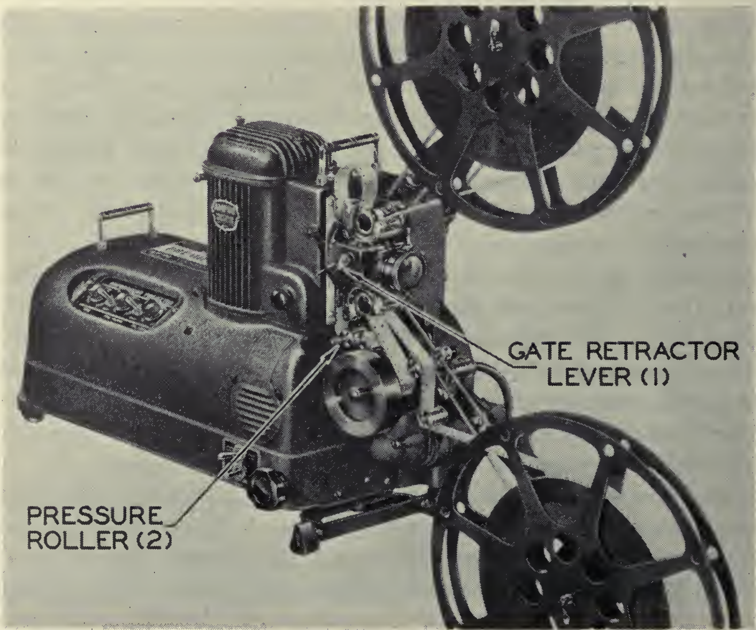

Fig. 3

amplifier was designed to operate on 50 or 60 cycles, 105 to 125 volts alternating current. A 25-cycle model is also available.

Removal of the main nameplate provides access to the tube sockets for voltage checks. The amplifier may be removed by taking off the bottom cover, disconnecting four leads from terminal boards, and removing eight retaining screws.

A 12-inch permanent-magnet dynamic speaker is used. The magnet weight is $4^1/_2$ pounds, and the voice-coil impedance is 15 ohms. The speaker is mounted in a case 16 inches high, 16 inches wide, and $9^3/_4$ inches deep. Fifty feet of speaker cable is standard equipment.

Simplicity of Threading—Since the sprocket shoes open automatically when the film gate is opened it is only necessary to move the gate-retractor lever (*1*) to the forward position and move the pressure roller (*2*) to the rear position in order to prepare the projector for threading (Fig. 3).

Size and Weight—The above-described projector is packed in a case $21^1/_2$ inches long, 16 inches high, and $9^3/_4$ inches wide. The projector alone weighs $33^1/_4$ pounds. Packed in the case with accessories its weight is 50 pounds. The speaker case which also contains a 1600-foot reel and the power and speaker cables, weighs 26 pounds.

ACKNOWLEDGMENTS

The writer wishes to acknowledge the assistance of Messrs. A. Shapiro, T. J. Morgan, A. S. Dearborn, and T. R. Neesley in the preparation of this paper.

REFERENCE

(1) A detailed description of the design and operation of this unit is contained in the paper "Design progress in an 8-mm projector," by Thomas J. Morgan, *J. Soc. Mot. Pict. Eng.*, vol. 49, pp. 453–463; November, 1947.

FORTY YEARS AGO

Moving Pictures in Schools

Moving pictures, as an aid to education, are now being utilized in the National Preparatory School, in the City of Mexico, where a machine of the latest pattern has been installed. The pictures will illustrate subjects in geography, history, physics, morals, and manual training. Mexico is the second country to adopt the cinematograph as an educational factor, Germany having been the first.

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

Optical Problems in Large-Screen Television*

By I. G. MALOFF

RCA Victor Division, Radio Corporation of America, Camden, New Jersey

Summary—**Optical problems in large-screen television are enumerated and present-day solutions of these problems are discussed. Details of one prewar and two postwar models of RCA large-screen projectors are described.**

Optical problems involved in producing large-screen television include: (1) choice of suitable source of picture; (2) choice of suitable optical projection system; (3) choice of a suitable screen to fit a particular auditorium; and (4) selection of proper ambient lighting in the auditorium.

In the past a great number of solutions to the above problems have been suggested, some of them tried, and some demonstrated. Among these are various types of light valves, supersonic light cells, and mirror and lens drums, also Mangin mirrors, refractive and reflective optical systems, lens and mirror-type viewing screens, and many others. Also the so-called "intermediate" or "zwischen" film method has been proposed and tried in the early thirties in Germany, abandoned, and now is again under development in this country at the Radio Corporation of America and other laboratories. In the intermediate film method a television picture appearing on the face of a cathode-ray tube is photographed on motion picture film, quickly processed, and reproduced through a regular film projector. Of course there is a certain delay and a certain amount of instantaneity is lost.

The RCA technical staff, while having investigated and tried most of the proposed methods, has directed its large-screen television development mostly along the lines of the combination of (1) high-voltage cathode-ray tubes; (2) reflective or "Schmidt" optics; and (3) directional viewing screens tailor-made to fit particular auditoriums; in other words, "instantaneous" systems.

* Presented October 23, 1947, at the SMPE Convention in New York.

Before the war, RCA produced and publicly demonstrated in a regular theater in New York City a large-screen television picture on a 15- × 20-foot screen. The equipment utilized a 7-inch projection cathode-ray tube operating at 70 kilovolts. The optical system was of the reflective or Schmidt type, using a 30-inch spherical mirror and a $22^1/_2$-inch aspherical correcting lens. The general appearance of this equipment is shown in Fig. 1.

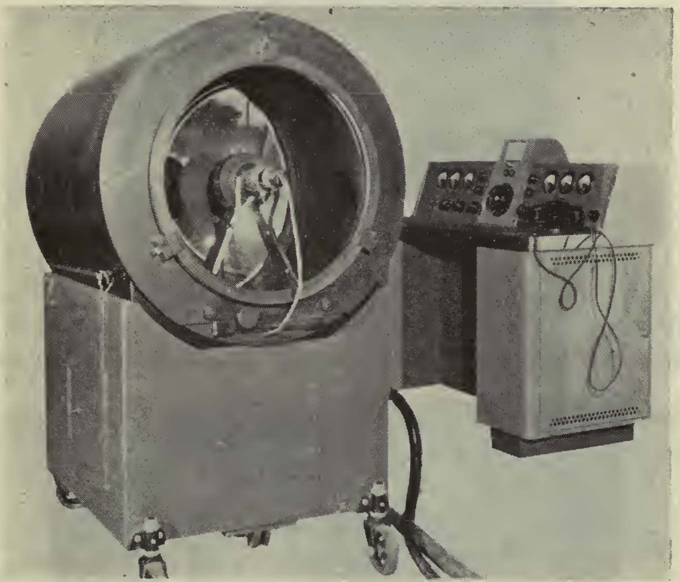

Fig. 1—Prewar television projector utilizing 31-inch mirror.

Since the war the RCA organization, basing its work on previous experience, chose to continue developments along the lines of the prewar prototype. Recent developments resulted in two types of large-screen television systems. The first, the auditorium type, utilizes a cathode-ray tube 7 inches in diameter operating at 50 kilovolts. The optical system consists of a 21-inch spherical mirror and a $14^1/_2$-inch aspherical correcting lens. This system, having approximately a 6- × 8-foot screen, was publicly demonstrated at the convention of the National Association of Broadcasters in Atlantic City last September and is being demonstrated at this Convention.

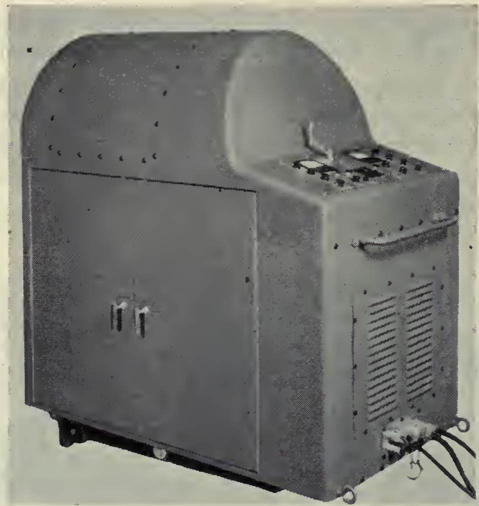

Fig. 2—Postwar television projector utilizing 21-inch mirror.

The second system, the theater type, makes use of a 15-inch cathode-ray tube operating at 80 kilovolts. The optical system consists

Fig. 3—Postwar television projector utilizing 42-inch mirror.

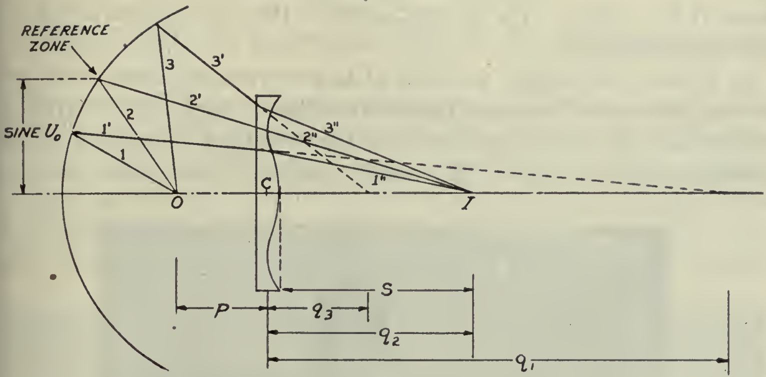

Fig. 4—Principle of reflective projection system.

of a 42-inch spherical mirror and a 30-inch aspherical correcting lens. At present it is the largest Schmidt-type system in the world, since the 72-inch Schmidt telescope of Mount Wilson as yet is not in operation. Two 42-inch RCA-Schmidt systems have been completed, tested, and found to be up to expectations. These systems give pictures of 18 × 24 feet in size and will be publicly demonstrated in

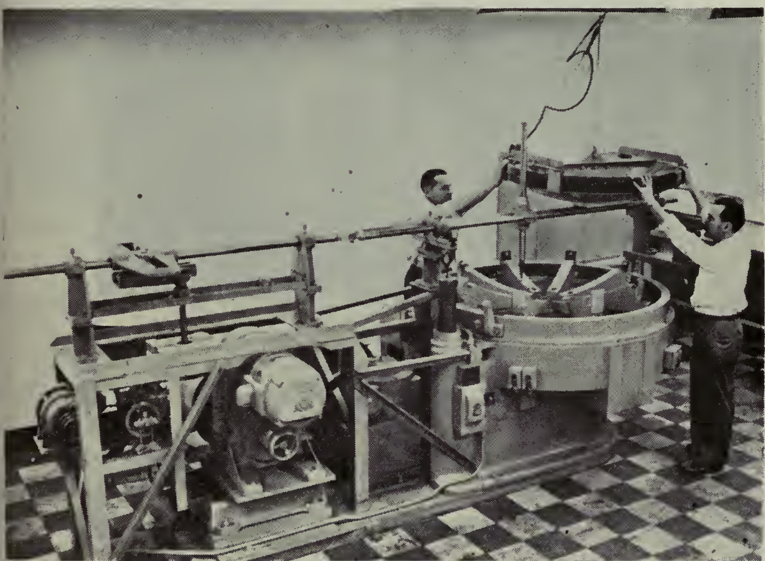

Fig. 5—Machine for grinding 42-inch mirror.

the next few weeks. The general views of the two systems are shown in Fig. 2 and Fig. 3.

In general, the optical problem of large-screen television is to produce on a given size screen a picture of sufficient high-light brightness, resolution, and tone gradation, so that nothing contained in the incoming signal is lost. The word "sufficient" has often been re-

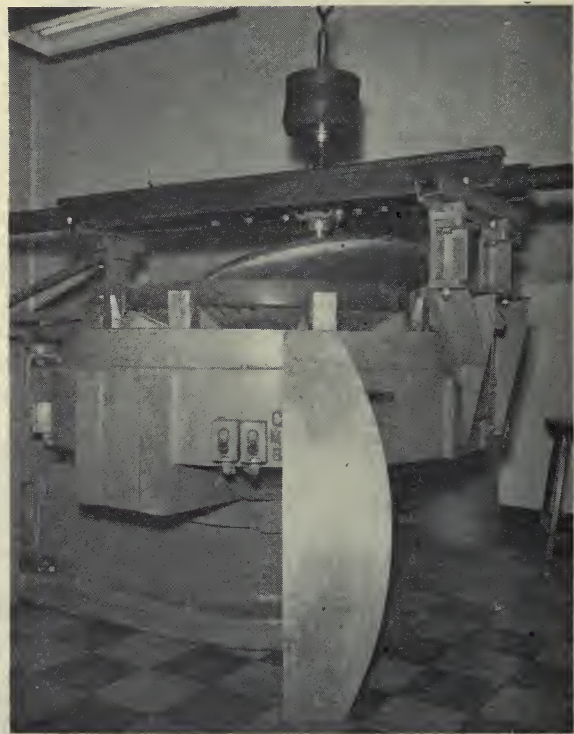

Fig. 6—Polishing 42-inch mirror.

placed by "maximum obtainable." It is a pleasure to state that with the new projector the standard of the Society of Motion Picture Engineers of 7 to 14 foot-lamberts of high-light brightness has been met.

The general principle of reflective or Schmidt optics, as used in projection, has been described in several publications.[1, 2] In Fig. 4 the essential features of it are shown. Here a thin aspherical lens placed at the center of curvature of a spherical mirror introduces an amount of spherical aberration equal to that of the mirror but opposite in sign.

The construction of the 42-inch mirrors (which was done at the RCA Camden plant) involved the development of a special machine shown in Fig. 5. This figure gives a general view of the grinder having a 53-inch turntable. A 42-inch mirror blank is being lowered into a cradle by an electric hoist operated by the author and an assistant. The weight of the blank is 350 pounds. A view of the polisher

Fig. 7—Aluminizing equipment and finished 42-inch mirror.

in operation is shown in Fig. 6. With polishing completed the mirror was aluminized in the tank shown in Fig. 7. A mirror already aluminized can be seen at the left. Such large mirrors having relatively short focal lengths can produce weird optical effects such as shown in Fig. 8.

The construction of aspherical correcting lenses has been done essentially by the methods described in cited publications. They were made of glass, an inherently costly process. Eventually, however, these lenses may be molded from plastics just as in the case of correcting lenses for home-projection-television receivers. These lenses are being manufactured by the thousands at a cost of a few dollars each. One of the advantages of plastic lenses is that they are practically unbreakable.

Fig. 8—Close-up of 42-inch mirror.

Acknowledgments

The author acknowledges with thanks the able assistance of Messrs. R. F. Leuschner and M. Di Lorenzo in the construction of the optical systems described.

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(1) I. G. Maloff and D. W. Epstein, "Reflective optics in projection television," *Electronics*, vol. 17, pp. 98–105; December, 1944.
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Developments in Large-Screen Television*

By RALPH V. LITTLE, JR.

RCA Victor Division, Radio Corporation of America, Camden, New Jersey

Summary—**An experimental large-screen program is being carried on to determine the requirement for theater use. The governing factors: the light source, the optical system, and the screen are discussed. Photographs show equipment built for an experimental program.**

The high degree of excellence achieved in the production and reproduction of sound motion pictures has placed this art above all others in popularity and entertainment value. With high standards already established, large-screen television makes its debut in the entertainment field, not as a competitor, but as an ally, an ally with mutual interest and, we believe, vast possibilities.

Large-screen television is still in the experimental stage but considerable progress has been made during the past two years. Experimental equipment has been built and demonstrated with excellent results. This equipment, which will now be described, will form the basis for determining specific requirements and future design.

There are three major elements in a large-screen projection system which are combined to produce the over-all result viewed on the screen. The first is the source of light and picture, the projection kinescope, which translates the video information into a pattern of light on the tube face by the scanning process; second, the optical system, the function of which is to collect the light rays from the face of the kinescope and direct them to the screen, properly focused. as an image of desired size; and third is the screen from which the picture is viewed. These three elements must each be designed for their best efficiencies in a co-ordinated system, in order to make possible the best in picture quality and brightness. We shall examine each element of such a system in order to understand their limitations and discuss the problems common to each.

Presented October 23, 1947, at the SMPE Convention in New York.

The projection kinescope is similar to that used in the direct-viewing table-model television receiver and requires the same video amplifier, deflection, and high-voltage functions as required for the receiver; the differences are those of magnitude in order to obtain the very bright picture required. We see in Fig. 1, the diagram of a typical projection kinescope tube; the electron gun here emits a stream of electrons which are focused by an electron lens and accelerated by the high-anode potential, which is 50 kilovolts for the 7-inch tube, to the screen where it causes the phosphor coating of the face to emit light in accordance with the density of the electron beam which is controlled by the video signal. The deflection yoke surrounds the neck of the tube and is provided with suitable currents

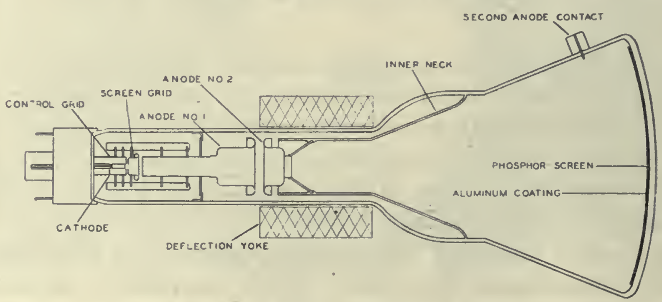

Fig. 1—Cross section of projection kinescope.

to make the scanning raster necessary to form a picture-image pattern. Television has no satisfactory method of using a supplementary high-intensity light source, such as a carbon arc, which might be controlled at video frequencies; so high-light brightness is a function of phosphor efficiencies. The method then of obtaining high-light output from a projection kinescope, as compared with a home-receiver kinescope, is to provide high accelerating voltage on the tube. This permits the phosphor to be bombarded with electrons of high velocity which produces more light while the current remains low.

The relative voltages used on typical kinescopes are: for the 10-inch home receiver, 9000 volts, while 50,000 volts is used for the 7-inch projection kinescope, and for the larger 12-inch and 15-inch projection kinescopes, 80,000 volts accelerating potential is used. Although the high voltages are used, the current requirements are small and are generated in safe radio-frequency power supplies which have very low stored energy. Future developments will be centered on the improvement of the phosphors and the electron optics of the kinescope. The typical projection kinescope high-light brightness is about 3000 foot-lamberts.

The second requirement of the projection system is the lens and since Mr. Maloff has discussed this subject in detail, only a brief summary will be made. You are familiar with typical motion picture lens which may nominally be an $f/2.0$ with a 5-inch focal length and uses elements $2^1/_2$ inches in diameter. A refractive lens of this type for a kinescope of 7-inch diameter would require a lens equal to the face diameter to gather sufficient light from the picture and in a

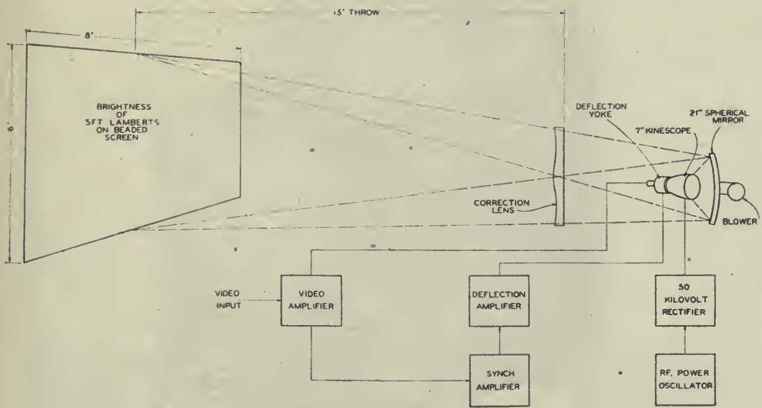

Fig. 2—Block diagram of simplifier.

practical design could not exceed a speed of $f/1.5$. The $f/1.5$ lens would have a gain of 1.75 over the conventional, thus leaving much to be desired in efficiency. Television engineers soon realized that the lens system was one place where more gain might be realized. The reflective optical system of the Radio Corporation of America was devised and gave effective speeds to $f/0.6$ with the 42-inch mirror system which has been completed for use with a 15-inch kinescope to produce an 18- × 24-foot picture. The relative speed as compared with the $f/2.0$ system would then be eleven times the gain in light, a truly remarkable increase. Reflective optical systems are characterized by short focal lengths which are necessary in order to produce the fastest lens speed or smallest f number. The projector for the 6- × 8-foot screen uses a 21-inch mirror, a 14-inch correction lens, a 7-inch projection kinescope, and has a throw distance of 15 feet. The projector for the 18- × 24-foot picture uses a 42-inch mirror, a 36-inch lens, a 15-inch kinescope, and requires a throw distance of 40 feet.

The screen then forms the final link in our over-all system and affords another opportunity to improve the gain in picture brightness. Consideration has been given to the various types of screens available. Experience obtained in our experimental work indicates that some form of directional-viewing screen gives the best compromise in high-

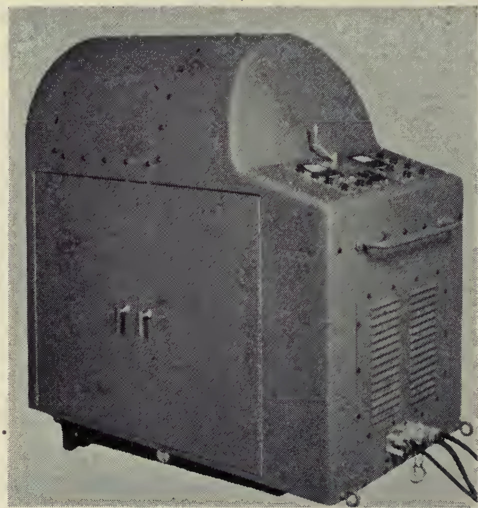

Fig. 3—Rear quarter view of 6- × 8-foot screen projector.

light brightness and viewing field. The beaded screen has given good results in this respect and is used with our demonstrations, but further development is in order. Developments in screens promise to permit greater gains and it is expected that gains as high as 3 may be obtainable to the advantage of the over-all system.

The Society of Motion Picture Engineers recommends an optimum screen brightness of 7 to 14 foot-lamberts. Television is approaching this requirement of the theater; developments under way will provide a picture equivalent to the recommended standard of brightness.

In Fig. 2 is a diagram of the essential elements of the large-screen projector, the projection kinescope, the RCA reflective optical system, the video amplifier, which modulates the kinescope to produce the light and dark areas corresponding to the television-camera image, the deflection circuits to produce the synchronized scanning raster, the radio-frequency oscillator and rectifier to supply the 50 kilovolts, and the necessary power supplies.

The projector for the 6- × 8-foot screen is shown in Fig. 3 and is a completely self-contained unit which operates from a video signal

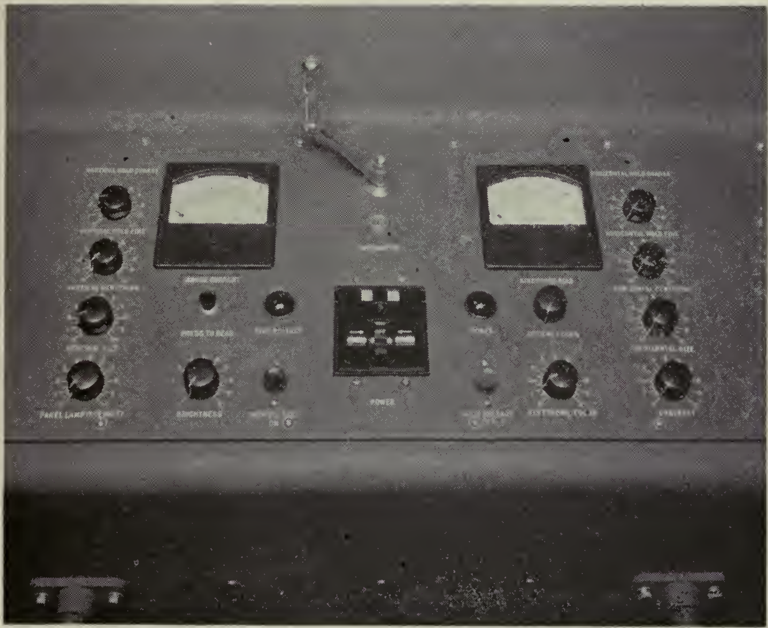

Fig. 4—Control panel.

supplied from a coaxial cable or a television receiver. The unit measures 53 × 32 × 60 inches and weighs 1200 pounds and requires 18 amperes at 115 volts 60-cycle alternating current or approximately 2 kilowatts. The cabinet houses the optical barrel containing the RCA reflective optical system, the 7-inch projection kinescope, and a 50-kilovolt high-voltage rectifier unit. Aligned on each side of the cabinet are the video amplifier, deflection units for vertical and horizontal scanning voltages, the radio-frequency oscillator which drives the high-voltage rectifier, and the necessary regulated power supplies. The control panel (Fig. 4) is located at the rear and has all operational controls accessible. It is noteworthy that most of these controls would not be made available on a commercial design, but would be on the associated chassis units since frequent adjustment is not required. The required controls would be found consisting of the contrast, brightness, optical focus, and electrical focus. A photograph of the optical barrel is presented in Fig. 5 to show the mounting of the mirror, the bottom tank of which houses the high-voltage supply

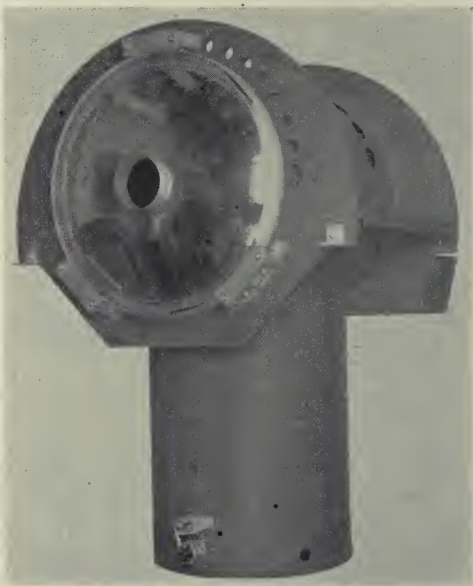

Fig. 5—Optical barrel showing mounting of mirror.

and effectively shields it from radiating. This unit must be very rigid to hold the optical system in precise alignment.

An interior view of the left side (Fig. 6) shows the orderly arrangement of the electrical equipment used. The left-hand panel is the synchronizing circuit panel, the major unit on the right is the deflection chassis which drives the deflection yoke on the neck of the tube. The other chassis are direct-current power supplies.

The other side (Fig. 7) shows the video amplifier on the right. The radio-frequency oscillator below it drives the high-voltage supply.

Fig. 6—Left side of 6- × 8-foot projector showing chassis.

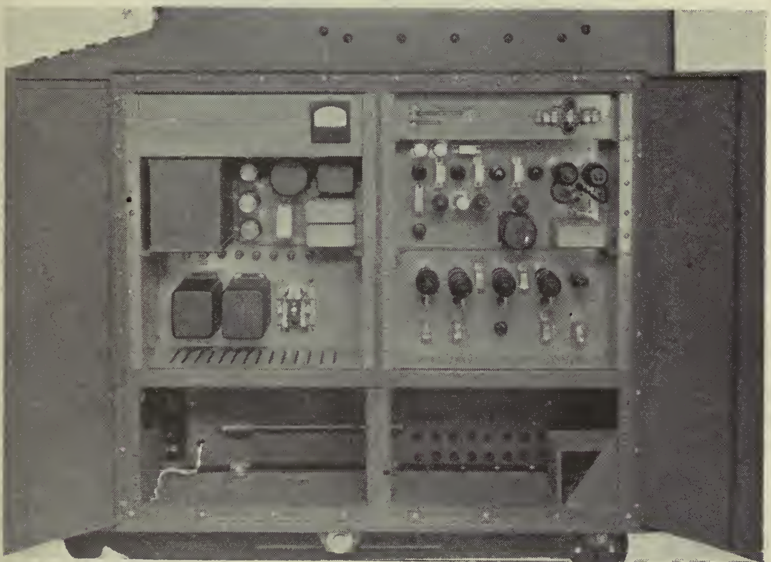

Fig. 7—Right side of 6- × 8-foot projector showing chassis.

On the left we have a power supply for the units just described and a fuse panel for the protection circuits.

A unique design feature of the projector is the high-voltage power supply, Fig. 8. As previously mentioned, it is driven from a power oscillator operating at 20 kilocycles. Energy at this frequency is fed to a step-up transformer which develops 25 kilovolts peak-to-peak alternating current, which is then doubled in the special rectifier

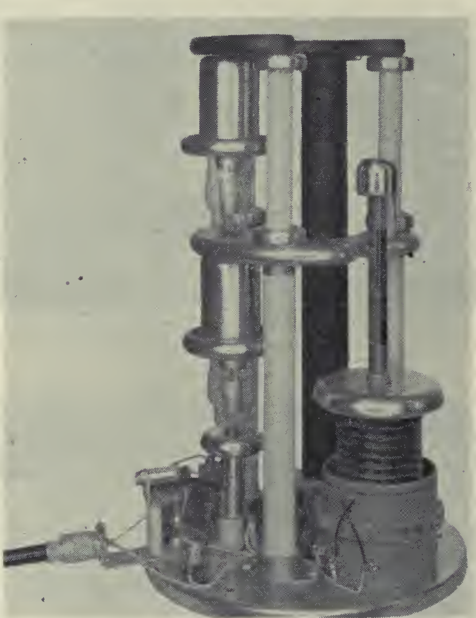

Fig. 8—50-kilovolt rectifier.

circuit to furnish the 50 kilovolts required. The figure shows the actual supply designed for this equipment, and its unique features include the self-contained filament transformers built into the socket of each tube.

A similar high-voltage rectifier is shown in Fig. 9, but with a quadrupler to supply the 80 kilovolts required for the projector using the 18- × 24-foot screen. The radio-frequency voltage generated in the coil is impressed on each rectifier tube. These tubes for direct current are in series so that four times the voltage is realized across the output resistor and kinescope. These unique power supplies employ a circuit developed by O. H. Schade of the RCA Victor Division, Harrison, and a mechanical arrangement devised by Fred G. Albin, recently of Camden Engineering and now at the Hollywood office.

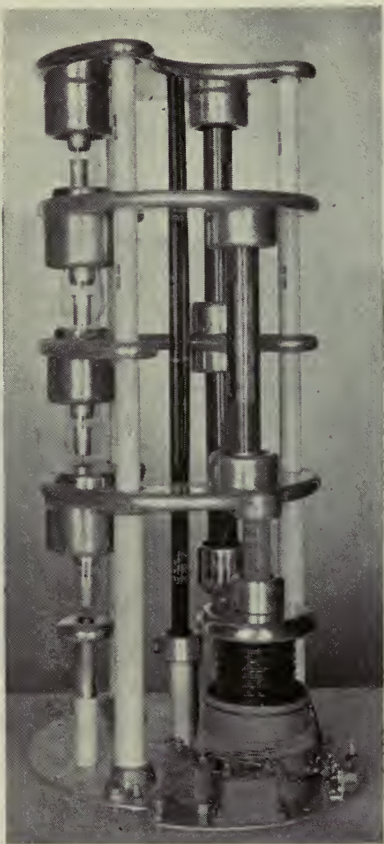

Fig. 9—80-kilovolt rectifier.

Fig. 10 shows the projector built for the 42-inch optical system and is the largest unit of its kind ever attempted. It will throw an 18- × 24-foot picture on the screen from the face of a 15-inch kinescope. The mechanical and electrical problems were of great magnitude as was to be expected. Any resemblance of this unit to another nationally advertised product is purely coincidental. This unit represents the accumulation of many years of effort on the part of many engineers in the RCA Victor Division located at Camden, Harrison, and Lancaster, and the RCA Laboratories of Princeton. Credit is due them for their contribution to the over-all project as well as to F. G. Albin who co-ordinated the design of the equipment described here.

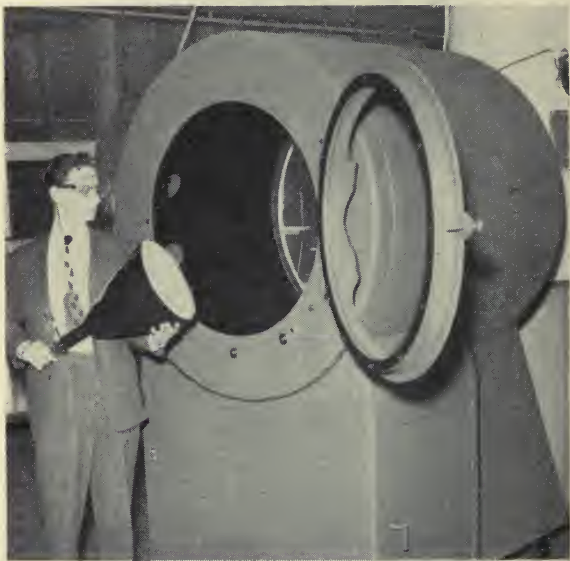

Fig. 10—Large theater projector for 18- × 24-foot screen using 42-inch mirror and 15-inch kinescope.

ACKNOWLEDGMENTS

In closing, I wish particularly to thank Mr. Earl Sponable of Twentieth Century-Fox for making available the equipment which we are demonstrating this evening. This equipment, together with the larger projector, form a part of a co-operative venture in theater television which the Radio Corporation is making with Warner Brothers and Twentieth Century-Fox as recently announced to the press.

Discussion

Note: Chairman Larsen requested that discussion on the two preceding papers be held until after the Large-Screen Television Demonstration. Therefore, the following discussion concerns both papers.

Mr. J. I. Crabtree: Does the aspherical lens need cleaning very often? If so, being plastic, do you not impair the optical properties in cleaning it?

Mr. I. G. Maloff: Not especially in the large-screen projector. If it is cleaned with the antistatic compound, we do not have to clean it very often. In the home-projection receiver, we make a hood that protects it from collecting dust. The normal cleaning with a soft cloth does not spoil it, because we use the hardest available plastic.

Dr. E. W. Kellogg: I should imagine the audience might be interested if Mr. Maloff would give us the figures of the optical speed or effective *f* number that is attainable in the Schmidt system, and also the field size in degrees so that they might compare it with what is possible with camera lenses or projection lenses.

Mr. Maloff: The *f* number as such loses its meaning at, I would say, about *f*/1.4. So the best figure is the efficiency of the lens. By defining efficiency as the ratio of the number of lumens delivered to the screen, to the lumens produced by the tube, we arrive at a figure between 30 and 40 per cent with the reflective optics, with a very large magnification. The figures for the *f*/2 lens, for the same magnification, run close to 4 or 5 per cent. I cannot tell you the field angles, offhand.

Captain A. G. D. West: How many lumens do you project in this projector and how many do you expect to project in the new 42-inch mirror projector?

Mr. Maloff: Suppose we turn the answers to your question around. The prewar projector gave us high-light brightness somewhere between 1 and 2 foot-lamberts. That brightness was found in a number of theaters around the country by the Committee on Screen Brightness of the Society of Motion Picture Engineers, which report was published around 1936 or 1937. The size of our screen in the New Yorker theater in 1940 was 15 × 20 feet. The screen gain was 2. By gain of a screen, we mean the ratio of brightness normal to the screen, to the incident illumination; that is, how many foot-lamberts' brightness are obtained for 1 foot-candle illumination or 1 lumen per square foot.

What we are doing now is this: We went to a 15-inch tube and increased the area of the emitter four times, roughly. Then we increased the voltage somewhat, and we used an aluminum-backed screen. Before the war we also used an aluminum-backed screen, but it was of an amorphous type, which did not have a mirror reflecting the light that was going back toward the gun. It was an absorber of that light. We put it on only to maintain the luminescent material at the second-anode voltage. There is such a phenomenon known as "sticking" of the luminescent material. That means it does not quite reach the voltage put on the second anode, never rising above the "sticking potential."

This gives us a gain of approximately eight times. There are a few other small gains, for example, in higher light output from the phosphor.

This would give us, with a perfectly diffusing screen having a gain of 1, a net gain of four times the prewar screen brightness.

We do not propose to use, with theater television, screens that illuminate ceiling and floor. We want the light to fall where the people are. Therefore, we propose to build screens that will throw the light only where the audience is. We have done this to a certain extent with the home projection receivers. We hope to do so with the theater projection receivers. The screen in the home projection receiver has a gain of 6. I doubt if we can get that kind of gain for a theater, but we ought to be able to get a gain between 3 and 4, and we are working hard at it.

CAPTAIN WEST: As to the answer about how many lumens, I believe the prewar, that is, 1941, projector gave about 200 or 300 lumens.

MR. MALOFF: On the New Yorker installation we ran close to 500 microamperes, average beam current. That gives us a peak, say, of 2 milliamperes. At 70 kilovolts, it is 140 watts. Now, 140 watts at 2 candle power per watt gives you 280 candle power. Assuming that we emit from the face of the cathode-ray tube according to Lambert's law, we multiply that by 3. That gives us somewhere in the neighborhood of 600 or 700 lumens. The same arithmetic applies again now, except that we are getting between 4 and 5 candle power per watt from the luminescent screen, this new aluminized screen. The new screen has mirror aluminum; it is not amorphous aluminum. We coat the screen with organic material. We fill all the little holes, the little depressions in the luminescent material, and the coating leaves a shiny surface. Then we evaporate aluminum on that shiny surface, and by baking and evacuating with pumps, we exhaust all the organic material. So we have left a shiny aluminum surface over the luminescent material. In this way we more than double the efficiency of the luminescent material.

CAPTAIN WEST: That is our practice, of course. However, I think we expect to get 1000 lumens from our 40-inch projector. You remember I mentioned about Dr. Zworkin's being in Paris. After he returned from that visit, I heard that he was achieving 12,000 lumens and 40 foot-lamberts on that size screen. So that rather depressed Professor Fisher, who was working on the other system.

I should have liked to bring a projector here to compare with the one used in the large-screen television demonstration, but it was not possible. However, in London we are projecting on a larger screen. It is very difficult to make a comparison, but, first of all, I should say my impressions of the picture are exceedingly good. My first impression is an impression of the color. It is a better color than we are having at the moment for a larger screen. I like the blue white and the bluish white in the home receiver.

Second, there seems to be good interlacing, which we do not have at home. The contrast range was very good. Was the center part film transmission?

MR. LITTLE: I believe certain portions of that program were from film.

CAPTAIN WEST: The transmission of the British Broadcasting Corporation suffers from a good deal of shading. Generally speaking, I am very favorably impressed. I think it is a very good picture, indeed.

DR. K. PESTRECOV: I think we need a committee on standardization of screen terminology. Recently we heard a report on screen-brightness measurements. At that time the ratio of foot-lamberts to foot-candles on the screen was called efficiency of the screen. As I remember, the efficiency would run from about 50 per cent to about 90 per cent. I believe Mr. Maloff prefers the term "gain." If it is really the same quantity, then a gain of 2 would correspond, as was defined a day or two ago, to an efficiency of 200 per cent. That is the first question.

Second, if television engineers can design a screen, or hope to design a screen, with a gain of 2, or an efficiency of 200 per cent, the screen also should be suitable for general motion picture projection. Perhaps, it will be a real advance so far as obtaining brighter pictures in general, because for theater television you are not inclined to use one screen and another screen for motion pictures.

MR. MALOFF: The first question is on efficiency and gain. There has not been any standardization in that field, so far, except among ourselves. Television engineers have a clear distinction between the two terms.

The one term, efficiency of the screen, is simply determined by putting a photometer on the other side and determining how much light at all angles gets through that screen. I am mostly talking about transmission screens, but the same applies to reflective screens. However, when we talk about gain, we measure this by comparing the light with what would come from a perfectly diffusing screen according to Lambert's law. We concentrate the returned light into a narrow pyramid, more or less. Horizontally it is wide. What we are trying to do is to get 60 degrees width from the screen, completely uniformly, with a sharp cutoff beyond that. Vertically, we are trying to get a 20-degree spread.

Theoretically, you can get close to a gain of 12 if you collect light that went to various places before. However, you can never get efficiency of the screen of over 100 per cent, because you absorb some light.

Before very long, we shall all have to get together and straighten out this matter, at least among us television engineers. Then we might have either conversion factors to translate to motion picture practice, or perhaps we can adopt the same terminology and the same definitions. Such is the case of resolution right now. When we talk about resolution in television, we say "500 lines." When an optical man looks at it, he will say it is only "250 lines," because we count every line, white and black, whereas he is counting only the black lines.

As to the second question, whether such screens as we are using now in the television industry are suitable for motion picture projection, we have various reflective screens. One concern is putting in a reflective screen with a gain of just about 6. It was demonstrated in New York and in other cities. Screens with a gain of 12 were demonstrated. That particular screen, however, has too narrow a vertical angle, and they have put in one with a lower value of gain.

So, all screens, both of the translucent type and the reflective type, could be used in theater projection of motion pictures. However, in some of the theaters the angles are so wide that you cannot use a directional screen; that is, where there is a second and third balcony. That is why we could not use a very high-gain screen in the New Yorker theater before the war.

In an auditorium like this one we should use a curved type of screen. There is an exhibit right outside the door of a curved screen, which definitely can give you a different directional distribution, vertically and horizontally. However, the problem is not so acute for the motion picture engineers as it is for television engineers. You start with such high values of light that you can waste it. If you can put a few extra seats here and there, you do so. The light goes down, but you still hold within your standard; that is, if it drops from 10 to 7 foot-lamberts, you do not mind that very much if you have a few extra seats.

We barely reach sufficient brightness. We cannot waste it, and we might have to waste a few seats in the theaters in order to show theater television.

DR. PESTRECOV: Thank you, Mr. Maloff. I purposely meant to provoke the discussion, because I have had discussions with Mr. Maloff before, and I more or less knew what he was talking about when he mentioned the term "gain." However, I believe that perhaps many people here do not know that term. As a matter of fact, I did not know it about two years ago, and many people in the optical industry and the motion picture industry still do not know that term. The point is that you get gain when you narrow the angle of reflection; is that correct?

MR. MALOFF: That is correct.

DR. PESTRECOV: So, perhaps, it really might be better to employ that term, make it standard, and then we shall not talk so much about the efficiency of the screen. As to the committee that reported on the brightness of the screen, what the committee actually measured at that time was the brightness of the screen in a certain direction. They did not measure the total light reflected, I believe. Perhaps some time in the future we can introduce that term and really talk about gain of the screen. In this particular case probably it does not have much meaning, but when we start to talk about television screens in the motion picture industry, then we have to use that term, and I think it should be more or less explained. Maybe if you explain it when you write this paper for publication, I think it would be very useful; at least, we shall have a definite and authoritative reference.

MR. LITTLE: Captain West might be able to answer a question on screens. In his paper he mentioned the lenticular screen which they were using in England, which gives a gain of 3. He also showed slides showing the distribution throughout the house, and that screen gave excellent coverage. Captain West, would you care to give us some explanation of the type of screen that you use?

CAPTAIN WEST: We are not using that screen at the moment. The one I referred to there under the heading of lenticular, which makes a large gain, was first demonstrated by Dr. Muller in Berlin at an exhibition. It consisted of a series of mirrors like a cat's eyes you see when you are driving on the road at night, looking out at you. It was very carefully arranged. I tested it very clearly on this television projector, which was similar to the one I illustrated on Tuesday night, of the pipe-shaped tube of the lens. I must say that if you were sitting at the end of the row and got out of your seat into the gangway, the picture vanished; and when you went back into your seat, it appeared again. The idea is that all the light was reflected back into the seats, and not all over the theater. That amount of light was conserved. It was always very expensive to make and had to be tailored for every theater.

There is an intermediate type of lenticular screen which we have been using. We have not used it so much as we wanted to, because of the shortage of metal and other materials. It is similar to what was described by Mr. Maloff for the home, except that it is a reflecting screen instead of a transparent one. I think that it corresponds to the screen in my diagram, which I referred to as a "stippled-metal screen." That gives a reflection factor right down the center of about $2^1/_2$ to 3 times.

One more question. I suppose you are getting a good show for one particular reason, in that it is all coming down from that little tower up there, is that right?

MR. LITTLE: Yes, that is correct. The program came from the Empire State Building, but I might add that the proximity really causes a great deal of difficulty. Tonight, about twenty minutes after seven, I would have said tonight's show was not going on, because we had a great deal of interference which apparently was cross modulation in the receiver between frequency-modulation and television signals. We were very much discouraged about putting on the show Some of the difficulty you did see in the picture during the show was caused in the receiver and not in the projection equipment. It was unforeseen, I assure you, and normally that type of interference is not present.

CAPTAIN WEST: That should please you very much, because we find that when everything goes wrong, before a demonstration, it is usually all right.

There is one other thing I would like to mention which helps very much, in presentation of television on the screen. That is the sound. We are doing experiments in theaters now which in the last eight years have had a little disturbance around them, not fit for the public to enter; in fact, all the seats had been taken out, parts of the roof were down, and that sort of thing. The sound is very bad in our television presentation. The sound was very good here tonight. I am absolutely certain that if you get good sound you get a much better picture.

MR. BEN SCHLANGER: If we can call this theater television a baby, I wonder if we are not making this baby run before it creeps. From what I can see, you are limited to a screen characteristic which throws the light back in a very narrow angle. Is it not better to take theater television and put it into shelters which are made for theater television? You are overstepping your bonds in trying to show television in existing theaters, where 50 per cent of the location will be inadequate and will not show the job off as well as it could be. The way you light the interior of the motion picture theater, there would be too much light in competition to the amount of light that you can get off the screen with television.

MR. LITTLE: I hasten to point out the remark during the paper, that the present equipment is the basis of an experimental program. We do not know what form television theaters will take, or what form television programming will take. We do not know what form television equipment, as such, will take. We are just embarking on this field, and we hope to get the answers. We certainly do not know them and as manufacturers we do not propose to give the answers to the industry. We are trying to help the industry find the answers. You gentlemen are part of the industry, and we expect the answers to come from you. We cannot give them. We can build you the equipment if you can tell us what you want.

MR. SCHLANGER: All the demonstrations and all the tests have been in existing theaters. It has never been given a really fair trial in a room that would really show it off the way it should.

MR. LITTLE: Maybe those limitations are inherent, but we do not believe so. We are certainly looking for an answer.

MR. R. B. AUSTRIAN: Mr. Maloff, in describing the screens and assigning the values to them which you did, I understood you to make a statement that there was no reason why they could not be used interchangeably for regular motion picture projection. Do I assume that the screens you worked with were nonporous; and if you had to perforate them for proper sound presentation as to be acceptable today, would that not change some of your reflection characteristics?

MR. MALOFF: Yes, very definitely, if you use directional screens. By the time you perforate it, you probably lose part of the effect that you gain. Maybe your sound effect will not be as good as you would like to have it. I do not think a perforated screen is an important item, but the industry probably thinks differently. If we perforate a directional screen, depending upon the percentage of the holes to the rest of the screen, we shall lose that much more light.

Motion Picture Theater Air Conditioning*

By DWIGHT D. KIMBALL

Consulting Engineer, New York, New York

Summary—Air conditioning as now defined involves four basic elements. These are a definite controlled temperature, the maintenance of the desirable relative humidity, a predetermined rate of air movement, and air filtration. In a properly installed air-conditioning system these elements can be predetermined and independently controlled, but temperature, humidity, and air movement must be controlled with a definite relation one to the other.

Basically modern air conditioning is but the ultimate development of ordinary ventilation. For example, the ventilating system installed in Carnegie Hall more than 50 years ago was made an air-conditioning system by adding to the existing ventilating system the necessary cooling equipment without changes in the fan equipment or duct system.

The generally accepted standard of summer theater atmospheric conditions is 80 degrees on a day of 95 degrees outside temperature, 50 per cent relative humidity, and approximately 12 to 15 feet per minute air movement within the seating area. An excessive relative humidity will more than anything else lessen the sensation of comfort of the occupants of the theater.

The conditions as above stated should extend to every seat in the theater and should not be merely the average over the entire theater seating area. Herein lies the importance of correct air distribution.

Seventy degrees inside of the theater with 95 degrees outside (a difference of 25 degrees) definitely may cause a serious shock to some people, especially the aged and those not in the best of health, and is a source of discomfiture to most people. Physiological tests have shown that a 12-degree difference between inside and outside temperatures is the desirable maximum.

* Presented October 24, 1947, at the SMPE Convention in New York.

Frequently it is asked when the air-conditioning industry will produce new type of equipment that will substantially reduce the cost of theater air conditioning. There is little or nothing of this nature in sight at this time.

The next advance to be anticipated is a means of independently providing for dehumidification. At present dehumidification is effected by first lowering the temperature of the air supply, to a point lower than that actually required for the cooling of the theater in order to extract the necessary amount of moisture from the air supplied to the theater, then raising the temperature of the air upon leaving the cooling coils by the use of the auditorium return air by-pass or reheat steam coils to raise the temperature of the air to a point at which it may be admitted to the theater.

Independent dehumidifying equipment is now available but it is expensive, space-consuming, and requires high-pressure steam or gas for the regeneration (or drying) of the moisture-absorbing material.

The major features of a modern air-conditioning system are air supply and its distribution; cooling equipment, such as refrigeration or well water; and treatment of secondary spaces, including the projection room, lounges, toilets, foyer, and lobby.

AIR SUPPLY

The volume of air supply, as well as the capacity of the cooling plant, is determined by calculating the heat load within the theater including transmission of heat from without through walls, floor, and roof; heat and moisture given off by the theater occupants, including standees; and electric load.

This calculation is so made as to determine separately the sensible heat and the latent heat. With total internal sensible heat load determined, a temperature differential between the desired room temperature and the temperature of the air admitted to the theater is selected, this depending upon the rate of air movement desired, the height of the air-supply diffusers above the floor, and the distribution of the air diffusers. This temperature diffusion difference may vary from 12 to 18 degrees.

Sometimes the resulting determination of the amount of the air supply to the auditorium will be found to be equivalent to 18 to 20 cubic feet of air per minute per occupant. But this is not the final answer because not 100 per cent of the air supplied can be applied directly to the benefit of the theater's occupants. Some of the air supplied may short-circuit to the return air and exhaust outlets, some is lost through doors and otherwise, and more air than thus determined is required to assure its distribution to all portions of the seating area.

Over a period of years it has been proved definitely that the air supply to the theater proper should be not less than 24 cubic feet of air per minute per occupant. For a de-luxe installation 30 cubic feet of air per minute per occupant may well be provided.

In determining the capacity of the main supply fan, the air filters, and heating and cooling coils, there must be added to the air to be supplied to the theater proper the amount of air which must be supplied to the lounges, foyer, lobby, and other parts of the theater.

Distribution of Air Supply

Quite as important as is the volume of air supplied to the theater is its distribution therein. This is determined by the number, size, and location of the air-supply diffusers which should be so determined as to, shall we say, spray the air over the entire occupied area of the theater, including the standee space, thus serving every person in the theater. In this matter the area under the balcony must not be neglected. Invariably the air should be admitted to the theater from the ceiling, and in the case of balcony houses also from the balcony soffit for the seating area under the balcony and the standee area.

The ceiling cannot be designed for the exclusive benefit of the ceiling diffusers but the utilitarian value of the ceiling diffusers and the inherent limitations upon the location thereof must be taken into consideration in the design of the ceiling. Ceiling diffusers may take various forms. There are the old-style plaster plaques, lacking the desirable diffusing and induction effects, and not especially sightly. Now more generally used are Anemostats, Aerofuse, or similar diffusing outlets. This type of air-supply outlet has the very important merit of producing a secondary air movement.

In determining the arrangement of the air distribution in a balcony theater the theater should be considered as divided into three zones.

1. That portion of the orchestra floor in front of the balcony rail.
2. The orchestra floor area under the balcony.
3. The balcony.

The air distribution should be so designed as to provide a direct supply of air and a withdrawal of return air in direct proportion to the number of occupants in each of these zones. (See Fig. 1.)

However small may be the seating and standee area beneath the balcony it is essential that a direct air supply and return air outlets be provided therefor.

The temperature of the air supplied to the theater during the winter at no time should exceed 80 to 90 degrees. With a higher temperature of the air-supply, stratification of the theater temperature will become very serious and promote wasteful operation. There was once found an air supply of 100 degrees temperature, a ceiling temperature of 95 degrees, and a floor temperature of 54 degrees. All steam was shut off from the air-heating coils for 30 minutes while 40-degree

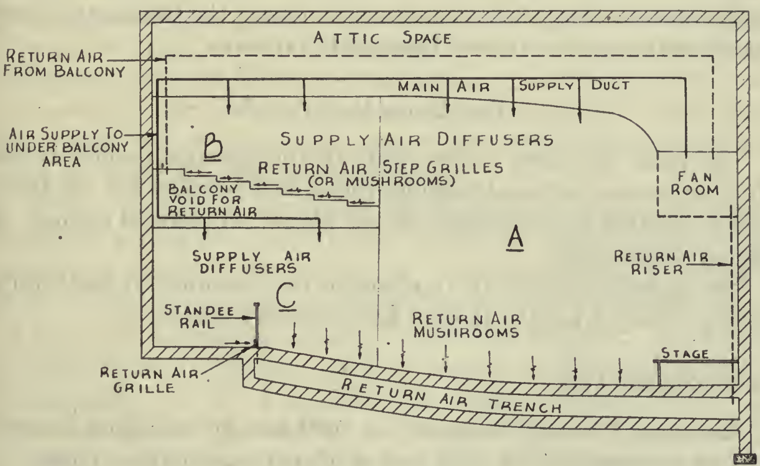

Fig. 1—Diagrammatic longitudinal section through theater.

air was blown into the theater to eliminate the high-temperature air at the ceiling, then 75-degree air was blown in for 30 minutes and the floor temperature became 70 degrees.

RETURN AIR

It is the universal practice to design theater air-conditioning systems upon the assumption that 75 per cent of the amount of air supplied to the theater auditorium is returned to the fan room for reconditioning and return (with 25 per cent of outside air) to the theater.

The supply of 25 per cent of outside air to the theater is desirable and adequate for the elimination of odors in the theater.

A general distribution of the air-supply diffusers is essential to a proper air distribution and equally essential is the general distribution of the return-air outlets within the theater.

A general distribution of the air-supply diffusers, with the return-air outlets limited to a restricted area, or vice versa, invariably proves unsatisfactory, causing excessive temperatures and a sensation often described as "dead" in those portions of the seating areas which are neglected by either supply-air or return-air outlets.

The most satisfactory and generally used means of withdrawing return air from the theater is through standard mushroom outlets located under the seats, usually communicating with return-air tunnels under the floor. In the balcony either mushrooms or riser grilles may be used, these communicating with the balcony void from which the return air is drawn back to the fan room.

Fan-Room Equipment

The main fan room is the heart of the air-conditioning system. The fan-room equipment includes the main air-supply fan, its driving motor, heating coils, cooling coils, air filters, sheet-metal casings, and piping connections.

The capacity of all of this equipment is determined by the total air supply required for the theater and accessory spaces.

Main Supply Fan

Assuming a theater designed for 1000 persons including standees, and an air supply of 24 cubic feet of air per minute per occupant, we have a base figure of 24,000 cubic feet of air per minute. To this must be added an amount of air equal to that which must be supplied to lounges, foyer, lobby, and other parts of the theater, from which spaces it is not customary to withdraw return air, some air to replace that which is lost through duct seams, and a small amount of air to assure a mild excess air pressure within the theater to counteract infiltration through the doors.

The finally determined capacity of the blower will be found to be about 30,000 to 32,000 cubic feet of air per minute. The total resistance, or static pressure, will be found to be $1^1/_4$ to $1^1/_2$ inches. A motor of 15 horsepower will be required to drive the blower.

To avoid noisy operation the blower should be so selected as to operate with an outlet velocity of about 1200 feet per minute, or under some favorable conditions up to 1400 feet per minute.

The pulleys of the V-belt motor and fan drive should be of the vari-pitch type to make possible any desired correction of the blower speed. The V-belts should be 25 per cent greater in capacity than that of the motor for greater durability.

HEATING AND COOLING COILS

The heating and cooling coils should be selected upon the basis of an air velocity of approximately 500 feet per minute through the coils, which is the generally accepted standard.

Heating coils using low-pressure steam will usually be two rows of tubes in depth, assuming a proper utilization of the return air. In general practice the number of rows of tubes required in cooling coils when using well water of 50 degrees or less in temperature is four. With well water above 50 degrees and up to 54 degrees six rows of tubes usually are used. If the well water is somewhat above 54 degrees eight rows of tubes are recommended. Additional rows of tubes serve no useful purpose in theater work.

With a well-water supply of 54 degrees and above the relative humidity within the theater on hot and humid days, or with capacity audiences, cannot be maintained at a level of comfort, say at 50 per cent or at the very maximum 55 per cent, and one of the main purposes of the air-conditioning installation is then defeated. Under such conditions the installation of supplementary refrigeration equipment is desirable. In fact, a condition frequently is found where refrigeration equipment may best be used to provide for all of the cooling.

Direct expansion cooling coils through which the refrigerant, usually Freon, is circulated through the cooling coils directly from the refrigerating plant will be discussed hereinafter.

AIR FILTRATION

Among the forms of air filters most generally used are dry-cell filters of the so-called "throw-away" type and similar types of wire-mesh air filters, the cells of which are dipped in an oil preparation and when dirty can be washed, redipped, and reused.

The problem of maintaining the efficiency of these air filters is a troublesome one in either case. After long experience the author adopted the use of the "throw-away" type of filter because in most cases the engineer or janitor may throw away and replace the dirt-loaded cells but would much more often neglect to remove, wash, immerse in oil, and replace the washable cells.

At best the operator generally regards the air filters as a nuisance. One engineer even removed the air-filter cells completely so that they would not become dirty.

The above types of air filters if allowed to remain in use until they become excessively loaded with dust and dirt may reduce the supply of air to the theater as much as 50 per cent.

Also available are automatically operating oil-immersed air filters in which the air-filter cells are attached to traveling motor-operated chains designed automatically to immerse the filter cells in a bath of oil contained in a liquid tank at the base of the filter unit, thus eliminating the frequent replacement or washing of the filter cells.

A much more efficient and desirable method of air filtration, but also much more expensive and space-consuming, is found in the electrostatic type of air-cleaning equipment, such as the Westinghouse Precipitron and the Raytheon Precipitator.

Wherever space may be made available and the considerably greater cost of this electronic air cleaning is acceptable to the theater owner its use is highly desirable. All replacement or washing of filter cells is then eliminated.

Assuming a theater air-conditioning system using 30,000 cubic feet of air per minute, the comparative cost of the different types of air filters mentioned above will be found to be about as follows:

Dry-cell throw-away type	$ 500.00
Air-mat type	1400.00
Oil-dipped reusable type	
2 inches thick	870.00
4 inches thick	1170.00
Automatic oil-immersed	2400.00
Electronic or electrostatic	5100.00

Clean air is desirable not only from a health standpoint but also as a protection of the theater furnishings and decorations.

Fan-Room Layout

As has been said the heart of the air-conditioning system is found in the main fan-room equipment. For the purpose of this discussion a plan of a typical fan room is shown in Fig. 2. Quite generally this space is found available at an elevated level at the front of the theater at one side of the screen platform.

In the interest of minimum total cost of installation of the heating and air-conditioning systems it is desirable that the boiler room and refrigerating machinery (or well-water pump) be located in the same general area but in the basement to shorten the interconnecting piping lines.

This arrangement of the fan-room equipment is designed to give access to each piece of equipment, including both sides of the heating and cooling coils. This last is important for the inspection and cleaning of the coil tubes and for repairs thereto when necessary.

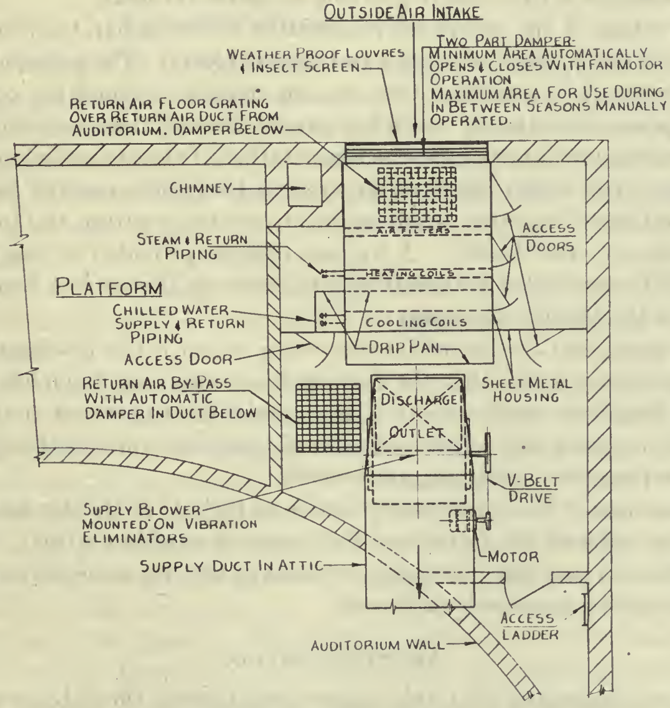

Fig. 2—Typical plan of fan room.

The outside inlet should be made of such a size as to admit an amount of air at 500 feet per minute velocity equal to the capacity of the blower so that 100 per cent of outside air may be utilized during the "in-between" seasons when neither heating nor cooling is required.

Back of the weatherproof louvers there is provided a louver-type damper made in two sections. The smaller section is sized to admit the amount of outside air required during the cooling and heating season. This so-called "minimum outside air damper" is automatically operated so as to open when the fan motor is started and close when this motor stops.

The larger section of the outside-air-intake damper is manually operated and is to be opened only during the period of fan operation in the so-called "in-between" seasons. The use of this so-called "maximum outside-air damper" will be found helpful during spring and fall seasons to provide ventilation and some cooling effect in mild weather with a resulting saving in operation costs.

A portion of the return air is admitted to the apparatus chamber between the outside-air intake and the air filters. The remainder of the return air is admitted into the fan chamber beyond the cooling coils to mix with the air which has passed through these coils to serve as a reheat medium to raise the temperature of the air coming off the cooling coils, which has been lowered to the point required for the elimination of moisture resulting in an air temperature too low for admission to the theater. A by-pass damper provided at this point should be controlled automatically to maintain the correct temperature of the theater air supply.

An important feature of this fan-room layout is the placing of the blower in such a way that the air may freely enter the fan inlet, especially important in the case of a double-inlet fan to prevent an unbalanced or a noisy fan. Free access to all fan-room equipment is essential for inspection, cleaning, and repairs.

Years ago it was a frequent practice to include in theater installations an exhaust fan to remove the excess of outside air used. This practice has long since been discontinued as serving no useful purpose and involving an unnecessary cost.

Air Sterilization

It was suggested that this paper should cover the subject of air sterilization but inasmuch as that problem will be described separately in other papers, the remarks thereon will be brief here.

Two methods of sterilization have been brought to the author's attention: ultraviolet radiation and glycol-vapor treatment.

That method which not only treats the air passing through the air-conditioning chamber but also carries the germicidal agent on into the theater and to the theater occupants would appear to be the more effective.

Glycol equipment, which is now available, requires but a small space, is relatively inexpensive to install and operate, is odorless, nontoxic, and is carried directly into the theater in the supply air stream.

The ultraviolet ray equipment involves the placing of lamp units in the theater walls and a considerable amount of wiring. The author is not at this time persuaded of the merits of this system for theater work.

So far as is known, no theater up to date has been provided with germicidal-air-treatment equipment but this subject does seem to be worthy of very serious consideration.

Projection-Room Ventilation

The ventilation of the projection room is governed by the rules of the National Board of Fire Underwriters and in New York City by certain provisions of the City's Building Laws. Some of these requirements are confusing and indefinite and are not specific in an engineering sense. Moreover, the situation is further confused by the varying interpretations given by different inspectors or engineers representing these Bureaus.

Fig. 3 shows the author's standard plan of projection-room ventilation which appears to be acceptable to all authorities having jurisdiction thereon.

The essential features are as follows: (*a*) a motor-driven exhaust fan with ducts to remove the heat from the projection machines, exhausting 50 to 100 cubic feet per minute from each machine; (*b*) a second exhaust fan to ventilate the projection room, the rewind room, the motor-generator room, and the toilet room. Twelve to 20 changes of air per hour may desirably be exhausted from these rooms because of the heat released therein. A single fan may not be used to serve both of these purposes, nor may either of these fans serve to ventilate any other spaces. The discharge ducts from these two fans should be carried directly to out-of-doors. No code specifically states this but the author has had objections filed to the carrying of these discharge ducts through other theater spaces; (*c*) two outside air ducts directly from the roof (or upper part of the side walls) to serve the machine rooms and the rewind room (New York City Code); (*d*) film cabinets of a capacity of 50 pounds or more of film are required to be provided with a vent directly to the outside of the building.

The rules of the National Board of Fire Underwriters specifically state that the "Ventilation of the projection-room area shall not be connected in any way with the ventilating or air-conditioning system serving other portions of the building."[1, 2]

LOBBY

The real problem in treating the lobby is that of counteracting the wind blowing in through the outer doors which is sometimes found to be blowing on into the theater resulting in annoyance to those persons occupying the rear theater seats.

The use of radiators in the lobby is generally unsatisfactory because a large amount of lobby radiation is required for which it is generally

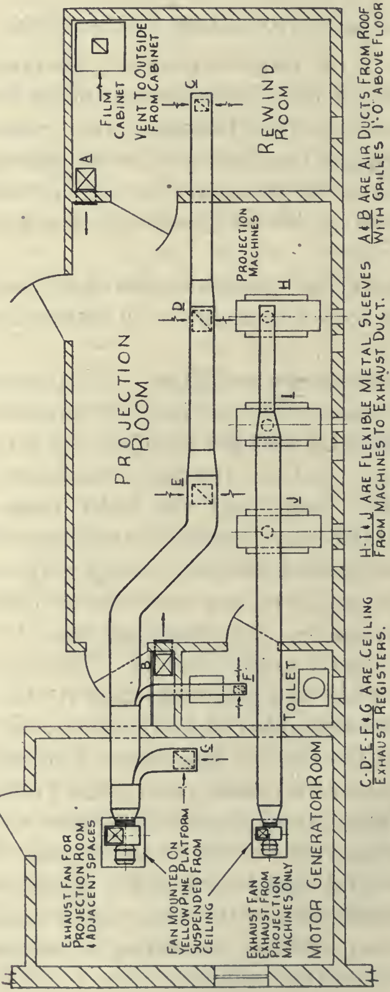

Fig. 3—Typical projection-room ventilation.

found difficult to find space, the radiators are objectionable in appearance even when recessed and grilled, and there will be times when the cold air will blow through the lobby into the theater, and the radiation is not immediately responsive to sudden demands for heat, such as when the outer doors are opened.

A more efficient means of heating the lobby, and with the same equipment supplying conditioned air thereto, is found in the extension to the lobby of a branch duct from the theater air-conditioning supply duct and interposing in this branch duct a booster air-heating coil and

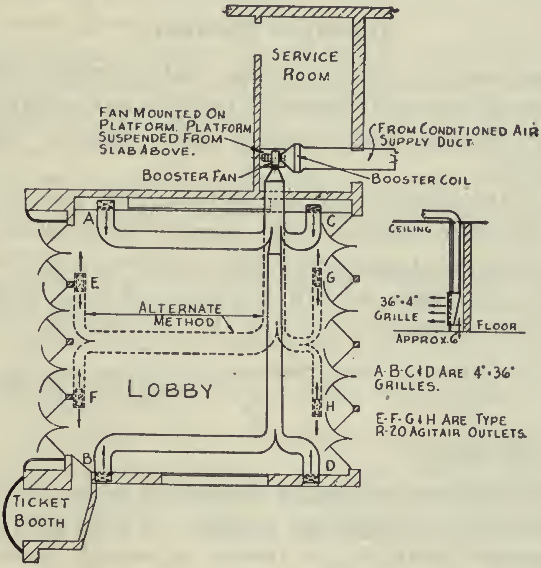

Fig. 4—Lobby heating and air conditioning.

a small booster fan which will supply air to the lobby at a pressure sufficient to counteract the pressure of the air blowing in through the outer doors. By this method the lobby is evenly heated during the winter and air-conditioned during the summer.

Fig. 4 shows a typical lobby treatment. The solid lines show the preferred method; dotted lines show an alternate method.

Lobby temperature control, during the heating season, may be accomplished by a thermostat operating a modulating steam-control valve at the booster coil or face and by-pass dampers at the booster heating coil.

Lounges and Toilet Rooms

All toilet rooms, whether or not having windows, should be provided with mechanical exhaust ventilation. Windows are generally kept closed during the cold weather but when opened they may serve to admit air which will blow the toilet-room odors into the theater.

Inasmuch as the toilet rooms are generally entered from the lounges the general practice is to supply conditioned air to the lounges and to draw air from the lounges through louvers in the toilet-room doors into the toilet room from which it is exhausted as above stated.

Automatic Controls

The operation of a theater-heating and air-conditioning system lacking automatic-control equipment involves an excessive amount of attention on the part of the operator and a degree of skill which is rarely available.

Automatic temperature and humidity control greatly lessens the amount of attention required of the operator, automatically compensates for varying occupancy and weather conditions, and lessens operating costs. Automatic control devices are delicate and should be the subject of an annual checkup by the manufacturer of the equipment used.

A simple system of automatic control would include the following:

For Winter Operation

A master duct-type modulating thermostat having its bulb located in the stream of the outside-air supply. A submaster modulating room thermostat located in the theater to control automatic valves inserted in the steam connections to the air-heating coils. A modulating duct-type thermostat in the main fan discharge duct designed to prevent the supply of air to the theater at too low a temperature.

For Summer Operation

A proper relative humidity in the theater is of prime importance because it more directly affects the comfort of the theater patrons than does temperature. To control the relative humidity an automatic modulating humidostat is located in the return-air duct near the fan room to so control the operation of a modulating three-way water valve inserted in the cold-water mains connecting to the cooling coils as to pass through the tubes of the air-cooling coils that amount of cold water required to lower the temperature of the air passing through the cooling coils to the temperature required to extract by condensation on the coils all excess of moisture beyond that required to maintain the desired relative humidity in the theater.

This may reduce the temperature of the theater air supply below the temperature at which it may be discharged into the theater.

Then a portion of the return air is carried around the cooling coils, thus utilizing the heat picked up in the theater for the raising of the temperature of the air supplied to the theater. An automatic damper is provided in this return-air by-pass controlled by the submaster modulating room thermostat described under "winter operation."

A manually operated summer-winter switch is provided to transfer the effect of the submaster room thermostat from the control of the steam valves at the air-heating coils during the heating season to the control of the automatic return-air by-pass damper during the cooling season. This switch also holds the three-way water valve closed during the heating season and the steam valves closed during the cooling season.

A simple means of opening and closing the minimum outside-air-intake damper when the main supply fan is started and stopped is desirable. This consists of a damper motor applied to the minimum intake damper and an electric-pneumatic switch wired into the motor circuit with a damper motor.

A lobby thermostat of the modulating type with an automatic valve in the steam connection to the lobby booster heating coil is essential to the control of the lobby temperature. The usual chronotherm is assumed to be provided for the control of the heating-boiler oil burner.

This system may be elaborated upon at will. It will include a small air compressor and other incidental equipment. An electrical automatic control system may be installed to accomplish the same ends.

It will be noted that reference is made above to the use of modulating thermostats. These may be used for heating controls only where a vacuum steam-heating system is installed. Such a system is highly desirable because it provides for the only successful method of controlling the temperature of the air supplied to the theater by making possible the modulation of the supply of steam to the air-heating coils in exact proportion to the demand for heat.

A vacuum steam-heating system is more economical in operation than is a gravity-heating system and a substantial portion of the cost of the vacuum-pump installation may be saved through a reduction in steam- and return-piping sizes and a saving in the cost of pipe covering.

PRIMARY COOLING MEDIUM

Well Water

Where well water is obtainable at temperatures of 50 to 54 degrees it will serve every purpose required of air conditioning and the well and pump installation will cost but 20 to 40 per cent of the cost of the required refrigeration installation.

If the well water is found to be above 54 degrees in temperature either supplementary refrigeration equipment must be provided or a higher relative humidity will occur in the theater with a sacrifice in comfort conditions.

Refrigeration

The capacity of the necessary refrigeration installation is determined by generally understood if rather involved calculations. An ample capacity in the refrigeration plant is a very comforting and reassuring thing.

It has been the author's experience, including a survey of 100 theaters for one chain, that a general checking figure on the tonnage of refrigeration required will run about as follows:

600-seat theater	12 occupants per ton
1000-seat theater	14 occupants per ton
1500-seat theater	15 occupants per ton
1800-seat theater	16 occupants per ton
Larger theater	17 occupants per ton

Generally, Freon is the refrigerant used ina ir-conditioning work.

The refrigeration plant will include one or two compressors as required; motor; means of condensing, i. e., the cooling of the compressed refrigerant; water chiller, a chilled-water circulating pump, and a chilled-water circulating piping system, if a water-circulating system is required or used; and starters, automatic controls, and other parts.

A single compressor may be installed if the tonnage is 50 tons or less or if a centrifugal compressor is used. Interruptions of service are very rare. Reciprocating compressors are very generally used, especially in theaters of 1500 seats or less; a centrifugal compressor may well be used for larger theaters.

The motor horsepower per ton of refrigeration will vary with the actual operating conditions and motors of ample capacity which will not become heated under maximum load conditions should be selected. Generally speaking the motor capacity should be not less than one and one tenth to one and two tenths horsepower per ton, or slightly less sometimes with very cold condensing water.

Condensing, or cooling of the compressed refrigerant coming from the compressor, may be accomplished by means of a standard shell and tube condenser supplied with water from the street mains, from a cooling tower, or by an evaporative condenser.

If the street water may be used the least cost of installation results. In New York City the supply of city water for this purpose is limited to 2,680,000 gallons of water per year and this is not sufficient for even a 600-seat theater. Then a cooling tower must be used to provide condensing water for a shell and tube condenser, or an evaporative condenser may be used instead of the shell and tube condenser and cooling tower except in some cases an evaporative condenser cannot be installed within restrictions of the New York City refrigeration code.

Where the indirect, or water-circulating system must be used, as in New York City, a shell and tube water chiller, similar in construction to the condenser, must be used with a chilled-water circulating pump.

Automatic high- and low-temperature controls, a low-temperature compressor cutout to prevent freezing of the water in the chiller, and usually compressor capacity controls are applied to the water chiller.

The well-water or chilled-water piping carrying the cooling water to and from the cooling coils must be insulated with molded cork, preferably 2 inches thick. An alternate to this indirect, or water-circulating, system is the direct expansion system in which the compressed refrigerant after being condensed or cooled in the condenser is conveyed directly to and from the cooling coils.

This direct expansion system is less expensive to install because it eliminates the water chiller and water-circulating pump and reduces insulation costs. However, it cannot be installed in places of public assembly in New York and certain other cities.

Where the main fan room with the air-cooling coils is located at a considerable elevation above the compressors the direct expansion system operates at a disadvantage, and there is a further disadvantage in the direct expansion system in that it does not lend itself to a satisfactory method of the automatic control of theater temperature and humidity.

NOISE

Sometimes a small matter can be the cause of very objectionable noise and still be difficult to locate. The most frequently found causes of noise might be listed in the following order of frequency of occurrence:

1. Lightly constructed duct work having poorly made seams and joints, insufficient bracing permitting the vibration of the duct sheets, bad turns, loose dampers, and edges of metal projecting into the ducts.

2. Excessive air velocities through the ducts or through the supply grilles and diffusers. Maximum duct velocities should not exceed 1200 feet per minute at the fan, or possibly 1400 feet under favorable conditions, the air velocity being gradually reduced as branches are taken from the main duct to about 600 feet in the individual branches.

3. The blower is by no means the most frequent source of noise although usually first suspected. An excessive fan speed or an excessive air velocity through the fan outlet will cause noise. The correct blower speed will depend upon the size, type, and characteristics of the blower. The air-outlet velocity from the blower should not be over 1400 feet per minute and 1200 or 1300 feet is better. No sharp bend in the duct work should be made near the blower outlet. The blower must be reasonably free from vibration. It must be so placed that the distance from the blower inlet ring to the enclosing wall should be approximately equal to the diameter of the fan inlet. This is especially important in the case of a double-inlet, double-width blower. A canvas sleeve must be provided in duct connections to blowers so that blower vibration will not cause a vibration of the ducts. A loose belt can cause much noise in itself and cause the blower to become noisy. A blower wheel out of balance or with loose shaft collars may cause pounding.

4. A motor is sometimes noisy, perhaps because of faulty setting or even due to its construction. The motor may have to be replaced by a quiet motor.

If the noise is caused by air travel in or out of the fan the simplest cure may be the installation of acoustical duct lining for a distance of about twenty feet.

MAINTENANCE

The installation of an air-conditioning system involves a very substantial investment of money and includes much equipment. Most assuredly it is worthy of the utmost care. Neglect of this equipment temporarily may save money but ultimately it will involve an expense largely exceeding the amount saved in failing to maintain the equipment properly. Moreover failure to maintain the equipment properly in good condition inevitably will increase the operating costs.

Costs

The costs of an air-conditioning installation will vary so widely with the type of installation involved that no general figures may be given.

Prices have been changing so rapidly that it is difficult to keep up to date on them. In 1942 bids were received on a theater air-conditioning installation which was not made because of war restrictions. Last month new bids were received upon the same plans and specifications. The new bids exceeded those of 1942 by 78 per cent. At least half of this increase appears to have occurred within the last two years.

Guarantees

Do not buy air-conditioning systems upon the basis of guaranteed theater conditions. Proving the facts in court is almost impossible.

The standard guarantee of results is that a condition of 80 degrees and 50 per cent relative humidity shall be maintained within the theater when an outside temperature of 95 degrees dry bulb and 75 degrees wet bulb prevails, with a 100 per cent occupancy of the theater, and while using a predetermined volume of outside air. In thirty years the author has yet to see these conditions simultaneously prevailing for such a test.

Conclusion

In the foregoing it has been possible to give but a bare outline of a theater air-conditioning system. Actually such an installation involves a multitude of details, all of which are important, many of which are highly technical, and all of which must be correlated carefully. To prove successful it must be a compound of theory and practical experience, with the latter predominating.

It has been said that he who serves as his own lawyer has a fool for a client. Looking back over many years of experience in theater air conditioning it seems that much the same thing may be said of one who assumes to act as his own engineer in the installation of an air-conditioning system. Competent advice will save the purchaser a great deal of worry.

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Theater Engineering Conference

Ventilating and Air Conditioning

Air Purification by Glycol Vapor*

By J. W. SPISELMAN

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Summary—The germicidal activity of glycol vapor on air-suspended bacteria and viruses has been clearly demonstrated. The most suitable compound thus far found for use in such air disinfection is triethylene glycol. When dispersed in air as a true vapor in exceedingly small amounts it is highly germicidal for pathogens of the respiratory tract, including influenza virus. It is nontoxic, nonirritating, odorless, tasteless, invisible, and inexpensive. Satisfactory devices for the vaporization and regulation of bactericidal concentrations of glycol are now made and are in use.

During the last fifty years great strides have been made in protecting our people from the spread of disease through the food we eat and the liquids we drink. Our water and milk supplies are guarded with unceasing vigilance; our foods and our drugs must meet tests of purity laid down in a rigid code.

But what about the air we breathe?

A man eats about two pounds of food a day. He drinks, say, a quart of liquids a day. But he breathes about 80 pounds of air per day. That air contains germs, dusts, smoke, organic matter, pollen, and noxious gases.

Man has through evolution and environment built up his ability to withstand the onslaughts of these air-borne enemies; but that line of defense is vulnerable, and is often beaten down. In fact, it has been established that better than 50 per cent of all industrial sickness absences are due to respiratory diseases.[1] And these respiratory diseases are due primarily to air-borne infection!

And the questions are quite properly asked—"What can be done about it? What can be done to sanitize, or disinfect, or sterilize the air which is being continuously contaminated with bacteria and viruses dispersed into it as people around us cough, sneeze, or talk?

* Presented October 24, 1947, at the SMPE Convention in New York.

What can be done to protect us when we are congregrated in places of public assembly, theaters, schools, and industry?"

This paper presents a picture showing how far one branch of air sterilization has gone toward answering those questions.

Early in 1941, Drs. Robertson, Bigg, Miller, and Baker of the University of Chicago announced[2] that they had succeeded in sterilizing air by using certain glycols. They used propylene glycol, one of a family of glycols, and obtained almost instantaneous sterilization of the air in a test chamber infected with high concentrations of staphylococcus and streptococcus germs.

In the latter part of 1941, just before the United States entered the war, while selective-service camps were expanding, the Surgeon General of the Army formed the Commission on Prevention of Airborne Infection and Control of Influenza and appointed the same Dr. Robertson as chairman. Because of the extensive experience The Research Corporation had acquired during the preceding years in glycol air conditioning, the Corporation was asked to assign the group, which now comprises Air Purification Service, Inc., to assist Dr. Robertson's Commission in various phases of further development and engineering.

The development since that early period has been extensive. At the very beginning, it became apparent that it was not the fine mist of glycol that was the active agent but it was the true gaseous vapor of the glycol.[3,4] For the vast majority of cases triethylene glycol rather than propylene glycol was more economical and efficient.[5] Equipment was developed for the true vaporization of the glycols,[6] and extensive field tests were performed.[7]

It also became apparent that the amount of triethylene glycol necessary for such sterilization was fantastically minute. One cubic centimeter of glycol liquid would sterilize 250 to 400 million cubic centimeters of air. Visualizing it in another manner, all the air in a building covering a full city block and six stories high could be sterilized by one pint of triethylene glycol. An air-conditioning system using 15,000 cubic feet per minute of fresh air would require only five ounces of triethylene glycol per hour for sterilization. The actual quantity of vapor in the air approaches that of our most rare gases; it is less than $^1/_{100}$ the quantity of neon in the air we breathe.

What are these glycols? Chemically they are kin to the alcohols; physically they look quite like glycerin. Triethelyne glycol (TEG) is a mildly viscous, colorless, and odorless liquid which, when vaporized,

[illegible] the first [illegible] and in the [illegible]

It should be remembered that at the stage of our present knowledge, glycol vapor definitely had been shown to be a preventive medium, but not a cure, for airborne infection. Yet, recent work in the aerosol field has indicated that the glycols may also have a therapeutic value by forming antibiotics with the blood serum.[12, 13] This work undoubtedly will be followed up for further knowledge on this point.

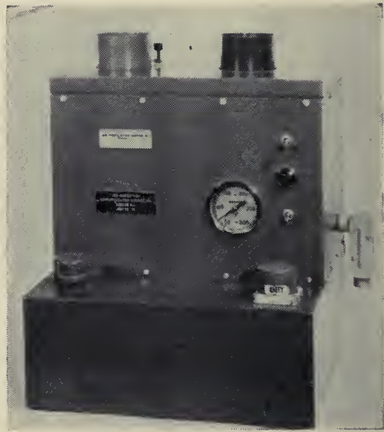

Fig. 1—Vaporizer.

Glycol is vaporized through the medium of heat and a preheated stream of air. Triethylene glycol for instance, cannot be simply boiled to vaporize it, since it boils at 550 degrees Fahrenheit, but starts to decompose chemically at approximately 300 degrees Fahrenheit. The equipment for such vaporizing is not complex; present equipment available is foolproof, economical of operation, and small for the job it can do. The present full-size glycol vaporizer has a base of 15 × 15 inches and is but 18 inches high, and will treat 20,000 cubic feet per minute of fresh air.

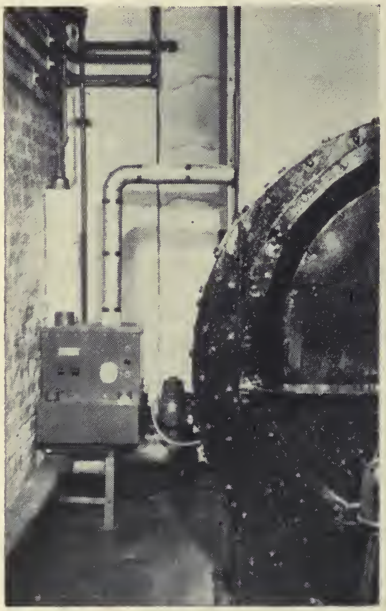

Fig. 2—Typical installation of vaporizer.

Its application to an air-conditioning or ventilating system is generally mechanically simple after the proper engineering considerations have been made. A small quantity of air, roughly about 20 cubic feet per minute, is continuously preheated within the vaporizer to the proper vaporizing temperature under close thermostatic control, and is then induced over evaporating surfaces containing heated TEG. This carrier stream, warm and laden with glycol vapor, is then injected into the main stream of air in the ventilating system. The glycol disseminates within that main stream and is thus carried through the distributing ducts throughout the ventilated area. Complete permeation of every nook and cranny of the treated space is thus obtained.

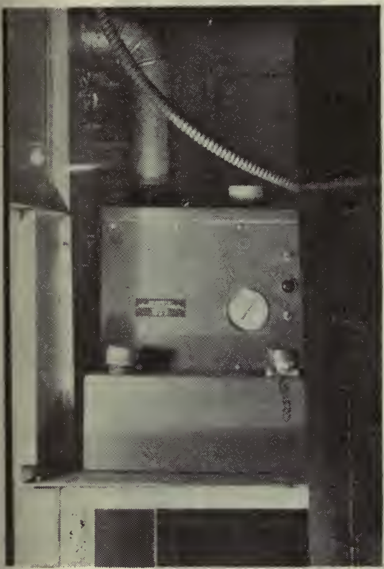

Fig. 3—Installation within a plenum chamber.

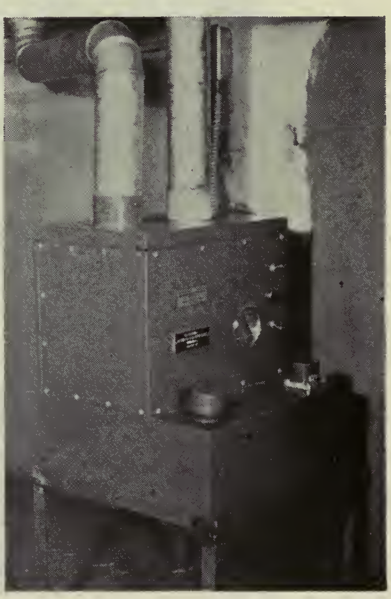

Fig. 4—Installation across a heating coil.

Figs. 1 to 5 show the glycol-vaporizing unit and typical examples of applications to air systems.

Fig. 1 shows the vaporizer itself. A small stream of air enters the top left-hand inlet, is preheated under thermostatic control, flows over evaporating surfaces and an indicating thermometer, thence out through the outlet port on the top right hand.. The output is based on the temperature of the leaving air and is a logarithmic relationship. The bottom of the vaporizer is a tank section holding five gallons of glycol. There are no moving parts in the unit.

Fig. 2 shows a typical installation. The vaporizer is set conveniently close to the suction side of the main blower of a ventilating or air-conditioning system. The small stream of air is induced through the glycol-vaporizing unit by the suction of the main blower, and the glycol-vapor-laden output stream flows directly to the blower to be distributed throughout the system.

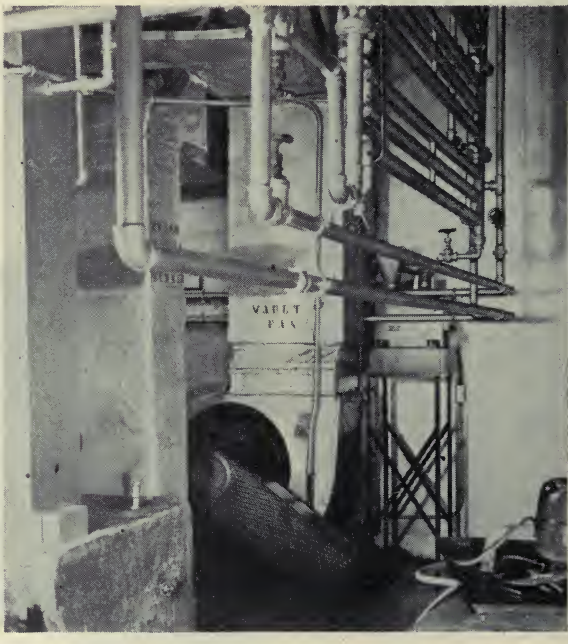

Fig. 5—Size of unit.

Fig. 3 shows another type of installation in which the glycol vaporizer is placed within a plenum chamber on the suction side of a blower. Here the difference in pressure between the outside of the plenum and inside is used to induce the small stream of air through the vaporizer.

Fig. 4 shows the unit operating by obtaining the necessary small pressure drop by means of the pressure drop of a coil in the ventilating system. The pressure drop across the heating coil in this case is sufficient to force the air through the vaporizer to insure proper operation.

Fig. 5 shows an installation similar to Fig. 2 and indicates the relative size of the unit in the far background as compared to other component parts of a ventilating system.

In all cases, the glycol-vaporizing unit is interlocked with the blower motor, so that when the blower is shut down, the heating elements of the vaporizer are also shut off and the vaporizer becomes inactive.

The cost of TEG is relatively low; a 1000-seat theater will use about eight cents worth of TEG per hour of operation. The electrical power required for the vaporizer is less than 750 watts, and would be lost in the total electrical bill of such a house. An illustration of such an installation in a large theater is in the Rivoli Theater, New York City. With the close co-operation of Mr. G. P. Skouras and Mr. Montague Salmon, managing director, operation costs and public reaction are being carefully noted.

One of the results noted in a glycolized atomsphere is the feeling of "freshness" which seems to pervade the air. The mustiness often associated with air-conditioning systems is eliminated. Our explanation for that is that the molds and similar organisms which will collect in duct work and give off odors in their life processes are killed by the glycol vapors, and the odor disappears.[14] We believe also that there is some control over odors generated in an occupied area.

In closing, it should be borne in mind that when a vapor is used for the control of air-borne bacteria and viruses, it pervades the entire atmosphere. It is where you want it when you want it at the source of such contaminating organisms, the mouths and nostrils of all of us.

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FORTY YEARS AGO

How Moving Pictures Originated

A paragraph is going the rounds of the press giving the following version of the origin of moving pictures:

Sir John Herschel after dinner in 1826 asked his friend, Charles Babbage, how he would show both sides of a shilling at once. Babbage replied by taking a shilling from his pocket and holding it to a mirror. This did not satisfy Sir John, who set the shilling spinning upon the dinner table, at the same time pointing out that if the eye is placed on a level with the rotating coin both sides can be seen at once. Babbage was so struck by the experiment that the next day he described it to a friend, Dr. Fitton, who immediately made a working model. On one side of a disk was drawn a bird, on the other side an empty bird cage; when the card was revolved on a silk thread the bird appeared to be in the cage. This model showed the persistence of vision upon which all moving pictures depend for their effect. The eye retains the image of the object seen for a fraction of a second after the object has been removed. This model was called the thaumatrope. Next came the zoetrope, or wheel of life. A cylinder was perforated with a series of slots and within the cylinder was placed a band of drawings of dancing men. On the apparatus being slowly rotated, the figures seen through the slots appeared to be in motion. The first systematic photographs taken at regular intervals of men and animals were made by Muybridge in 1877.

—*The Moving Picture World, April 4, 1908*

Theater Engineering Conference

Ventilating and Air Conditioning

Ultraviolet Air Disinfection in the Theater*

By L. J. BUTTOLPH

General Electric Company, Nela Park, Cleveland, Ohio

Summary—Theater attendance, and the decrease during times of epidemic respiratory disease, involves a public-health and a theater-operation problem possible of partial solution by an increase in ventilation, a sanitary ventilation, probably effective only when provided in amounts physically and economically impractical because of the power and duct capacity required to heat and distribute outdoor winter make-up air. Ultraviolet air disinfection provides a way of making the air in the upper third or half of theater auditoria and accessory rooms as good as outdoor air, or a sanitary ventilation of the lower air, equivalent to 50 to 100 air changes, resulting from the usual random vertical air circulation throughout the horizontal cross section of occupied rooms. Any sanitary ventilation value in the make-up air of a duct-heating and air-conditioning system, may also be increased five- to tenfold by using ultraviolet energy to disinfect all recirculated air to the bacterial equivalence of outdoor air. There are tabulated lamp requirements for upper-air and duct-air disinfection and schematic installation sketches.

Annual newspaper notices urging people to stay away from crowds during times of epidemic respiratory disease call attention to the public-health problem of the motion picture theater. Those who stay away may be benefited but the resulting decrease in attendance is usually only enough to create an economic problem for the theater operator without solving his health problem.

The only solution of this problem is basically one of ventilation, of providing about ten times as much air volume per patron, or ten times more air changes per minute or hour, than has been provided in the past. Optical considerations of screen-viewing distance and angle, to say nothing of the economics of building construction, make any radical increase from the current practice of about seven square feet of the floor area per patron out of the question. The alternative is that

* Presented October 24, 1947, at the SMPE Convention in New York.

of providing a greatly increased ventilation, a sanitary ventilation, in contrast with the minimum past practice found essential for the dilution of body odors and the distribution of heat. In the northern half of the United States, the heating of much more oudoor air than is essential for the removal of the body heat of the theater patrons is economically impractical.

The recently available process of ultraviolet air disinfection has neatly solved the whole problem of sanitary ventilation directly in the theater auditorium itself by providing throughout the whole upper half or two thirds of the theater auditorium and the accessory rooms, reservoirs of air as relatively free of disease-producing bacteria as is the outdoor air brought into the theater by mechanical means. Recently available air-sampling techniques[1, 2] have demonstrated that in any occupied theater auditorium properly equipped with germicidal lamps, the internal air circulation induced by the ventilating system and by the body heat of the patrons is such as to provide at the breathing level a sanitary ventilation from the disinfected zone above, equivalent to one to two air changes per minute or 50 to 100 air overturns per hour, in contrast with the five to ten practical by the mechanical introduction of fresh air.

To whatever extent there may be recirculation of air by the theater-heating or air-conditioning system there is a similar reason for installing germicidal lamps in the air ducts to make the recirculated air equivalent to outdoor air for sanitary ventilation. In so far as any sanitary ventilating value may be attributed to the make-up air of the usual air-conditioning system, that value can thus be increased five- to tenfold.

A detailed discussion of the unique germicidal effectiveness of the 2400- to 2800-angstrom wavelength of ultraviolet energy[3–7] is beyond the scope of this paper. Apparently, however, because the peak of the absorption curve of the nuclear protein of bacterial organisms occurs at a wavelength of about 2600 angstrom units, the resonance radiation of electrically activated mercury vapor, wavelength 2537 angstrom units, is, as has recently been pointed out by McDonald,[8] "the most lethal wavelength yet discovered. It is hundreds of times more lethal to cells than high-voltage X rays. . . ." Also Luckiesh[9] has shown the same energy to be hundreds and even thousands of times more lethal than the ultraviolet and visible radiation in direct sunlight. It is for this reason that it is possible to disinfect air with intensities and total amounts of germicidal ultraviolet entirely practical to produce and

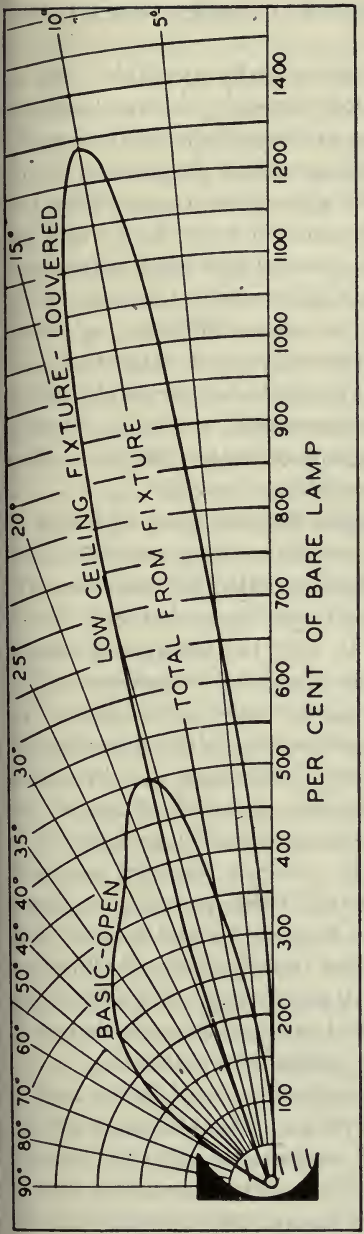

Fig. 1—Spatial ultraviolet distribution of lowered and basic open side-wall germicidal fixtures.

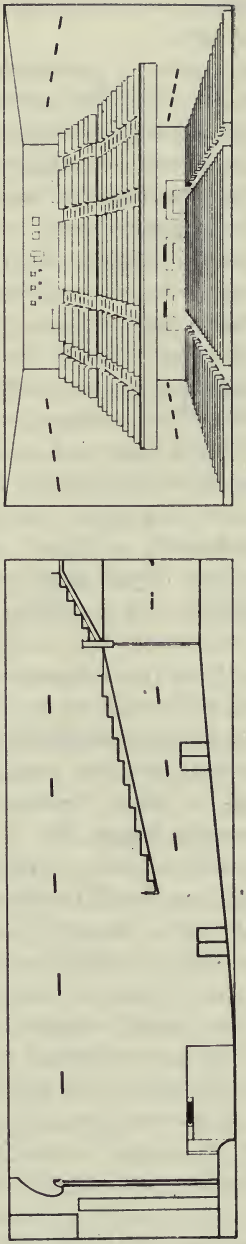

Fig. 2—Schematic of germicidal fixtures in a balcony-type theater.

distribute in occupied places without risk or inconvenience to the occupants.

A variety of germicidal lamps is commercially available. All of them are basically low-temperature, low-pressure, electric-discharge lamps containing mercury vapor. They are electrically and physically identical with or similar to corresponding tubular fluorescent lamps except that they are made with special glass tubes transmitting the 2537-angstrom energy with about the same efficiency with which, in fluorescent lamps, phosphor powders convert this same ultraviolet energy to longer wavelengths of visible light readily transmitted by ordinary glass tubing. The energy-conversion efficiency of these lamps is such that of the total electrical-energy input to the tube and ballasting device from 10 to 20 per cent is emitted as germicidal ultraviolet. For example, a typical commercially available 30-watt germicidal lamp and its ballast taking approximately 40 watts electrical input will produce 7 watts of germicidal ultraviolet.

An even greater variety of germicidal fixtures than of lamps is commercially available. All of them provide for the proper electrical operation of the lamp and, except when intended for duct use, are equipped with enclosing reflectors, and sometimes louvers. Such fixtures should be carefully designed to keep the ultraviolet energy away from the occupants of a room and to prevent its ineffective dissipation through short distances to near-by walls and ceilings. In meeting such specifications these fixtures become ultraviolet-energy-projecting devices providing a fanlike distribution of ultraviolet energy in planes inclined 10 to 20 degrees above the level of the germicidal lamps, Fig. 1. Since such fixtures may vary greatly in their effectiveness, depending upon the reflector contours and material, they should be chosen with care to suit their operating locations. Of the total ultraviolet output of the bare germicidal lamps, such fixtures may emit 25 to 50 per cent giving them an over-all efficiency in terms of the electrical input of 5 to 10 per cent, over-all efficiencies still considerably higher than are secured with incandescent lamps in spotlighting equipment of comparable optical characteristics.

Air disinfection in the auditoria, the accessory small rooms, and in the air ducts of theaters, can be done with germicidal lamps in accord with theoretical investigations[10] and engineering interpretations[11] backed by considerable practical experience in medium-sized rooms. The theater auditoria provide, however, unique opportunities to take advantage of the fact that, because the air absorption of germicidal ultraviolet is negligible, the effectiveness of germicidal lamps goes up linearly with the room dimensions.

The installation of germicidal lamps in the motion picture theater presents two problems not encountered in hospitals, schoolrooms, offices, or even the theater presenting stage shows. These problems result from the fact that along with the ultraviolet from germicidal lamps there go, inseparably, 3 or 4 lumens of visible blue light per watt of tube input which, aided by the Purkinje effect in a darkened theater, becomes visible to an extent out of all proportion to the lamp-tube brightness or the illuminated walls and ceilings.

The general auditorium- or balcony-installation practice is to place the germicidal fixtures as low as possible on the side walls in or slightly above a plane passing from the head level of standing patrons in the back of the auditorum or balcony to the top of the projection screen. With properly designed and sometimes louvered fixtures, such a placement will keep the germicidal lamps themselves out of sight of anyone in either the auditorium or balcony, although this results in rather high placement of fixtures over the front balcony in the older type of theaters with high balconies over a shallow auditorium. The usual low-ceiling-room practice can prevail in the portion of the auditorium under the balcony.

The problem of blue light reflected down into the auditorium and down onto the projection screen from the ceiling and side wall is not so easily solved. In theaters where an unusually dark auditorium is maintained during projection, light from the germicidal lamps scattered from the side walls and ceiling may be objectionable, especially during the projection of Technicolor pictures. This problem results primarily from the light reflectance of the ceiling and side walls but is also dependent upon the ultraviolet and light-distribution characteristics of the fixtures used. Although all ultraviolet and light from the fixture eventually must reach the ceiling and side walls somewhere, the light is much less objectionable on the side walls than on the ceiling; for this reason, in theaters with light-colored walls or lower-than-usual ceilings, or with a high balcony necessitating placing the fixtures relatively near the ceiling, only louvered low-ceiling-type fixtures of the spatial distribution shown in Fig. 2 should be used. In theaters without a balcony, and especially those with side walls and ceilings of light reflectances less than 25 per cent, the basic open type of generally available fixture usually can be used.

In this connection it should be noted that in those theaters providing sufficient illumination of the projection-screen surroundings to reduce contrast glare, in accord with recent good illumination practice, the problem of blue light scattered to the screen may not exist. Even with rather highly reflective ceilings and side walls, the total lumens of light in the theater is only that usually provided by the stand-by illumination in theaters where patrons may find their seats without the assistance of aisle lights or flashlamps. When the installation of germicidal lamps is anticipated in a theater design or decoration, the apparent amount of blue light can be almost completely controlled by the choice of wall and ceiling treatment, generally for reflectances of less than 25 per cent.

Since the blue light from germicidal lamps is accompanied by about the same amount of energy in the near ultraviolet, of the wavelength frequently used in theaters for the fluorescent activation of carpets and decorative wall treatments, there are unexplored possibilities of using fluorescent wall treatments to replace relatively high reflectance of visible light with very low-level fluorescence by the near ultraviolet to produce just visible decorative patterns without objectionable reradiated or reflected energy to the projection screen.

Fortunately, there can be considerable freedom of choice as to the location of germicidal fixtures on the theater side walls as nonuniformity of ultraviolet distribution in space is amply offset by the random circulation of the air during the process of disinfection. Every effort should be made to fit the germicidal lamp into the architectural and decorative features of its surroundings even to the extent of enclosing stock fixtures in custom-made enclosures. It is often very difficult to adapt germicidal fixtures to the conventional architecture of older theaters but, fortunately, many fixture designs are adaptable to the modern treatments of theater interiors.

Since the ozone-producing ultraviolet from germicidal lamps is completely absorbed by a few inches of air, the small amount of ozone they produce does not increase with the room dimensions as does the air-disinfecting action of the unabsorbed germicidal ultraviolet. For this reason ozone is not likely even to be detectable in a ventilated theater nor at all objectionable for such an installation as has been suggested for accessory rooms.

Experience indicates that a normal germicidal-lamp installation is of value for odor control in the theater. The effect is easily observed but difficult to measure. The ultraviolet may promote the oxidation of odorous substances, usually of an unstable chemical nature anyhow, either directly or by way of the very active form of oxygen present in the air from the formation and decomposition of ozone. The ozone itself also doubtless has a desensitizing action on the nose analogous to the effect of certain sound and light waves, or of certain flavors on the corresponding senses. It is interesting to note that this odor suppression seems to be effective under conditions where the ozone itself is barely if at all detectable.

Manufacturers of fixtures suitable for theater use provide installation tables based upon the room dimensions and ceiling heights, although few such tables are extended to the dimensions of theater auditoria. Table I is an attempt to consolidate in a single relatively

TABLE I

NUMBER OF 30-WATT LAMPS FOR 99 PER CENT UPPER-AIR DISINFECTION (BASED ON 6.5 ULTRAVIOLET WATTS OUTPUT AT 100 HOURS)

	Average Room Dimensions	12–23	24–35	36–47	48–61	62–73	74–85	86–97
	Over 25	. .	1	2–3	4–5	6–7	8–9	10–11
	15	. .	1	2–3	4–5	7–8	9–11	12–13
Fixture to Ceiling, Feet	10	1	1–2	3–4	5–6	8–9	11–13	15–16
	7	1	2–3	4–5	7–8	10–12	15–18	21–24
	5	1	2–4	5–7	9–11	14–18	21–25	29–33
	4	1–2	3–5	7–10	13–16	20–25	29–34	39–44
	3	2–3	4–6	9–14	19–23	28–34	39–45	51–57

compact form a recommendation based on the most commonly used germicidal lamp, the so-called hot-cathode 30-watt type. By "Average Dimension" is meant a figure obtained by dividing by two the sum of the length and breadth of the volume under consideration. The theater with a balcony should be broken up into three areas, the front auditorium, the auditorium under the balcony, and the area above the balcony. In such a large theater, the increased effectiveness of fixtures in the larger-dimensioned front auditorium is fully offset by greatly decreased effectiveness under and over the balcony. It is also important to note that under and over the balcony only louvered fixtures should be used and but one half as many as are specified by Table I to secure a theoretical upper-air disinfection of 90 instead of 99 per cent. Only an exceptionally dark treatment of the ceilings over these areas will permit the use of the full number of lamps specified by the table.

The simplest case of the theater or auditorum is that without a balcony, with dimensions of about 70 by 100 feet, and with a 30- to 40-foot ceiling height. A seating capacity of 1000 may be considered representative of such a theater. The average dimension of 85 feet and the possibility of a 20- to 30-foot fixture-to-ceiling distance indicates, Table I, the need of a total of 8 to 10 units (depending upon the type) to provide a 99 per cent theoretical upper-air disinfection. This is provision for a lower-air disinfection at a rate equivalent to about 100 air changes per hour.

In the case of a theater with a balcony the calculation should be broken up into three parts, the open space above the front orchestra section, the orchestra area under the balcony, and the space over the balcony. A typical larger theater with balcony and seating about 2000 people would have an orchestra area about 90 feet wide and 90 feet deep, one half of it being under a balcony, 90 feet wide and about 60 feet deep. The ceiling height over the front orchestra would be about 50 feet, over the back orchestra 12 to 18 feet, and over the sloping balcony 25 to 10 feet.

Table I calls for 6 to 8 lamps for an average room dimension of 65 to 70 feet and a fixture-to-ceiling distance of over 15 feet, but for the same area under the balcony, with an average fixture-to-ceiling distance of 7 feet, one half the listing of Table I for accessory rooms or 5 to 7 units should be used. Similarly, for the area above the balcony, with an average dimension of 75 feet and an average fixture-to-ceiling distance of 10 feet, 6 to 8 units would be needed. The total lamp requirement for the seating area of the theater thus would be about 20, or one 30-watt lamp for 100 patrons.

Small accessory lounging rooms and wash rooms with low ceilings may be handled in accord with the lower left of Table I.

To make the recirculated air carried by the theater-ventilating and -heating duct system equivalent to outdoor air for sanitary ventilation, the same germicidal lamps used for upper-air installation may be installed directly in the ducts, but the number required is not so easily determined as for the upper air of the room because of the high and variable air speed and the great variations in duct shapes.

For ducts whose greater dimension does not exceed the lesser by more than 50 per cent, and with nonreflecting walls, the maximum lamp requirements for a 99 per cent disinfection may be read from Table II. If the cubic feet per minute of air flow is not known it may be calculated as the product of the duct cross section, in square feet, and the air speed in feet per minute.

Note in the following table that the cubic-feet-per-minute figures in the body of the table are directly proportional to both the number of lamps and the lesser dimension of the duct so that the tables may be expanded indefinitely by direct proportion and by lamp addition. For example, the requirement in 30-watt lamps for 220,000 cubic feet per minute of air carred by a 120- × 150-inch duct would be 10 times

TABLE II

GERMICIDAL-LAMP REQUIREMENTS FOR 99 PER CENT DISINFECTION OF DRY AIR IN NONREFLECTIVE CIRCULAR OR NEARLY SQUARE DUCTS, CUBIC FEET PER MINUTE

Lesser Dimension, D Inches	Number of 30-Watt Germicidal Lamps: 1	2	3	4	5	6	7
5	100	200	..	..	..	..	..
6	120	240	360	..	..	..	..
7	140	280	420	560	..	..	..
8	160	320	480	640	800	..	..
9	180	360	540	720	900	1,080	..
10	200	400	600	800	1,000	1,200	1,400
11	220	440	660	880	1,100	1,320	1,540
12	240	480	720	960	1,200	1,440	1,680
13	260	520	780	1,040	1,300	1,560	1,820
14	280	560	840	1,120	1,400	1,680	1,960
15	300	600	900	1,200	1,500	1,800	2,100

Lesser Dimension, D Inches	Number of 30-Watt Germicidal Lamps: 7	8	9	10	20	30	40
20	2,800	3,200	3,600	4,000	..	..	..
25	3,500	4,000	4,500	5,000	..	..	..
30	4,200	4,800	5,400	6,000	12,000	..	..
35	4,900	5,600	6,300	7,000	14,000	..	..
40	5,600	6,400	7,200	8,000	16,000	..	..
45	6,300	7,200	8,100	9,000	18,000	27,000	..
50	7,000	8,000	9,000	10,000	20,000	30,000	..
55	7,700	8,800	9,900	11,000	22,000	33,000	..
60	8,400	9,600	10,800	12,000	24,000	36,000	48,000
65	9,100	10,400	11,700	13,000	26,000	39,000	52,000
70	9,800	11,200	12,600	14,000	28,000	42,000	56,000
75	10,500	12,000	13,500	15,000	30,000	45,000	60,000
80	11,200	12,800	14,440	16,000	32,000	48,000	64,000

The above duct ratings are for a duct-air temperature of about 85 degrees Fahrenheit. These ratings should be decreased 10 per cent for temperatures of either 75 or 100 degrees Fahrenheit, by 20 per cent for 65 or 115 degrees Fahrenheit, and by 30 per cent for 60 or 125 degrees Fahrenheit.

the 9 lamps required for 10,800 cubic feet per minute in a 60-inch duct, or 90 lamps.

For a 95 per cent disinfection but seven tenths the above number of lamps may be used, for 90 per cent one half, and for a 70 per cent disinfection only one quarter as many. Installations to deal with bacteria that have been exposed to a relative humidity greater than 60 per cent and to deal with fungi require many more lamps than are called for in the preceding tables and should be treated as special cases for which engineering data are available elsewhere.

In the frequent case of flat ducts having one dimension two or more times as great as the other there should be reference to more detailed methods of calculation available elsewhere but the maximum lamp requirements may still be determined from the preceding tables by subdividing the duct, and the air capacity, so that the dimensions of the subdivisions fall within the range of the tables. For example, a 2- × 9-foot duct carrying 9000 cubic feet per minute should be treated as 3 ducts each 2 × 3 feet and carrying 3000 cubic feet per minute. The tables call for a maximum of eighteen 30-watt lamps, but if the duct is calculated as a whole by a more adequate method the number is reduced to 15 lamps.

The mechanical details of a germicidal-lamp installation follow closely those of the dust-filter installation and it is anticipated that manufacturers will provide similar standard-unit assemblies. Although there are many ways of installing germicidal lamps in air ducts, the best compromise on the mechanical and radiation factors calls for placing them lengthwise on the duct wall, on 4- to 5-inch centers grouped in the center half of the duct walls and out of the corners of rectangular ducts. The duct walls near the lamps and the duct width in both directions from them should be of polished chromium plate or aluminum if the conditions are such that the reflective duct walls can be easily cleaned whenever the lamps are cleaned. Standard wiring-channel strips, such as are used with the corresponding fluorescent lamps, may be attached to the outside walls of the duct with the lamp sockets projecting through holes in the duct walls and the reflector lining. Two-lamp assemblies using high-power-factor ballasts and moistureproof lampholders, especially designed for this type of installation are commercially available.

Since the germicidal lamps must be kept reasonably free of dust, there must be convenient access for cleaning. This usually can be arranged by hinged panels on the sides or the bottom of the duct, and, if necessary, the lamp may also be mounted on these panels as well as on the stationary duct walls, Figs. 3A and C. Where the mechanical conditions demand it, the lamps may, of course, be installed end to end along the duct. In any case, the reflector lining should be used on all walls of the duct and should extend beyond the ends of the lamps a

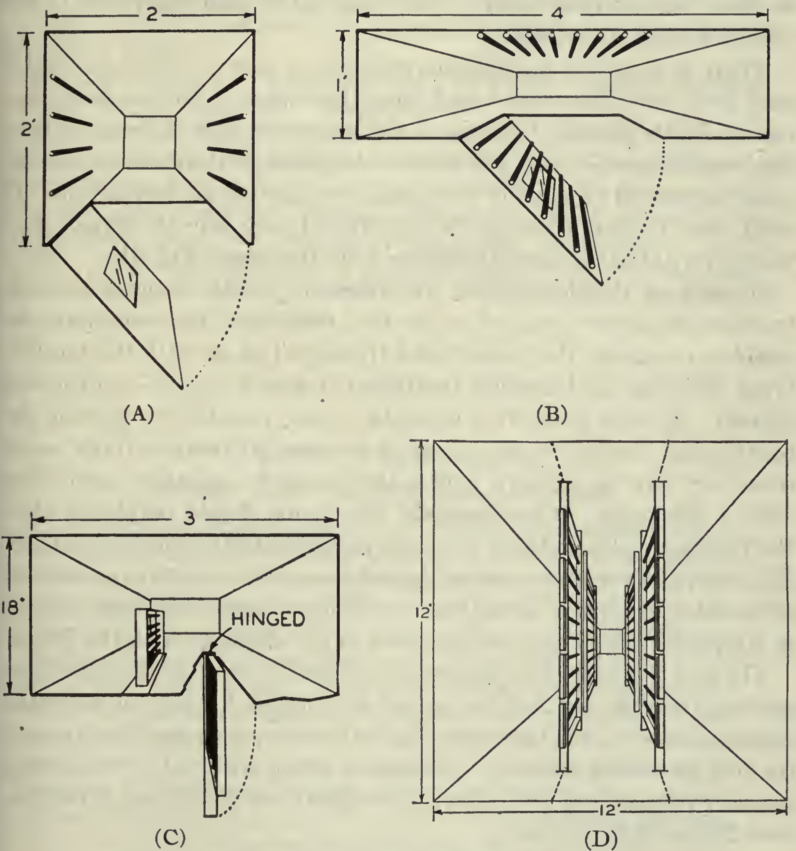

Fig. 3—Schematic of germicidal lamps in ducts.

distance twice that to the opposite side of the duct. If chromium-plated sheet steel is not available aluminum-foil-surfaced building paper or board, or certain special aluminum paints may be used as substitutes.

In large ducts and plenum chambers germicidal lamps may be assembled like the rungs of a ladder in vertical frames supported out in the center of the chamber in whatever series or multiple arrangement best fits the local conditions and provides access for cleaning and replacement, Fig. 3D. In very large ducts, where the air speeds are relatively low, the lamps should be so placed, when possible, as to provide a maximum average distance from the lamps to the duct walls in directions perpendicular to the lamp tubes, and regardless of the direction of air movement.

There is a special installation problem in case of flat ducts which may have one dimension 4 to 6 times the other. Such a duct cross section limits the effectiveness of the lamps not only in proportion to the lesser dimension but also because but little of the duct volume beyond the actual location of the lamps is useful for air irradiation. In such cases the lamps should be distributed only over the longer duct walls to within the lesser dimension from the edges, Fig. 3B.

In spite of the desirability, for efficiency, of the longest possible travel of the ultraviolet before the first reflection, it is sometimes desirable to combine the bactericidal treatment of air with the humidifying, filtering, and heating treatment it gets in an air-conditioning system. In such cases, it is desirable, when possible, to provide the bactericidal treatment at a point of average air temperatures, away from very hot air or very cold make-up air to maintain germicidal output efficiency. When possible, the lamps should be placed after the filtering which reduces the lamp cleaning, but before the humidification which tends to increase the tolerance of bacteria for germicidal ultraviolet and may, in extreme conditions, cause electrical trouble in lampholders and starters mounted in the chamber with the lamps.

The fact that statistical evidence as to health value to the individual patrons from air disinfection cannot be secured, because of the small amount of their total time spent in the theater, is obviously no reason for not providing sanitary ventilation along with other recognized sanitary precautions to reduce the possibility of the spread of respiratory disease in the theater.

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FORTY YEARS AGO

Moving Picture Operators Dread the Summer

Moving picture machine operators dread the approaching hot weather. Already they have experienced some of the discomforts that the Summer will bring. When the temperature commences to remind one of the good old Summer time and the mercury starts to climb, the stuffy little picture booths become so hot and the air so stifling that it is almost impossible to remain in them any great length of time without going out to get a whiff of the fresh air. Even in the Winter time it is necessary to keep revolving fans constantly in motion to overcome the heat generated by the powerful rheostats. In Summer the conditions are well-nigh unbearable. Up to this Summer the machine owners adopted their own methods of constructing their booths and ventilating them. Recent State restrictions have compelled them to enclose the machines in asbestos fireproof booths of certain dimensions, and these are like sweatboxes while the carbons are burning, the heat from them and the rheostats being intense.

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

Service and Maintenance of Air-Conditioning Systems*

By W. B. COTT

Westinghouse Electric Corporation, New York 17, New York

Summary—Because of shortages of raw material and parts in the air-conditioning and refrigeration field, it is necessary that theater owners maintain and place in operation and service the apparatus already installed.

The older type refrigeration cycle installed prior to the development of the Freon refrigerants and the more modern refrigeration cycle is designed by the manufacturer and engineered by the installer to operate under exacting conditions and must be kept in clean, lubricated, and effective operating condition for satisfactory operation.

The product of the manufacturer of air-conditioning apparatus, such as refrigeration compressors, condensers, water-saving devices, dehumidifiers, coils, heating elements, fans, motors, switches and starters, thermostats, and diffusers, is a result of painstaking research and diligent effort to produce a lower-cost product that can be marketed in a highly competitive business.

These products are assembled by an installer or contractor together with ducts, wiring, insulation, and piping, for a purchaser into an installed air-conditioning system. The reliable installer will design an air-conditioning system for low maintenance costs taking into consideration motor horsepower required, hours of operation, cost per kilowatt-hour, lubricants required, paint, accessibility of service valves and switches, worn parts replacement, and countless other factors. The final picture presented to the buyer by the reliable installer is the total cost in dollars out of pocket to the owner over a given period of time. Low first cost is not always the cheapest in the over-all picture.

Check the layout of your equipment room to see that a maintenance man will have sufficient room to check and lubricate apparatus.

* Presented October 24, 1947, at the SMPE Convention in New York.

Lubrication points, valves, and gauge parts that are not accessible are seldom checked. The best of mechanical equipment breaks down occasionally or must be overhauled and ample room will result in a faster, better repair job with resultant low cost and the system placed in operation quicker.

An air-conditioning system in a theater represents a sizable investment to the purchaser and replacement of apparatus is high in equipment cost and delay involved in procuring parts together with qualified installation labor. The owner of an air-conditioning system must arrange service and maintenance of his plant to assist in preventing breakdowns that result from lack of attention to the entire air-conditioning system including a check of the system for Freon leaks, particularly at the compressor seal, inspection and cleaning of drains, the inspection and adjustment of all belts, safety controls and temperature-regulation devices, and the cleaning and adjusting of all water valves, sprays, pumps, starters, and gauges, the lubrication of motors and bearings, the cleaning or replacement of air filters, and the adjustment of dampers. Prompt replacement of worn parts is imperative in view of required operation of a plant and the annoyance attendant to a shutdown with loss of business. Periodic service and maintenance checks will enable you to keep a full charge of refrigerant in your plant and will locate leaks which may result in expensive repairs, loose fan belts or sheaves, and dirty filters that result in inefficient operation. Regular checks may reveal other defects prior to serious trouble.

Various engineering societies and trade associations and all manufacturers of this apparatus have drawn up service and maintenance-check charts with accompanying reports and varicolored or marked tags of plates to be attached to various check points to assist in checking and servicing apparatus. They have also prepared simple service and maintenance contracts for use in the trade. It is strongly urged that you contact the manufacturer, or his representative, of your refrigeration machinery and request his advice and recommendations regarding competent service and maintenance people and institute a periodic service and maintenance program. You will have many more hours of operation with less over-all expense in following the recommendations of the manufacturer and his accredited representative who can supply factory parts and lubricants and who receive manufacturers' bulletins on products.

Average costs of maintenance and service contracts, on a yearly basis, have been 19 to 27 cents per seat, dependent, of course, on the amount of equipment involved and the length of travel to the job.

Theater Engineering Conference

Ventilating and Air Conditioning

Note: For the Theater Engineering Session on Ventilating and Air Conditioning, Chairman Seider requested that all discussion be held until after the delivery of the last paper in the group. The material which follows, therefore, is in the nature of a panel discussion and deals with all four papers in this particular section.

Discussion

Mr. Hubert: Mr. Kimball spoke about return diffusion wells in cooling systems to get rid of the water. At Lowell we found out that when we returned the water to the ground, depending, of course, upon the volume of water and the size of the return well, the well is effective for a period of about six months. Then it will take no more water.

The pump man surges it with acid and it commences to take water perfectly again. It lasts for three months this time. The next acid treatment lasts for about six weeks. About the fourth time, it is effective for about a day.

Is there any way that you have had success in returning water to the well? The reason we are interested in it is because the city has imposed a sewer charge on us; in other words, if you put water into your theater, then they charge you 50 per cent of your water bill as a sewer charge. In the case where you are using well water, they meter the well and if you use 600 gallons a minute, they figure up what the cost would be. If you brought that water from the city, they charge you that much for a sewer charge.

If we can return that water to the ground, we would save ourselves a great deal of money, but so far we have not been able to do it. Is there any way that you can assure a successful operation of these return wells over a period of time?

Mr. Dwight D. Kimball: You must be in a district where you have a peculiar subsoil condition. There is in New York State a limited area, largely around Long Island, where the State Conservation Commisssion requires return of water. I have had return diffusion wells that have been used for years without such trouble. Once in a great while you get a condition where you have to surge a well, but it stands up for quite some time after that.

I do not know what your problem could be, but you certainly must be in a strict area where you get these charges, because you can drill all the wells you want to, if you get permission of the State Conservation Commission and abide by their rules, but you do not pay any water rate.

Mr. Hubert: As I understand it, the City spent about $150,000 in one year on municipal sewers. Under this new arrangement, they are going to collect about $2,500,000 a year on the water charge.

However, our wells there are gravel wells. In most cases, the gravel is a mixture of anywhere from half an inch up to about two inches in diameter. The reason they started these return wells is that during the war the rubber companies, and similar plants, used an immense amount of water. They were using about 75,000,000 gallons a day in the war industries. Naturally, the recovery is about

50,000,000 gallons a day. So they made them put the water in the ground, because they could not keep the water table up; but they ran into trouble on the wells and the wells would not take it.

We were formerly using 800 gallons a minute in our cooling system, when it was a street-water job. We have now installed refrigeration, and we have four theaters there. Two hundred a minute is the smallest and about 450 is the largest.

MR. W. B. COTT: We found in our experience, particularly in our own plant, that if you alternate the use of waste wells, you will prevent the silting up of the gravel there. Louisville has a very low water table. There is a range of hills back of Louisville that lowers the water table; and as you get down to the flat of the river, alternate the use of the wells. As an example, we are drilling one well to put the water in now. Another well to put the water, in fifty to sixty days, helps considerably there. The wells have not been silting up so fast as they have been in the past.

It might be well for you to examine the possibility, with your well contractor, of drilling additional wells for their disposal; that is, alternate the use of wells, one in this period of time and the other in the next period of time.

MR. HUBERT: We have never tried that. The Deal Pump and Supply Company near Louisville used to drill quite a few of those wells, and now they have given up the idea of drilling return wells for the people, because everything has been tried to keep them from liming up, but they always do, except for a short-term operation where you want to use it for six months, then it is all right and they will drill a return well. However, if you have the idea of using it over a period of time, it is a waste of money. The liming process takes place over quite a large area, and forms a large cone there. When you surge it, you just push this liming process away from the well. Then it limes up to the well again. When you treat it again, it pushes it farther. Eventually, it gets so limed up that you cannot push it out, and that is why the well quits altogether.

If you drill two or three wells and alternate them as you suggest, would not that be a case of prolonging the process until your wells lime up again?

MR. COTT: I do not think so. The various whiskey distilleries there return their condenser water and the processed water to alternate wells.

MR. PHELAN: Mr. Kimball, I was impressed by your costs on filters, but, in mentioning a throwaway-type filter costing $500, that is only the initial cost.

MR. KIMBALL: Yes.

MR. PHELAN: Do you not think that we should consider what they will cost over a period of time in comparison to the electric filter, where the operating cost only amounts to what an electric light bulb would use?

MR. KIMBALL: The difficulty is that most theater people want to make their investment returnable in matters of replacing material on a basis of something like four to six years, and you do not come out even on that basis. If you can do it over a longer period of years, you have a saving in favor of the electrical. However, they look too much not alone on this, but on their investment costs.

MR. PHELAN: When you enter into the cleaning costs, the drapery costs, and so forth, I think that that would pull down the over-all cost on them, too.

MR. KIMBALL: It is pretty hard to get a theater man to take that into account. I venture to say here in the Times Square district, you can go to theater after theater and most of them have not been redecorated since they were built.

MR. ROBERT LEWIS: Dr. Buttolph, I have been using ultraviolet disinfecting lamps for some time. I have observed two factors. First, the reflectors on these lamps, apparently, by virtue of their being pointed upward, act as sort of a catch-all for dead bugs, silting, and other things. Second, apparently, there is a degeneration of the glass envelope, either by bombardment at the end or by a general glass degeneration.

I am well aware that you are required to have decent reflector performance, but the thing which struck us as peculiar was that it appeared to us after a period of not more than a day or so, that these small dusty positions on the reflectors appeared fluorescent. We wondered if you have any figures on that type of problem and efficiency, and, second, what is the average life you should expect from glass envelopes.

DR. L. J. BUTTOLPH: The germicidal lamps themselves depreciate very rapidly the first few hours and the first day of operation. As a matter of fact, they are officially rated after 100 hours of operation, to offset that to some extent. After that, they depreciate about the way fluorescent lamps do.

The problem of collection of dirt on the reflectors is exactly the problem you have with lighting fixtures. If the installation has been engineered with an adequate factor of safety, that is not too serious a matter, however; but it is important that you originally specify two or three times as much germicidal ultraviolet as is really necessary, just to take care of those variations.

MR. LEWIS: Perhaps I did not make the question quite so precise as I should. It was our observation that the effectiveness of the reflector was zero after a day.

DR. BUTTOLPH: No, it is not that bad. We have measured many of them. The ordinary dust that settles on the reflector acts as a neutral filter between the particles. You can get dust absorption up to 25 or 50 per cent, but your installation should take care of that. Again, it is the same problem that you have with an installation for illumination.

MR. LEWIS: I believe that ultraviolet of that wavelength is not the same problem as illumination. Otherwise, I think it is an answer.

MR. ALBERT STETSON: Mr. Cott commented on the fact that the cost of service had been accelerated upward. He said that it was now running from 23 to 27 cents. I believe he means 23 to 27 cents per seat per year.

MR. COTT: That is correct.

MR. M. D. KICZALES: Mr. Cott mentioned the use of ammonia refrigerant in air-conditioning systems. I am curious to know what states permit the use of ammonia in air-conditioning systems.

MR. COTT: There are quite a few ammonia systems installed; in fact, I can take you within seven blocks of the hotel you are in, and show you four.

MR. KIMBALL: In places of public assembly?

MR. COTT: Yes, sir, in old equipment. They are carefully trapped and they are carefully watched by the City of New York. There are several theater installations using ammonia in Chicago and several in New Orleans. However, we have been trying to sell those people replacement equipment in the past. It may amaze you to know that there are six installations within the city limits of Manhattan, using methyl chloride, which is highly poisonous and highly dangerous. As a matter of fact, it is equipment that we as a manufacturer have a responsibility for now, because we purchased the company that made the methyl chloride.

MR. KICZALES: We agree that present codes in practically all states of the Union do not permit the use of ammonia.

MR. COTT: That is true on new installations, but there are existing installations using those poisonous refrigerants. Under the new codes the use of ammonia refrigerants is not permitted.

MR. KICZALES: Mr. Kimball, this afternoon we had quite a session on acoustics and the prevention of noise in the systems. Particularly, some recommendations were made to prevent the transmission of noise from air-conditioning equipment. One of the speakers recommended certain limitations in the design of air-conditioning systems primarily, saying that the air-supply ducts should be set at 500 feet per minute, and the recirculating grill should be set at 250 feet per minute, in order to be safe and remain within the 35-decibel allowance for the theater.

MR. KIMBALL: Those are, economically or from an engineering standpoint, rather absurd limits, because I do not know of any jobs installed with those very low velocities. If you take a large 1000-seat theater, particularly under the present rate, we could not get space in the building in many cases. However, I have used 1200, in some cases 1400 feet, for years without trouble; that is, in the main larger ducts. You get smaller ducts, of course, but we have no trouble if the duct work is substantially designed and built.

MR. KICZALES: I made a recommendation like that this afternoon, and it seemed that certain architects and engineers did not hold to that stand, when I mentioned that we were using 1200- to 1400-foot velocity starting at the fan, and reducing as we go along down to the outlet. It went as far as 600 feet per minute at the outlet itself, and we wanted to design 400 to 450 at the recirculating grills.

Mr. Kimball mentioned extending the air-supply duct into the lobbies in order to prevent a back draft from the opening of doors into the theater. I have very successfully made use of a concealed unit heater with a recirculating grill at the bottom, and filtering the air across the lobby entrance with proper controls at the ceiling and at the floor to give a proper temperature. That would heat the air before it moved down the lobby into the rear of the theater.

MR. KIMBALL: That is perfectly possible, but it lacks one advantage. If you install it as I suggest, you not only get heat in the winter, but you get air conditioning into the lobby in the summer.

MR. KICZALES: With the air-conditioning system in the summer time, you can do with a lower air temperature in the lobby as it usually, passsing through, is more or less a cooling-off chamber to prepare you for the lower temperature in the theater proper. We use more or less the exhaust system from the lobby and pass it on through; I mean, from the auditorium to the theater and then on out. That is the air you have to throw away normally.

MR. KIMBALL: In the case of ultraviolet treatment, where in the theater would you place your lamp to meet the approval of the architect? Second, what would be the approximate cost of such a treatment, say, in a 1000-seat theater?

DR. BUTTOLPH: In the old theaters, it is almost impossible to find any place that would satisfy even the architect who designed it, to say nothing of the modern ones. Fortunately, the modern theater designs are rather adaptable. We have one or two installations where they are perfectly adaptable. They are horizontal wall treatments into which fixtures can be recessed, to be practically unnoticeable.

The installation cost runs about $1.00 per seat. The lamp replacement cost is about 10 cents per seat. That cost does not include the maintenance, which can be thrown in with the maintenance of the illumination of the place, because there is just the matter of dusting up whenever they clean up the theater.

MR. KIMBALL: I have had two occasions within the last two years of giving the theater a designed air-conditioning system, and the architect gave me the pronouncement that there should be no opening outlets in the ceiling or walls. If he will not permit air outlets, how will he allow those light outlets?

DR. BUTTOLPH: That light outlet is a horizontal slot only about 6 or 7 inches high, at the most, and 3 feet long per unit. So it is not too conspicuous. It should be broken up by horizontal black louvers, and thereby mask the reflectors. So, it can be designed into a new place rather easily.

MR. KIMBALL: The great problem in a theater is this: In a filled auditorium, you do not like sitting next to somebody who is coughing violently and sneezing. Will that ultraviolet treatment take care of such a condition?

DR. BUTTOLPH: No, particularly not the psychology of that particular situation. Glycol will handle that particular job, at least the psychology of it. I do not know whether it works fast enough to catch the drop in its foot of travel.

MR. J. W. SPISELMAN: Dr. Robertson and his associates have recently published a paper in which they actually, by advanced methods of collecting air samples, have tested the exact killing rate. What they found was that the kill was so rapid within the first second that they could take their first air sample and see that at least 80 to 85 per cent of the kill had been completed. That is within the first second of the injection of droplets simulating that of a sneeze or a cough. Within the second second, another 50 per cent of the remaining 15 per cent will be killed. At the end of the third second, they were down to virtually a zero count as far as the bacteria injected into the chamber was concerned.

Other evidence, such as the direct spray into hospital wards, which I had mentioned before, and into cages with mice and into other guinea-pig tests, has indicated that the glycol reaction is an extremely rapid one.

I might point out that glycol has been used for years as a dehumidifying agent in massive absorbers; in other words, in much the same way that lithium chloride is used, the same way that silica jel is used. Triethylene glycol has been used as a chemical humectant, in a dehumidifying agent.

In some installations, air flowing at the rate of 500 feet per minute over a distance of only some 2 feet, we can almost calculate how rapidly it is dehumidified. Air has been dehumidified from, let us say, 60 to 70 per cent humidity down to 25, indicating a very rapid absorption of water.

Conversely, the argument is that at that same rate of speed a moist particle will pick up glycol, indicating that the actual pickup of glycol must be an extremely rapid affair; and once the concentration has been formed on the bacterial particle, death will take place.

MR. KIMBALL: How quickly?

MR. SPISELMAN: As quickly as medical men have been able to pick up an air sample. In this one particular piece of work, they feel that they picked it up within one half of one second, which is the first one that they want. At that time there was between 75 and 80 per cent of kill; in other words, they had that much less than they had sprayed in. I have heard that when ultraviolet kills germs, it will kill them just as quickly.

DR. BUTTOLPH: We think that the sneeze has been entirely overrated as a spreader of disease. The probability that an adjacent person actually will be able to inhale any considerable number of organisms from a particular sneeze is surprisingly remote. The rate of diffusion even in a foot or two, is rapid. In general, the inhalation is not so timed with the sneeze as to gather much of the contamination. It is largely a psychological problem.

MR. KIMBALL: I was going to say you have a psychological problem, and you have confirmed it.

MR. KICZALES: The American Society of Heating and Ventilating Engineers has always felt that the determination as to what germs are really effective and detrimental in air-conditioning systems, was up to the medical profession itself and not up to mechanical engineers. I believe at the last meeting held about a year ago at Cleveland, there were some talks presented about the use of germ-killing means in air-conditioning systems, and no definite conclusion was reached as to whether they were needed or not, even in large air-conditioning systems.

However, in my opinion, since we are talking about theaters in this particular meeting, where you are being exposed to germs for about two hours, I doubt whether there is any need for any germ-killing means in an air-conditioning system in a theater. From my small knowledge of the medical profession and germs, we find that there are germs in the air, but they are not all disease germs; that they will not attack the body. You can put a glass of water or a little globule of water under a microscope and you will find it crawling with germs, but it is still considered pure water. They do not kill. They do not cause disease. I wonder how many germs there are in an air-conditioning system that do spread disease; whether it is economically sound to put in some kind of germ-killing apparatus.

DR. BUTTOLPH: The Society of Heating and Ventilating Engineers, through one of its committees on air disinfection and the Research Laboratory in Cleveland, is working on some research projects for the Society itself. It recognizes bacteria as one of the real contaminants of air, along with body odor and dust. There is no question about the recognition. Both the Society of Bacteriologists and the American Medical Association recognize that there is a problem. The Council of the American Medical Association has a setup by which it examines equipment for air disinfection. That does not happen to be on air ducts, but it does read on the need for air disinfection.

MR. SPISELMAN: It has been part of the work that I have done, although I am an engineer. I have set out dishes and I have collected some of these plates that show the amount of bacteria and germs that are in the air. I was interested in it, very much the same along the lines that your were, and I had a few medical men, bacteriologists, examine the plates. I was really amazed at the number of pathogens that will fly around in the air.

I have asked the same question: Just why doesn't it affect all of us? Quite often, the answer is that there is a certain threshold level to which you can withstand the bacteria and the pathogens. Beyond that threshold level, which is determined by the concentration of those bacteria in the air, they start working on the various people, on some more than on others.

Moreover, in a recent issue of *Science Newsletter*, I read that the cold virus is particularly bad in that one respect: By the time you know you have gotten the cold, it has been in your body for a long time and has incubated. As a matter of fact, they are trying to determine the rate at which a person does pick up a cold, if he is susceptible to it, and they have it down to within minutes once they have been exposed to it. That is about all I can say in reference to your question.

MR. KICZALES: Has the medical profession ever stated that the air-conditioning systems in theaters do cause disease? Have they come out point-blank and stated that they should be provided with some germ-killing apparatus? No one has yet determined that some disease is caught in a theater.

We cannot be too sure whether anyone caught the cold after he left the theater, whether the contact was made in a streetcar coming home, or on the street, or in the theater. I believe the purpose of the research being done by the American Society of Heating Engineers is to determine that. True, it is a project, but no definite determinations have been made by the committee as to what was needed.

MR. SPISELMAN: I do not know whether any public health outfit has come out and said flatly that the theaters are a hotbed of disease or anything of that nature, but time and again I have picked up papers during epidemic periods, and one of the first places that you are warned to stay away from are theaters and places of public congregation. That of itself, coming out from individual public-health servants, quite probably shows what they must have in the back of their minds as to where the probable focal points of any disease or any epidemic may start. The same thing is applied to swimming pools and to other places of public congregation. By and large, they do not leave out the moving picture houses or the theaters. They usually see to it that those are included in the statements.

MR. KICZALES: Someone should combat these statements by the public officials; that a theater owner should put in some sort of system just to advertise that he has some sterilizing equipment in his air-conditioning system.

MR. NEIL WHITE: Mr. Kimball, in the average air-conditioning installation in a theater, what is the period over which a complete air recirculation takes place?

MR. KIMBALL: It will vary to a certain extent with the density of the seating and the height of the theater; in other words, the cubic feet of space per person. However, they run around seven changes an hour on an average.

MR. WHITE: I have had a little experience with one unit of this ultraviolet lamp. I seemed to detect a change in odor in the room, and as though there had been ozone generated or some ionization had taken place.

DR. BUTTOLPH: All germicidal lamps, at least if they are built so that they are effective at all, produce minute amounts of ozone. It is a manufacturer's problem to prevent their producing too much. There is probably some odor masking due to the ozone. Other than that, germicidal ultraviolet is a remarkable photocatalyst; that is, ordinary oxidation by oxygen goes on much more rapidly in the presence of germicidal ultraviolet. Probably both those things are effective. Practically, I believe there is no effective installation of germicidal lamps where there is not a noticeable change in odor.

Recently, a number of companies started promoting the lamps purely for that purpose. They are entirely comparable with these recently advertised chemical substances for that purpose. We have chosen not to feature that, because we think that is a minor job the lamps can do in the long run. It is incidental to their more important use for air disinfection.

Display Frames in the Motion Picture Theater*

By LESTER RING

Stanley Displays, Inc., New York 18, New York

Summary—There is no need to enter upon the importance of displaying advertising in a theater. The reasons are too well known by all; but, the number of frames, type and size, are worth considering in planning the installation of display frames.

While there exists no history of the events leading to the evolution of the display frame, it may have begun with a fanfare of trumpets, followed by a courier announcing a message, meant to reach as many as possible; and when in later years we learned to read, the rescript was fastened to the side of a prominent building, thus starting the oldest form of what we know today as "billposting." There is still with us, on highways, barns, roof tops, and sides of buildings, in the form of 24 sheets and smaller sizes of lithographs, hand lettering, electric signs, and other forms of displays.

The earliest print, I have seen, of a theater with posters on each side of the entrance, was the Globe Theater in London, where plays were written and produced by Shakespeare.

Our own "Opera House" of yesterday used the three-sheet lithographed posters, 40 × 80 inches in size, pasting them to "House Boards" in front and around the theater. Such boards consisted of a wood backing with trim molding around the perimeter. Posters were pasted on over another, as each attraction played the theater.

This method was used by the first theaters showing motion pictures; and, as producers and film exchanges started renting one-sheet and three-sheet lithographs, 11- × 14-inch photographs, and similar material, with a rebate upon their return in good condition, a need was apparent for their display without pasting. Thereupon, this

* Presented October 24, 1947, at the SMPE Convention in New York.

was done by thumbtacking, and in order to protect them from embryo artists and weather, a glass door was hung in place, the forerunner of today's display frames.

The number of frames is dependent on space available, as well as the policy of the theater, whether playing single or double features, and the number of changes per week. Frames, each side of entrance to theater, are always for "NOW SHOWING." Additional frames, on the front or side of the theater, may be used for "NOW PLAYING" or "NEXT ATTRACTIONS," those in the vestibule are usually for "NEXT ATTRACTIONS," and those in lobby and foyer for "COMING." It is important that all frames be equipped to take the same layout of advertising material, so that the advertising may progress from COMING to NEXT ATTRACTION, to NOW SHOWING, without additional purchases, or having some of it left over in the manager's office. The total number of frames required for any theater cannot be worked out by formula, but from the foregoing, six frames, or two for each category, such as COMING, is the minimum.

Types of frames are usually of wood or metal; wood frames should be of hard wood, such as walnut, oak, or birch. Metal frames should be of such material as will obviate polishing, and aluminum should be anodized to prevent oxidation and pitting.

With the indirect illumination of lobby and foyers with cove lighting and pinpoint downlights, it has become necessary that display frames be illuminated from within. Contemplated theaters should make necessary provisions for this by providing recesses, and carrying electrical outlets to them. In an existing theater, if cutting recesses in the walls, or furring the walls to create room for shadow boxes is inadvisable, display frames can be built out with suitable depth, creating shadow boxes within the display frame itself.

The front or outside frames should be illuminated, even though the marquee may furnish sufficient light for readability of advertising matter; this is done to create a point of interest at all times, and especially when the marquee ceiling is not lit, as, between the time the box office closes and the break of the show. If fluorescent tubes are used for outside, they should be the low-temperature ones, to insure proper starting in cold weather.

Fluorescent lighting and cold cathode are the two best media, embodying maximum illumination with less current consumption and a minimum amount of heat. Where sufficient recess depth of shadow box is available, approximately 12 inches, incandescent lights of 150 watts set in reflectors top and bottom 9 inches on centers, are very effective. Fluorescent and cold cathode should be installed on all four sides, for an even distribution of light.

The size of frames is dependent upon policy and the number of changes for each theater. It is important, however, to use frames as large as possible, consistent with architecture and ceiling height. Frames should be a minimum of 40 × 60 inches and a maximum of 40 × 80 inches inside for the individual frame with hinging sash. One opening sliding-glass frame can be 10 to 16 feet long and 72 inches high, glass size. The latter type should have but one sliding glass to each track, to prevent chipping and breakage.

Since advertising material today is well standardized, equipment inside the frame to receive such advertising is easily arranged. Where double features are played, it is desirable to equip a frame to take advertising of both pictures. Prominence can be given to one picture with stills or 11 × 14's of the cofeature. An ideal layout is a 30- × 40-inch, date strip, cofeature title card, and two stills.

Poster exchanges and frame manufacturers will be pleased to work out sizes of frames required for various layouts. Auxiliary stand frames can be used in a prominent location, to advertise a coming attraction, a list of future coming titles, or institutional copy. In some localities, building and public-assembly bureaus frown on stand frames, classifying them as hazards.

Another type of display is the banner, or reader board; this is a frame set above the entrance doors, and is used for COMING, NEXT ATTRACTION; and when placed above the first set of doors on the street side, NOW PLAYING. Lobby banner frames may have a trough of fluorescent or cold-cathode strips, top and bottom, or both, for greater visibility. To realize the maximum from this type of frame, it is advisable to have more than one banner board to progress the material.

Society Announcements

Convention Papers

Preparations are being made for the Fall Meeting of the Society which will be held at the Statler Hotel in Washington, D. C., October 25 to 29, 1948, inclusive. Authors desiring to submit papers for presentation at this meeting are requested to obtain Author's Forms from the Vice-Chairman of the Papers Committee nearest them. The following are the names and addresses:

Joseph E. Aiken
225 Orange St., S. E.
Washington 20, D. C.

N. L. Simmons
6706 Santa Monica Blvd.
Hollywood 38, Calif.

E. S. Seeley
250 West 57th St.
New York 19, N. Y.

R. T. Van Niman
4431 West Lake St.
Chicago 24, Illinois

H. L. Walker
P. O. Drawer 279
Montreal 3, Que., Canada

Technical Societies Council Elects Officers

On May 20, 1948, the Technical Societies Council of New York held its annual meeting and election of officers. Those elected were the following:

PRESIDENT

C. S. Purnell
American Institute of
Electrical Engineers

SECRETARY

W. F. O'Conner
American Chemical Society

VICE-PRESIDENT

O. B. J. Fraser
American Institute of
Mining and Metallurgy

TREASURER

M. C. Giannini
American Society of Heating
and Ventilating Engineers

In addition, five of the six directors on the governing board were elected.

The Council was incorporated one year ago with local groups of fourteen leading engineering societies, representing some 25,000 engineers in the metropolitan area, as charter members. Each society has two delegates to the Council, which serves as a medium for mutual professional betterment, more effective public service, the furtherance of high professional standards and the advancement of engineering and scientific knowledge.

Journal Exchange

To complete a set, copies are urgently needed of SMPE *Transactions* numbers 1, 2 (1916); 5 (1917); 6, 7 (1918); 8, 9 (1919); 16 (1923); 18 (1924); and 30, 31 (1927). Will anyone who wishes to sell any of these numbers please write to R. Kingslake, Eastman Kodak Company, Rochester, New York.

Book Review

Developing—Technique of the Negative, by C. I. Jacobson

Published (1948) by the Focal Press, Inc., 381 Fourth Ave., New York 16, N. Y. 309 pages + xiv pages + 10-page index. 52 illustrations. $5^1/_4 \times 7^1/_2$ inches. Price, $3.50.

This book describes in detail the process of converting an exposed photographic film into a negative. It makes no attempt to explain the why or wherefore of the processes involved. A knowledge of a certain minimum amount of physics and chemistry would be required were this included. Instead, word descriptions and "practical illustrations" are used throughout, to make the subject matter understandable to the reader. As a result, one obtains a rather oversimplified picture of the developer technique, but the picture serves very well to an operator whose knowledge of science is limited. The more mature reader with a knowledge of chemistry, can also read the book with profit, for he would obtain a bird's-eye view of the entire field, one that can serve as an introduction for a later and more detailed study.

The book describes the composition of the developer solution, the methods of formulating it, and the properties of the ingredients involved. It contains a somewhat extended discussion of the differences between the many concoctions that are now in common use as developers, grouping them into three general classes. This is a useful generalization as it enables the technician to choose a specific solution for a specific purpose.

While the discussion of the developing solutions forms the most important part of the book, it also contains sections on the aftertreatment of the negative. Not the least interesting of the extraneous matter is a chapter dealing with darkrooms and darkroom equipment. Apartment-house dwellers will be especially interested in the section which describes how a lavatory can be converted into a darkroom.

Several errors were noted, but these appear to be not too important. The most glaring of these appears on page 207. There it is noted that Kodak's D-76 and Ansco's A-17 are compounded with sodium carbonate as the energizer. These developers use borax. However, on page 153 the correct formula is given for D-76.

The binding and the paper appear to be of good quality, a noteworthy event these days of inferior quality. The book will stand considerable thumbing, and it is the type of book that asks for such treatment.

Joseph S. Friedman
Ansco
Johnson City, N. Y

Current Literature

In the March, 1948, issue of *Steelways*, there appeared, on page 9, a popular article entitled "Report from Hollywood," by Hannibal Coons. Nails, steel tubing, structural steel, and other items made of this metal, are considered in relation to their use in the construction of motion picture studios and within the completed buildings.

Copies of *Steelways* may be obtained on request from

The American Iron and Steel Institute
350 Fifth Avenue
New York 1, New York.

RCA Index—1947

Recently the *RCA Review* issued a 24-page Index of substantially all published English-language technical papers on subjects in the radio, electronics, and related fields, the author or a coauthor of which was associated with the Radio Corporation of America at the time of the paper's preparation or at the time the work described in the paper was performed. The full title of this booklet is "RCA Technical Papers (1947)—Index—Volume II (b)" and it may be obtained on request from the *RCA Review*, RCA Laboratories Division, Princeton, N. J.

EMPLOYMENT SERVICE

POSITIONS WANTED

CAMERAMAN: Twelve years' experience in industrial production, three years as chief cameraman with commercial studio. Familiar with all types of work, 16 and 35, studio and location, black-and-white and color, sound and silent. Knows editing, sound and laboratory problems. Single, willing to relocate. Write P. O. Box 1158, Grand Central Station, New York 17, N. Y.

CINEMATOGRAPHER: A-1 references, wants employment with industrial company anywhere in the United States. Will travel any needed time. Experienced documentary, 35-mm and 16-mm, color or black-and-white. Active Member SMPE. Charles N. Arnold, P. O. Box 995, Peoria, Ill.

ENGINEER: Recent graduate B.S. in Mechanical Engineering from The University of Texas. Desires junior engineering position with a manufacturing firm in the motion picture industry. Background in mechanical and electronic equipment design. Write to A. Kent Boyd, 3308 Liberty, Austin, Texas.

Journal of the
Society of Motion Picture Engineers

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Subscription to nonmembers, $10.00 per annum; to members, $6.25 per annum, included in their annual membership dues; single copies, $1.25. Order from the Society's general office. A discount of ten per cent is allowed to accredited agencies on orders for subscriptions and single copies. Published monthly at Easton, Pa., by the Society of Motion Picture Engineers, Inc. Publication Office, 20th & Northampton Sts., Easton, Pa. General and Editorial Office, 342 Madison Ave., New York 17, N. Y. Entered as second-class matter January 15, 1930, at the Post Office at Easton, Pa., under the Act of March 3, 1879.

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Television Transcription by Motion Picture Film*

By THOMAS T. GOLDSMITH, JR. AND HARRY MILHOLLAND

Allen B. Du Mont Laboratories, Inc., Passaic, New Jersey

Summary—**The paper describes the electronic and camera equipment for recording television sight and sound on film, the picture made directly from the face of the cathode-ray tube. The application of this technique will be discussed with regard to documentary recording, network syndication use, and theater television. Representative films recorded in this manner are available.**

For over ten years Du Mont Laboratories have photographed television programs from the face of the cathode-ray tube using both still cameras and motion picture cameras. The early motion picture recording employed conventional cameras which were nonsynchronous with the television system, and stroboscopic patterns of blanking, overexposure, and underexposure were present on the films. Later there was developed a synchronously driven camera operating at 15 frames per second, thus exposing one entire frame of television and skipping the next during pulldown. This camera, however, produced a nonstandard film making it difficult to utilize the picture either for regular viewing or for television rebroadcast.

Since the camera equipment is specialized, we then approached Eastman Kodak Company to develop a commercial camera of this style. Boon, Feldman, and Stoiber describe this special camera developed for use in television transcription.** We shall discuss some of the electronic problems which arise in television transcription, and consider the use of transcriptions by the broadcaster, advertiser, and theater.

Television transcription is accomplished by recording a program on motion picture film directly from the face of a cathode-ray tube. The sound-channel recording is done by conventional means but the picture recording is rather complex in order to achieve high quality. A major consideration is the fact that the television picture rate of transmission is 30 complete frames per second. On the other hand, the standard of motion picture recording is 24 frames per second.

* Presented October 23, 1947, at the SMPE Convention in New York.

** Journal of the SMPE, this issue, pp. 117–126.

We record the television pictures on film at the rate of 24 frames per second so as to allow reprojection of the film either in a conventional projector for direct viewing or in the standard projector for rebroadcast by television.

A transcription recording console consists of a special monitor receiver and a film camera, with associated sound-recording facilities. The photograph of Fig. 1 shows a special monitor of this type and the recording camera as constructed by Eastman Kodak Company. Particular precautions must be taken in the design of the monitor to eliminate as far as possible many of the fluctuations which are readily tolerated in home television receivers. For example, a high-

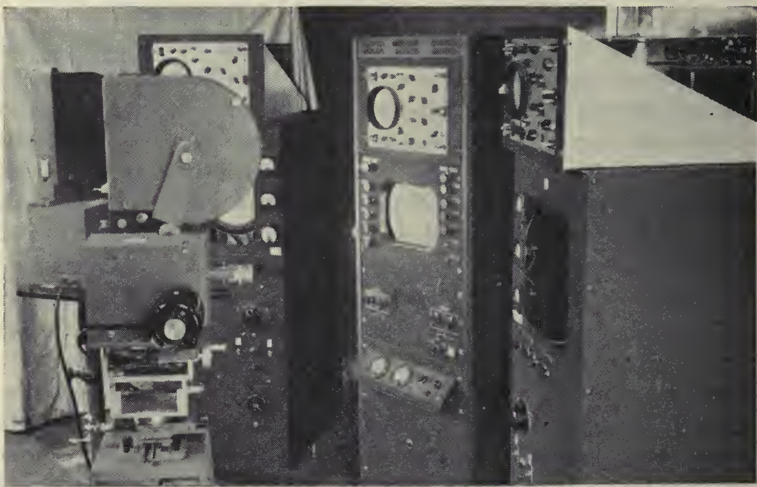

Fig. 1

voltage supply of excellent regulation is required so as to avoid any change in picture size with the variation of picture brightness in the scene being televised. The screen material of the cathode-ray tube must be very fine so as to be below the spot-size limit of the electron beam. Obviously, the linearity of scanning is adjusted as well as possible. A form of gamma correction is inserted so that to some degree the chemical gamma factor of the film can be matched to produce most faithful contrast gradations in the pictures. It is customary to use a positive picture on the monitor, but in some cases where speed is essential, a negative picture is produced on the monitor by means of video reversal of the signals which drive the cathode-ray tube. Where the negative picture is used, it is necessary to generate a reverse blanking signal in the equipment so as to suppress completely the normal synchronizing pulses, and obscure the return trace lines from the picture. If a system were being developed exclusively for theater television, the synchronizing signals could be in the whiter-than-white direction, and it would be unnecessary to have this complication. Where the negative polarity picture is reproduced on the cathode-ray tube, it is even more important to provide gamma correction by electrical circuit design. Use of the negative picture allows direct photography on positive stock resulting in both increased speed and reduced cost.

We found it desirable to utilize a 12-inch cathode-ray tube operated at 25,000 volts. Because of the large aperture of the lens, it is customary to scan an area of only 6 × 8 inches on the face of this large tube in order that the full rectangle of the picture be substantially flat and be exposed to the camera without any cutting of the corners, thus keeping good focus both electrically and optically.

Fig. 2 shows a timing diagram which illustrates the phase and frequency relationships between the television signals and the recording camera. At the top line is a timing indication expressed in intervals of $^1/_{120}$ second. This interval is a subdivision of both the 30-frame-per-second television-picture interval and the 24-frame-per-second film-picture interval. The next line indicates the television blanking interval and the useful television-picture interval. The actual picture signals and horizontal synchronizing signals occur in the interval entitled "scan" in the second line. Here the television field interval of $^1/_{60}$ second provides half of the interlace picture, and the succeeding $^1/_{60}$-second field interval provides the other half of the television interlace. Accordingly, two fields of television scanning vertically from top to bottom constitute one complete frame of television picture in an elapsed time of $^1/_{30}$ second. On the next line there is shown the camera-shutter characteristic which must be very carefully adjusted for proper interval. On the bottom line the pulldown cycle is illustrated. The most critical characteristic in the recording camera is the timing of the shutter blanking and exposure interval. The absolute intervals are the most important, and if they are appropriately adjusted, then the exact phase relationship is not very critical. As shown in Fig. 2, the phase relationship has been so adjusted that one of the lap-dissolve points for opening and closing of the shutter has been tucked under the television blanking interval. However, the other lap-dissolve point is shown approximately in the middle of the television field interval. If this shutter is not adjusted correctly, then a bar of distortion is likely to appear in the recorded film picture. Such a lap-dissolve bar is noticeable as a flicker caused either by underexposure or overexposure on a few elements or lines of the picture.

It is customary to drive a recording camera by synchronous motor, and where the television signal and the recording camera power are both controlled by the same power mains, then the camera runs in exact synchronism with the television synchronizing generator. However, it is desirable in many cases to record programs in one state

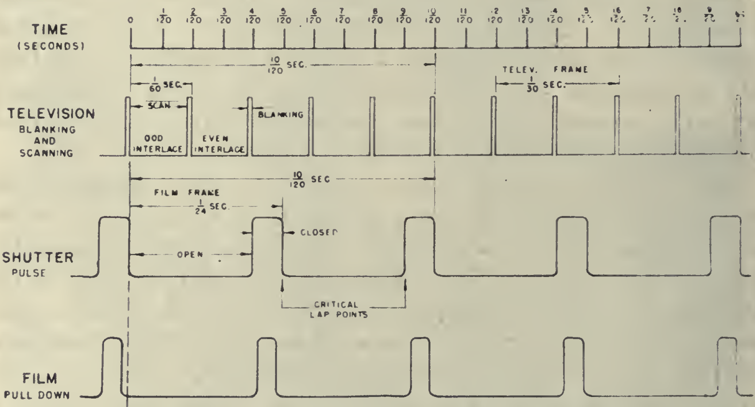

Fig. 2—Television-transcription-camera timing diagram.

which have originated in another state, thus not necessarily involving synchronized power lines. Many films which we have taken have been recorded in the nonsynchronous manner, and thus it is highly desirable that the shutter angles be appropriately adjusted so that the lap-dissolve bars are eliminated. It is best to have a slight double exposure on the lap-dissolve lines rather than an underexposure in order that the distortion be minimized.

On nonsynchronous power supplies the two regions of lap dissolve are in slow motion up or down the picture at the rate of the difference frequency between the 60-cycle supply controlling the synchronizing generator and the 60-cycle supply driving the synchronous motor of the field camera. Two such bars are present as seen in Fig. 2.

The camera shown in Fig. 1 uses 16-mm film and can employ a reel having 1200 feet of stock thus allowing about 33 minutes of recording.

In practice, a dual system is employed so as to record programs for an indefinite period. The teletranscriptions may be used for rebroadcast, promotional advertising, criticism of program techniques and content, and legal records.

Fig. 3 is a picture which illustrates some of the work that can be done by recording from television. This is an original enlarged from a frame of 35-mm motion picture film. Fig. 4 is a recorded television transmission of the same scene. Fig. 5 is another original, of which Fig. 6 is the television recording. These were not taken on a 16-mm camera and do not indicate any of the banding.

Another very promising use of transcriptions is for theater television. The equipment and films discussed here have been primarily for use on 16-mm film, but the same principles apply to the project of theater television, using 35-mm film and a process of rapid development for immediate projection in a minute or less after reception.

Fig. 3—Original.

Fig. 4—Photograph received on cathode-ray tube.

Much thought is being given to the theater-television possibilities and systems are being studied having other than the standard broadcast-line and frame rates. However, the immediate demand for recorded television programs is so great that the 16-mm equipment here described has been developed to a practical degree and is in active use.

Television networks eventually will rely upon radio relay or coaxial cable to connect the various stations. However, until such facilities can be provided and can be operated at a reasonable cost, it is possible for the network syndication to be accomplished by television transcriptions, recording the major programs in the originating stations on film which may then be shipped to the subscribing affiliates. Where this method is employed the recording-camera equipment will employ a separate sound system for best quality, since there is time for limited editing and time for the special processing of the two films in preparation of the prints.

On the other hand, for some applications such as a documentary record of transmission, which eventually might be required by the Federal Communications Commission it is entirely adequate to employ a single sound camera whereby the general subject matter and sound are recorded on a single film. Here it is probable that no prints would be required, and therefore greatest economy should be practiced. However, for rebroadcast the highest possible quality of sight and sound is desired and a separate sound system is preferred.

For some forms of recording the picture may be photographed on to negative stock as a negative picture. Then, a television system

Fig. 5—Original.

Fig. 6—Photograph received on cathode-ray tube.

may be employed for viewing this picture since we have a regular means of reversing the picture polarity electrically in the television chain. We have used this method in regular broadcasts to save time in film processing, taking regular newsreel records on the original negative and playing the negative film through the television film camera, reversing the video polarity so as to transmit a positive picture.

Now a word about future possibilities with television transcription. Already the sensitivity of television cameras using the image-orthicon tube exceeds the sensitivity of most photographic emulsions. Thus, we can say that the television-camera chain serves as a light amplifier, extending the range of photographic recording to scenes having lower lighting levels than can be successfully recorded by a film camera alone. However, further development must occur before the sensitive television system can fully match the contrast gradation fidelity and resolution and sharpness available by direct film camera methods.

The intermediate film technique has already developed to such a degree that the transcription compares favorably with an original film used as the subject matter for such a transcription.

The television camera promises excellent utility in a motion picture recording studio. At present such a camera is primarily an aid to the regular picture recording camera. Used as such, it gives the Operations Personnel a means of seeing immediately the setup and programming for the scenes, thus providing a control far more useful than the customary waiting until development of the film can provide for a means of analysis of what is being filmed.

Usually such a viewing takes place the day after the scene has been photographed; this unnecessary delay proves very expensive. The television camera used in conjunction with the motion picture camera can provide at once on television monitors the scenes being recorded.

Ultimately it may well be that the television camera head alone may be used in the studio to pick up the scene and the complex film equipment will be located in central permanent laboratories where both sight and sound are recorded. This procedure of placing microphones in the studio and the complex sound-recording equipment in the laboratory is customary at present in many studios. It is entirely possible that both the sound and the picture recording equipment may be located in the central laboratories. In this way the scenes can be monitored while they are being recorded, thus aiding the co-ordination between directors, cameramen, and performers.

DISCUSSION

MR. J. G. BRADLEY: I am interested in the recording aspect of this because I see in this recording a possibility of creating and preserving records as library material. What losses do you sustain when you retelevise these pictures taken by camera from a televised image? In other words, how does the retelevised picture compare with the original televised image in sound and picture quality?

DR. T. T. GOLDSMITH, JR.: The film recording compares favorably with the original televised image. The sound was degraded pretty much tonight. This sound was dubbed in from various sources. The camera that you see here does not have sound facilities with it. The sound, for example, on the President's message was recorded in New Jersey in my house, and the picture was recorded here in New York, and the President was speaking in Washington. So it was a rather peculiar combination which resulted in the film you have seen. Other parts of the sound here were dubbed from other recordings.

We are putting together complete sound-and-picture recording apparatus all under one control, where we expect the sound quality to be quite comparable to the reproduction obtained over the radio channel by direct reception.

As to the picture quality, which I believe is a primary consideration that you have, we have rebroadcast quite a number of the programs which were recorded in this manner. We know there are many flaws left in this system. We know there are many cures for some of the flaws. Some of them will, inevitably, degrade the picture somewhat. However, even at the present status, we have had things working as we want them for film recording. Then we have played over the air a test film consisting of a section of 16-mm film and then a section of teletranscribed film. It was very difficult to tell at the receiving point just where one stopped and the other started.

There is a noticeable difference particularly for those who are looking for the flaws and the bars that are present, but teletranscription does give you a quite faithful recording of what is going on the air. I think the Eastman people will agree with me that many of the tests we have made have recorded just about all there is on the cathode-ray tube. Some of the films that you have seen tonight were taken with mobile field equipment, which does not have the full resolution and the resulting characteristics of the iconoscope cameras. Some of the shots were recorded from iconoscope-camera signals, and they are better. However, even those suffer from lack of depth of focus in the studio. The iconoscope is not too sensitive. So we have to use a fairly large aperture lens on the pickup iconoscope camera. As a result, the background is badly defocused, but we have means under development for eliminating that characteristic and having good resolution and at the same time good depth of focus in the studio equipment. Thus we shall have something that can realize more nearly a full 525-line television system.

Obviously, you cannot go to much better resolution than that and still keep the broadcast standards that we have today; but I do believe for many documentary records the 16-mm film recorded by television can compare very favorably with 16-mm direct recordings, and certainly be equal to the average recordngs used for film work generally.

MR. BRADLEY: I think my question is more technical than the way you have answered it. In preserving motion picture records, we have to look forward to copying the film. Each time we copy it we lose some light, whether it is 5 per cent or 10 per cent, but there is a limit to the number of times we can copy a motion picture, until there is complete degradation of light. Suppose you televised a motion picture and copied it with a camera. Then you televise the copied picture and copy it again. How many copyings can you get before this degradation?

DR. GOLDSMITH: There is a small degradation each time. Do you mean the degradation by retelevising, or by printing a lot of positives from one negative?

MR. BRADLEY: Degradation by rephotographing the televised image. I understand you can televise a picture many times without any degradation, but when you photograph it again from a television screen, what degradation sets in there?

DR. GOLDSMITH: There will be some further loss, of course, because each time you televise it you change the contrast fidelity a little, and that would penalize it. However, I do not know just what conditions you would encounter that would make it necessary to transcribe again and again, for example, down to the tenth transcription. If you transcribe once to get the film record down permanently on a first negative, then you can make positive prints in any number, with the normal limitation of printing, distribute them that way, and thereby, say, have

50 positive prints going out to 50 affiliated stations, each one suffering only one degradation due to retransmission.

MR. COOK: I noticed in the presentation of the last motion pictures that there was less disturbance of the picture than in any of the previous ones, either the projected demonstration tonight or the pictures that Captain West had the other night; in other words, the picture was extremely stable. Were these broadcast or were these taken directly from a coaxial cable to your tube?

DR. GOLDSMITH: We have done both. If I remember these particular clips that were put together here, most of these were done at the station, but many of them were by radio-relay link; not many of them, but many that we have done have been that way; for example, the baseball game came over by radio-relay link on some of its paths. Of course, the President came from Washington to New York on the 2.7-megacycle band with coaxial cable. There were various transmission means employed on many of the shots that you saw tonight. Some of the others were taken off what we call a studio line right from the studio without any broadcast interference. The quality that you saw here is quite representative of what you get in many good receiving locations around New York, which is perhaps 50 per cent of the locations that have television sets.

MR. BLOOM: You mentioned you had difficulty with the power-line frequencies being different at one point of transmission than at the point of receiving. Is it possible to use a synchronizing system, an automatic-frequency system, to drive your synchronous motors to operate that?

DR. GOLDSMITH: We have done that. On some tests we have driven our power equipment from a synchronous supply operated that way, but we feel that if we can get this shutter phasing and shutter angle appropriate, particularly the shutter angle, then it will be unnecessary to take that precaution, and it is a far simpler set of equipment. You can run completely synchronous with the transmitted signals by using a synchronizing process of vertical field control to lock in your mechanical mechanism as well.

MR. HUGH CHAIN: Are you offering this commercially yet? Is it out of the experimental stage? If it is, have you any idea of the rates for this service?

DR. GOLDSMITH: It is a little premature. We are building the units. We built quite a few of them experimentally and we are getting the things into production, but one of the major problems has been the commercial camera. The commercial electronic equipment is pretty well along, too. The general plan, so far as we know, is to sell these units to interested subscribers, primarily thinking that the first people that would want them would be broadcast stations to use for regular transcription at the broadcast stations. The units are available.

MR. CHAIN: But are you offering the scripts and transcription service to advertisers to your stations?

DR. GOLDSMITH: Yes, that has been done for some time. We have been recording programs for sale to advertising agencies, and so forth.

MR. CHAIN: Mr. Feldman, the Jack Kilty part of the transcription did not seem to have high contrast. You mentioned to me that it was done on sound positive film. Is that lack of contrast inherent in the film, or what was the situation there?

MR. W. FELDMAN: We have used a couple of different types of sound positive films. As to the particular one of the Jack Kilty Show, it was on 5302.

MR. ROBERT FRASER: That film was a work print, a very hasty print. As soon as we saw the banding, we did not go any farther. So the quality is very poor. However, the negative would be capable of a much better print.

MR. FELDMAN: Actually, this print was made up specifically to show banding, and not for any picture quality. That was not the prime purpose.

MR. LEWIN: There was a statement made by Dr. Maloff that confused me quite a bit, and I did not have an opportunity to question him at the time. I wonder whether one of the authorities in television would help to clarify it.

Dr. Maloff said that in counting the number of lines the television engineer counts both the black and the white lines. I have always been under the impression that when you say there are 525 lines, you mean the electron beam actually scans 525 lines in the 30th of a second. That would be 525 white lines. Am I wrong in that or not?

CHAIRMAN PAUL J. LARSEN: That is correct.

MR. LEWIN: In other words, if you count the black and white lines, there are 1050 lines.

DR. GOLDSMITH: I shall try to clarify that in this way: In television we use scanning lines which are potentially either white or black, or some gray intermediate tone, depending upon the signal that is being produced. In the motion picture terminology of lines, they refer to a series of black lines ruled on a paper with equally spaced white lines between.

In television it is true that if you look at a television picture you can see the scanning lines in the high-light part of the picture as white strips of light across, with a very thin space between that may be black. We try in television to make that space as small as possible; in other words, the spot size is just the size of the space between the centers of two lines, in the interlace system. So that the lines that are white just merge with one another on their edges.

Theoretically, in a perfectly square spot-scanning system in television you have no black lines in between, and there comes a difference between the motion picture terminology of black lines separated by white spaces and the television system where the scanning processes, as to lines, can either be black or white or gray, at the control of the grid in the cathode-ray tube.

MR. DAVID B. JOY: I understood the speaker to say that by using a 35-mm camera, a picture could be taken of the television image, developed, and ready for projection in the regular projection equipment of the theater within a few minutes after the picture was received, thus giving you as much light on your projection screen as you would get with an ordinary motion picture. If that equipment is not too complicated, it might be one solution to the theater television.

DR. GOLDSMITH: That is right. It is not too complicated; in fact, that few minutes that you talk about has been experimentally pulled down to less than a one-minute delay. A film frame is exposed in front of the transmitted picture at the cathode-ray tube, is run through a developing machine, having both developing and fixing, at high temperatures and high drying speeds, and threads right on through into the projector in the theater and can be projected in that manner. The equipment is rather complex in the developing and fixing process. I do not know about the permanency of such records, but it does allow editing, saving the film if you want to for longer times, or allowing almost instantaneity of broadcast, almost as soon as received.

Television Recording Camera*

By J. L. Boon, W. Feldman, and J. Stoiber
Eastman Kodak Company, Rochester, New York

Summary—A 16-mm motion picture camera for recording television programs at sound speed from a monitor receiving tube is described. Basic camera-design features include a 1200-foot magazine, which permits continuous recording of a half-hour program, separate synchronous-motor drives for the shutter and film-transport mechanisms, an 8-tooth sprocket pulldown actuated by an accelerated geneva star, an *f*/1.6, 2-inch focal length coated lens, and a 72-degree shutter. Other features include a "bloop" light to provide registration with the sound-film recorder, a film loop-loss indicator, and appropriate footage indicators.

Some general operating characteristics of the camera are included along with a description of the pulldown system and the general problem of film steadiness. The last is particularly critical because of the high accelerations involved in the pulldown, in addition to the reaction of film to temperature and humidity changes.

In the recording of television-tube imagery on film, one is confronted with the primary problem of reducing an image frequency of 30 cycles per second on the tube to one of 24 cycles per second on film. It is possible to record television images satisfactorily at 15 cycles per second or even at $7^1/_2$ cycles per second. In conforming with the standards of the American Standards Association of recording sound on film, however, one is limited to a frequency of 24 frames per second. Since the ratio of the two frequencies is 5:4, it is evident that the transition is most easily accomplished by omitting one of every five scanning traces. More exactly, the following sequence of events occurs: With the camera and television tube synchronized, film is exposed for one complete tube cycle, lace, and interlace patterns. During the first quarter of the next complete cycle the film is advanced one frame. Exposure takes place for the remaining three quarters of this cycle and the first quarter of the next cycle, after which the film is again advanced. Fig. 1 shows an exterior view of the camera and in Fig. 2 may be seen the schematic representation of the events.

As a direct consequence of the limited pulldown time indicated above, the camera is restricted to a closed-shutter angle of 72 degrees. In addition, the pulldown angle for the film must be less than 72 degrees by the angle which the aperture subtends.

* Presented October 23, 1947, at the SMPE Convention in New York.

In our camera the pulldown action is accomplished by means of an 8-tooth sprocket which is indexed by an 8-point geneva star. It may be readily seen from the geometry of the star and its driver that the latter must rotate 135 degrees during the indexing operation. But since this angle is greater than the permissible pulldown angle, it is necessary to interpose an accelerating mechanism between the constant-speed drive shaft and the geneva star. A variable-arm, spline-and-slot movement, shown in Fig. 3 and treated mathematically in the Appendix, is used to reduce the pulldown time from one which is equivalent to 135 degrees to one which approximates 57 degrees. The effect of this accelerator is to produce extremely large peak film accelerations. As an example, the peak acceleration shown in Fig. 4, for operation at 24 revolutions per second, produces a linear film acceleration of the order of 6×10^4 inches per second. A standard 8-point geneva star driven by a constant-speed shaft at the same speed reaches about one tenth the above acceleration at its peak. As may be expected, a large force is produced on the intermittent movement. In addition, such problems as optimum pressure-pad tension, film steadiness in the gate, and a general increase in noise level become more evident. In view of the large forces produced, it was deemed advisable to use a sprocket pulldown instead of a claw since the life of the latter would not be long enough for the heavy-duty operation required.

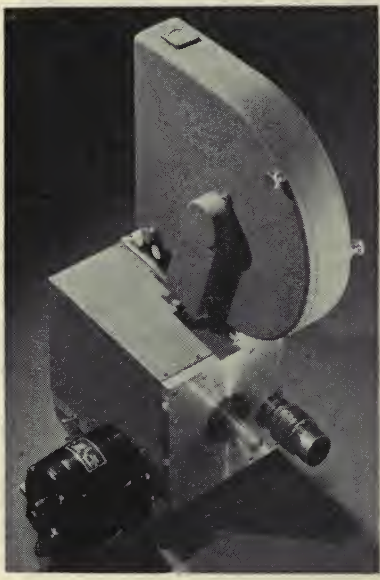

Fig. 1—Exterior view of camera.

FILM STEADINESS

During the preliminary camera tests it was observed that film steadiness was very erratic and was particularly dependent upon humidity conditions. As the relative humidity reached 85 per cent or higher, it was impossible to obtain any semblance of picture steadiness.

This general effect is not new and has been attributed to an adhesive action between the film and the gate and pressure pad, somewhat analogous to the behavior of two polished glass surfaces in contact and moved parallel to each other. Since the ratio of static to kinetic friction is large, the forces required to start the motion and continue it vary considerably. It was noted that so far as the film was concerned, consideration had to be given to both surfaces, the base as well as the emulsion. As a consequence, both the gate and pressure-pad constructions were modified. Instead of permitting the film to ride on a continuous track in the gate, six studs, three on each side, were embedded in the tracks and then lapped so that the stud surfaces were three or four thousandths of an inch above the track surface. The studs not only served to decrease the contact area between

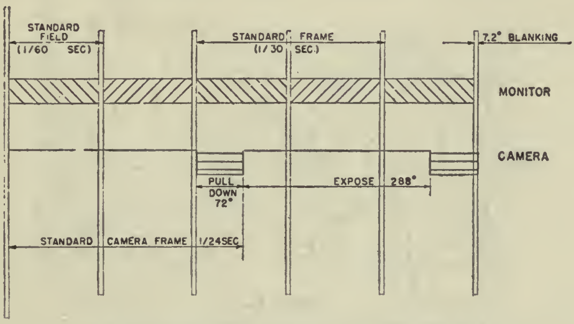

Fig. 2—Timing cycle of television monitor and camera.

the gate and film, but also reduced emulsion pile-up and its attendant effect on steadiness. It should be mentioned, in passing, that a straight gate and pressure pad are being used.

Modifications made on the pressure pad consisted in replacing the usual type of continuous chrome-plated track with a 6-studded track which matched the studs in the gate. In addition, another pressure pad constructed solely of nylon and with continuous tracks was used. Both pads provided steady film registration. It was observed, however, that the former permitted the film to buckle slightly and so was discarded in favor of the latter. To date, no life tests have been made on the nylon, although no physical changes have been noted after some 25,000 feet of film have been run through the camera. It is anticipated that the nylon will provide satisfactory operation and a reasonably long life.

GENERAL PROPERTIES

Two synchronous motors are used to drive the camera. One is used solely for the purpose of driving the shutter, and the second one, a larger motor, takes care of the entire film transport. It was felt necessary to isolate the two systems in order to prevent any "hunting" from affecting the shutter. A coupling which ties the two motor shafts together permits continuous observation of synchronization. Once this coupling is set, it should not be necessary to readjust the two motor positions, since their operation will remain synchronized.

The importance of a separate motor drive for the shutter is evident when one considers that it is necessary, on alternate exposure frames, to record from the middle of one scanning trace, as shown in Fig. 1,

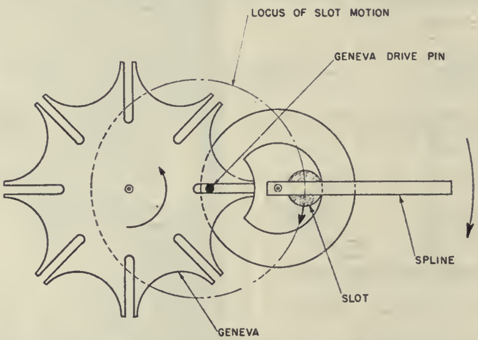

Fig. 3—Slot-and-spline driving geneva.

and to complete the full cycle on the first half of the third scanning trace. Unless the shutter is able to reproduce its action, the scanning lines show up as not meeting or overlapping. The net effect is a type of banding which is reproduced on the film as an alternately varying density region. It is not anticipated that one will be able to synchronize shutter operation so that recording takes place at precisely the same position on alternate frames. It should be possible, however, to reduce the banding to, say, one scanning line. In tests made at both the National Broadcasting Company and Du Mont Studios, it was observed oftentimes that it was possible to record with no trace of banding. On other occasions, a form of banding, which resulted from shutter unsteadiness or from shifting scanning lines, took place.

A 1200-foot, double-chamber magazine is supplied with the camera and is a self-contained unit in that it permits housing both the unexposed and the exposed film and may be readily removed from the camera. The take-up drive consists of a sprocket-and-chain movement, which is driven from a clutch-controlled shaft on the camera proper. Separate arms are used to guide the film on both the supply and take-up sides of the magazine chamber. Appropriate light locks are provided to permit changing of loaded magazines in a lighted room.

It was mentioned above that some difficulty in film steadiness in the gate was encountered. In tests made on the pulldown sprocket, it was noted that there was a need not only for a "snubbing" roller, but also a stripper roller which would aid in stripping the film from the

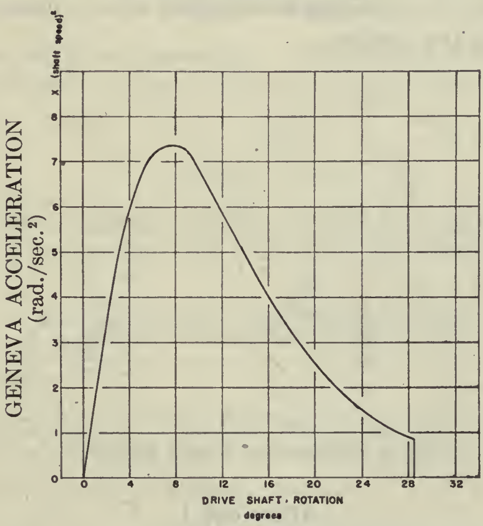

Fig. 4—Acceleration curve for 57-degree accelerated pulldown.

pulldown sprocket. The former was located in a position approximately three frames from the edge of the aperture, although it was observed that within plus or minus 10 degrees its position was not too critical. The stripper roller was located below the sprocket and in such a position as to aid the film in following its natural stripping path. Several tests were made in an effort to determine the optimum pulldown sprocket diameter. However, since there seemed to be little difference in their operation, a final choice was made of a 0.762-inch diameter sprocket.

One other property which has been mentioned is the operation noise level of the camera. The high accelerations which take place in the pulldown mechanism, as well as the gear-reduction drives which are used, all contribute to camera noise. The level is not high enough, however, to be objectionable.

ACKNOWLEDGMENTS

Considerable credit and thanks are due to the technical staffs of both the Allen B. Du Mont Studio, Station WABD, and the National Broadcasting Company Studio, Station WNBT. We are especially grateful for their many suggestions which have been offered and incorporated in the preliminary camera model and also for their continual assistance in providing studio time and facilities for the purposes of testing the camera.

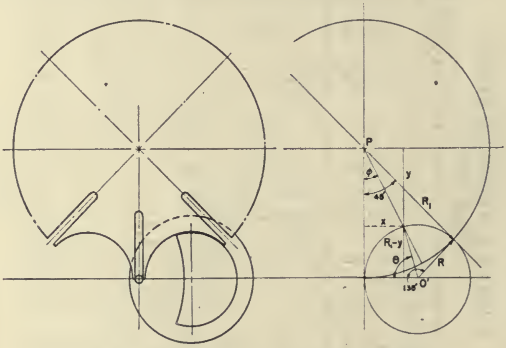

Fig. 5—Eight-point geneva geometry.

APPENDIX I

Motion of Eight-Point Geneva Star

In Fig. 5 is shown the geometrical arrangement of the intermittent geneva star with center at P and the driving pin with center at O'. Since we require that the driver move the star 45 degrees during its period of engagement, certain well-defined relations are determined. From the figure,

$$R = R_1 \tan 22.5 \text{ degrees} \tag{1}$$

$$x = R\,(1 - \cos\theta) \tag{2}$$

where x is the horizontal component of displacement, R the distance from O' to the center of the driving pin, and θ the angle of rotation of the driving pin. Also,

$$R_1 - y = R \sin\theta, \tag{3}$$

whence

$$R \cot 22.5 \text{ degrees} - y = R \sin\theta, \tag{4}$$

and
$$y = R(2.41 - \sin\theta). \tag{5}$$

Thus,
$$\frac{x}{y} = \tan\varphi = \frac{1 - \cos\theta}{2.41 - \sin\theta} \tag{6}$$

where φ is the angle of rotation of the star. We have taken the origin of motion at the initial point of engagement of the driving pin with the star, but it turns out to be more useful if the origin is selected coincident with the maximum position of engagement of the star and pin. Consequently, the shift in origin changes (6) to

$$\tan\varphi = \frac{1 - \cos(A + \theta)}{2.41 - \sin(A + \theta)} \tag{7}$$

where A is an arbitrary phase angle. We shall later take it to be $67^1/_2$ degrees, consistent with the requiiements stated above. Solving for φ we obtain

$$\varphi = \tan^{-1}\left[\frac{1 - \cos(A + \theta)}{2.41 - \sin(A + \theta)}\right]. \tag{8}$$

We shall now obtain the relations between the angular velocity and acceleration of the pin and star. The first derivative with respect to time yields

$$\dot{\varphi} = \frac{2.41\sin(A + \theta) + \cos(A + \theta) - 1}{7.82 - 4.82\sin(A + \theta) - 2\cos(A + \theta)}\,\dot{\theta} \tag{9}$$

which reduces to

$$\dot{\varphi} = \frac{(\cos A + 2.41\sin A)\cos\theta + (2.41\cos A - \sin A)\sin\theta - 1}{7.82 - (2\cos A + 4.82\sin A)\cos\theta + (4.82\cos A - 2\sin A)\sin\theta} \tag{10}$$

and which, for $A = 67^1/_2$ degrees, becomes

$$\dot{\varphi} = \frac{2.61\cos\theta - 1}{7.82 - 5.22\cos\theta}\,\dot{\theta}. \tag{11}$$

The angular acceleration of the star is obtained by a second time differentiation.

$$\ddot{\varphi} = \frac{(7.82 - 5.22\cos\theta)(-2.61\sin\theta) - (2.61\cos\theta - 1)(5.22\sin\theta)}{(7.82 - 5.22\cos\theta)^2}\,\dot{\theta}^2 + \frac{2.61\cos\theta - 1}{(7.82 - 5.22\cos\theta)}\,\ddot{\theta} \tag{12}$$

which reduces to

$$\ddot{\varphi} = -\frac{15.18\sin\theta}{(7.82 - 5.22\cos\theta)^2}\,\dot{\theta}^2 + \frac{2.61\cos\theta - 1}{(7.82 - 5.22\cos\theta)}\,\ddot{\theta}. \tag{13}$$

If the driver were moving at constant velocity, the second term in (13) would vanish. Since, however, we shall be considering a system where the driving pin is not moving with constant velocity, the second term will be of significant importance.

APPENDIX II

Spline-and-Slot Accelerating System

At a fixed distance R_2 in Fig. 6, about A as center, we drive a slot at constant speed. The slot engages a spline whose driving center is at O' and is tightly coupled to the geneva drive pin. An angle of rotation α in the constant drive produces a rotation θ in the output.

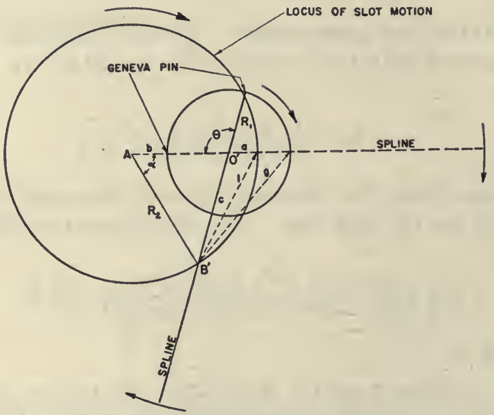

Fig. 6—Slot-and-spline geometry.

From the law of sines we obtain

$$\frac{C}{\sin\alpha} = \frac{R_2}{\sin\theta} \text{ in triangle } AOB'. \tag{14}$$

Also $$C^2 = (R_1 + b)^2 + R_2^2 - 2R_2(R_1 + b)\cos\alpha. \tag{15}$$

But $$(R_1 + b) = (R_2 - a),$$

whence $$C^2 = (R_2 - a)^2 + R_2^2 - 2R_2(R_2 - a)\cos\alpha. \tag{16}$$

From (14) and (16) we have

$$\sin\theta = \frac{R_2 \sin\alpha}{\{(R_2 - a)^2 + R_2^2 - 2R_2(R_2 - a)\cos\alpha\}^{1/2}}. \tag{17}$$

Also $$\tan\theta = \frac{R_2 \sin\alpha}{R_2\cos\alpha - (R_2 - a)},$$

and $$\cot\theta = \frac{R_2\cos\alpha - (R_2 - a)}{R_2\sin\alpha}. \tag{18}$$

Equation (18) provides the necessary relation between θ and α, i.e., the output and input angles of rotation. Once R_2 and a are selected, one has a well-defined relation for the two angles. The zero point of operation of the system has been taken with the slot engaging the spline at the closest distance of approach to O'.

From (18) we have

$$\theta = \cot^{-1}\left[\cot\alpha - \left(1 - \frac{a}{R_2}\right)\csc\alpha\right]. \tag{19}$$

The first derivative with respect to time provides us with an angular velocity relation; namely,

$$\dot{\theta} = \frac{1 - \left(1 - \frac{a}{R_2}\right)\cos\alpha}{1 + \left(1 - \frac{a}{R_2}\right)^2 - 2\left(1 - \frac{a}{R_2}\right)\cos\alpha}\,\dot{\alpha}. \tag{20}$$

To obtain the angular acceleration relation we differentiate a second time, noting that $\dot{\alpha}$ is a constant, and obtain

$$\ddot{\theta} = \left\{\frac{-\left[\left(1 - \frac{a}{R_2}\right) - \left(1 - \frac{a}{R_2}\right)^3\right]\sin\alpha}{\left[1 + \left(1 - \frac{a}{R_2}\right)^2 - 2\left(1 - \frac{a}{R_2}\right)\cos\alpha\right]^2}\right\}\dot{\alpha}^2. \tag{21}$$

From (11) in Appendix I we obtain the geneva velocity as a function of its input drive. But the input drive of the geneva is governed by the output of the pin-and-slot drive since the two are coupled. Thus, we are able to treat the geneva motion in terms of the constant-velocity drive. Given

$$\dot{\varphi} = \frac{2.61\cos\theta - 1}{7.82 - 5.22\cos\theta}\,\dot{\theta} \tag{22}$$

and replacing $\dot{\theta}$ by (20) we obtain

$$\dot{\varphi} = \frac{2.61\cos\theta - 1}{7.82 - 5.22\cos\theta}\left\{\frac{1 - \left(1 - \frac{a}{R_2}\right)\cos\alpha}{1 + \left(1 - \frac{a}{R_2}\right)^2 - 2\left(1 - \frac{a}{R_2}\right)\cos\alpha}\right\}\dot{\alpha}. \tag{23}$$

Substituting for $\cos\theta$ in terms of α gives

$$\dot{\varphi} = \frac{2.61\,[R_2\cos\alpha - (R_2 - a)] - Z}{7.82Z - 5.22[R_2\cos\alpha - (R_2 - a)]}\left\{\frac{1 - \left(1 - \frac{a}{R_2}\right)\cos\alpha}{1 + \left(1 - \frac{a}{R_2}\right)^2 - 2\left(1 - \frac{a}{R_2}\right)\cos\alpha}\right\}\alpha \tag{24}$$

where $$Z \equiv \sqrt{2(R_2^3 - 2R_2a)\,(1 - \cos\alpha) + a^2}.$$

In a similar manner we may obtain the angular acceleration equation of the geneva in terms of the constant-speed shaft rotation. From (13) in Appendix I we have

$$\ddot{\varphi} = -\frac{15.18 \sin\theta}{(7.82 - 5.22 \cos\theta)^2}\,\dot{\theta}^2 + \frac{2.61 \cos\theta - 1}{(7.82 - 5.22 \cos\theta)}\,\ddot{\theta} \qquad (25)$$

where $$\dot{\theta} = \left\{\frac{1 - \left(1 - \frac{a}{R_2}\right)\cos\alpha}{1 + \left(1 - \frac{a}{R_2}\right)^2 - 2\left(1 - \frac{a}{R_2}\right)\cos\alpha}\right\}\dot{\alpha},$$

$$\ddot{\theta} = \left\{\frac{-\left[\left(1 - \frac{a}{R_2}\right) - \left(1 - \frac{a}{R_2}\right)^3\right]\sin\alpha}{\left[1 + \left(1 - \frac{a}{R_2}\right)^2 - 2\left(1 - \frac{a}{R_2}\right)\cos\alpha\right]^2}\right\}\dot{\alpha}^2,$$

$$\cos\theta = \frac{R_2\cos\alpha - (R_2 - a)}{Z},$$

and $$\sin\theta = \frac{R_2 \sin\alpha}{Z}.$$

Performing the indicated replacements in (25), we obtain

$$\begin{aligned}\ddot{\varphi} = &\left[\frac{-15.18R_2Z\sin\alpha}{\{7.82Z - 5.22[R_2\cos\alpha - (R_2 - a)]\}^2}\right] \\ &\times\left[\frac{1 - \left(1 - \frac{a}{R_2}\right)\cos\alpha}{1 + \left(1 - \frac{a}{R_2}\right)^2 - 2\left(1 - \frac{a}{R_2}\right)\cos\alpha}\right]^2\dot{\alpha}^2 \\ &- \left[\frac{2.61[R_2\cos\alpha - (R_2 - a)] - Z}{\{7.82Z - 5.22[R_2\cos\alpha - (R_2 - a)]\}}\right] \\ &\times\left[\frac{\left[1 - \frac{a}{R_2} - \left(1 - \frac{a}{R_2}\right)^3\right]\sin\alpha}{\left[1 + \left(1 - \frac{a}{R_2}\right)^2 - 2\left(1 - \frac{a}{R_2}\right)\cos\alpha\right]^2}\right]\dot{\alpha}^2.\end{aligned} \qquad (26)$$

The appropriate constants foı a 57-degree pulldown angle have been substituted in the final equation and one half of the symmetrical acceleration curve of the geneva plotted in Fig. 3. For ease of observation, the curve has been inverted and shifted from its true position on the other side of the zero line.

Development of Theater Television in England*

By A. G. D. WEST

Director, Cinema-Television, Ltd., London, England

Summary—This paper will give a historical review of the progress of theater television projection in Great Britain, both before and after the war, and will describe the design and performance of the equipment which has been developed for distribution and projection of television programs. It will also indicate the proposals now being made for the setting up of a theater television service in England, first in London, and then throughout the country.

I. Introduction

The English cinema exhibitor is somewhat bewildered regarding the subject of television and how it will affect him in the future. Previous to the war, certain cinemas had large-screen television equipment installed where programs of a topical nature transmitted by the British Broadcasting Corporation were reproduced on the screen to paying audiences. Results achieved indicated that with the normal course of technical progress, television projection could, in time, provide a picture equal in quality to that given by normal film projection. But the practical problem of the use of television for cinema entertainment, particularly in respect to how programs could be built using the television medium, was the subject of much conjecture, and sufficient experience was not available then, nor is it even now, to enable the exhibitor to obtain a clear view as to how such entertainment would be organized and presented to the public. I have spent some time trying to get the entertainment industry to study the practical problems concerned with the successful utilization of television in its applications to the cinema industry. I have spent much more time, naturally, endeavoring to press forward with the solution of the technical problems, holding the view that, in the achievement of an acceptable technical result, the technician will have carried out his part of the bargain; it may be that as this state of technical perfection is more closely approached the clarification of the program requirement will be accelerated, and we shall find the means of revitalizing the cinema industry in a way which will be a source of

* Presented October 21, 1947, at the SMPE Convention in New York.

satisfaction to both technician and exhibitor. Large-screen television has provided a means of interesting and attracting the cinema patron on certain special occasions. On the other hand, we are not yet satisfied that, either technically or in respect to program value, we can yet retain the permanent interest of the public. We are only part of the way through our job. Let us, therefore, take stock of the present situation, and obtain clarification on some of our problems, and how best to attack them.

In the advent of a new art—this was exemplified when sound, arising out of broadcasting, was applied to cinema technique—we must find how the new art can help existing practice and vice versa. Our chief problem today in the cinema industry is to study how television can help the cinema, and also how the cinema can help television. This is the vital moment, when television is just beginning to show its head, for the cinema industry to take into account in its planning for the future, both technically and commercially, the invaluable aid which television can provide in the field of theater entertainment. Television enthusiasts (we shall call them "tele-visionaries") who have made a close study of the commercial possibilities of the use of television for the entertainment of cinema audiences, have forecast that, provided a broad co-operative view is taken by all the various entertainment interests, including those which promote sporting and similar events, opportunities for expansion in the entertainment industry can be considerable, and would fully justify the wildest dreams of the most imaginative exploiters in the entertainment field.

The following observations aim at giving a review of the position of theater television in Britain, and a summary of the aims of the technician in preparing for full commercial use large-screen television equipment, and the means whereby programs can be provided for such an equipment, together with a statement of the various aspects which will need to be considered in detail by the exhibitor, between now and such time when commercial equipment will be available on the market. The paper is concerned only with black-and-white projection. We have nothing as yet to show on color.

II. Review of Progress up to 1939

Early History of Large-Screen Projection

Up to the beginning of the war in 1939, home and theater television progressed side by side during those prewar years; therefore, a few words should be said on the development of the home television service.

The beginning of official transmission of television in England was due to the dogged persistence of John Logie Baird, who, as a result of his experiments and demonstrations, over the period from 1923 to 1928, was able to get the British Broadcasting Corporation to radiate vision signals, first in 1929 by an experimental service, and later, from August, 1932, in the form of a regular program service. These television transmissions provided over the normal broadcast channels a low-definition picture on a 30-line basis. Such a coarse texture of picture rendered the transmission of small detail impossible, and the program, although interesting, had little entertainment value. But it started the ball rolling, and, as you well know, from 1933 onward work was commenced in many laboratories in England, America, France, and Germany, toward the development of a higher standard of definition.

The low-definition broadcast service ceased in September, 1935, and its place was taken by regular transmissions from the new television station at the Alexandra Palace, London, on a 405-line interlaced standard developed by the Marconi and Electrical and Musical Industries companies.

Home and Theater Television

During the three years from August, 1936, to September, 1939, some 20,000 home television receivers were sold in the London area; the majority of these incorporated direct-viewing cathode-ray tubes with a picture size between 8 × 6 inches and 13 × 10 inches.

During this period there was very rapid development in the type of program material. Not only was studio space at Alexandra Palace considerably enlarged to allow a variety of studio programs to be transmitted, including plays and variety (vaudeville) productions, which involved the use of multistudio technique, but the range of outside events was increased by the laying of a ring cable of the coaxial type, connecting the more important points of entertainment and interest in the London area, and also by the provision of mobile equipment which linked such events as Rugby football matches, on the outskirts of London, and the Derby at Epsom Downs 20 miles away, with Alexandra Palace, for rebroadcasting from that station.

The hours of transmission for home screens averaged 18 hours a week, usually one hour in the afternoon and two in the evening, and the improvement in programs, particularly in respect to outside broadcasts and actualities (such as cricket, tennis, and boxing matches) was so considerable in 1938 and 1939 that the home televiewer had exceedingly good entertainment. (Figs. 1 and 2.) So far the London area was the only favored area, but plans were in hand for the extension of the service to other centers of population. However, television was brought to an abrupt conclusion in Great Britain on September 3, 1939, and from that date onward no transmissions of any type took place until the London Television Service was reopened in June, 1946, following the report of the Government Television Committee published in April, 1945, which recommended early resumption and expansion of the television service in London and in the provinces. Contracts have been placed for the erection of the Birmingham and Manchester Stations, which will, in the first instance, act mainly as relays of the London program. Eventually four more provincial stations will be built, providing a home television service by 1952 which will be available to 75 per cent of the population of Great Britain.

Fig. 1—B.B.C. television cameras at the trooping of the color, Horse Guards Parade, London.

As you well know, commercial sponsoring of programs, both sound and television, is not tolerated, and, therefore, the provision of the service, which at the moment costs the B.B.C. half a million pounds per annum, in return for which they receive 25,000 pounds per annum, being one pound per set per annum for the 25,000 sets already in operation in the London area, does not appear, at the moment, to be an economic proposition. But the B.B.C. remains undaunted by this problem, looking forward to a reversal of the economic picture, when the country is covered with the television service, and when there are sufficient material and labor available to manufacture enough television receivers, at a reasonable price, to satisfy all requirements. All programs, of course, do not satisfy all tastes, but the B.B.C. is doing wonderful pioneer work, considering the limitations of space and equipment. I am perfectly satisfied to receive two good programs a week, for example, a good play or a good variety show, or a good sporting event, for my one pound a year license fee. My satisfaction is, of course, subject to the somewhat selfish provision that I am not required to look at programs which I do not want to see; we are beginning to realize that home television can be a remarkable time-waster, if rigid self-control is not exercised in switching "on" or rather "off" the receiver.

The progress of home television in Great Britain has been referred to in some detail, because in many respects, and particularly in relation to the provision of a program, the service is quite different from

Fig. 2—B.B.C. television cameras at the Oxford and Cambridge boat race.

what you have here and this possibly may indicate slight differences of approach to the application of the theater television technique.

From 1930 onward attention was paid to the possibilities of producing television pictures for demonstration to larger audiences. There were three main lines of development each of which had a practical result: mechanical systems, intermediate film projection systems, and cathode-ray-tube projection methods. To these can be added a fourth, light-valve systems, which were being thought about without yielding anything to indicate possible practical results.

Large-screen television was first demonstrated to the public in Great Britain by John Logie Baird in 1930 at the London Coliseum Variety Theater, when he used a screen of 2100 lamps, operated by a mechanical commutator switch to provide a picture 30 × 70 inches in size. This novelty was retained in the theater program for three weeks, and, therefore, we are justified in saying that it excited considerable interest, although the definition was crude, but the brightness was adequate. An extension of this system was demonstrated in Berlin by Karolus, who employed a bank of 10,000 lamps arranged in a square frame of 100 horizontal rows, each containing 100 lamps. These lamps consisted of miniature cathode-ray tubes arranged in individual compartments in the screen, and the illumination was produced by the excitation of the fluorescent screen on the end of the bulb. The operation of the lamps was controlled by electronic switches in which an electron beam was rotated over a ring of 100 contacts.

At the same time the old mechanical methods were pushed to the limit, and in June, 1932, Baird gave a demonstration of the Derby in a London theater using a three-channel transmission over a distance of 25 miles, each channel providing 10 lines of a 30-line picture 9 × 6 feet in size. The projector consisted of a mirror drum with Kerr-cell modulation of the light. These events are mentioned because we must not forget the work of the old pioneers. By their spade work they were able to lay the foundations and excite the interest of the public, and thereby find the means whereby progress could be made and better methods developed.

Early Color Demonstrations

Before leaving the reference to these mechanical systems, we must mention the first large-screen color demonstration in Great Britain, which was presented by Baird as part of a variety program in the 3000-seat Dominion Theater in 1938. Looking back at that demonstration, in which a two-color process was employed in providing a 120-line interlaced picture, we find that the results were remarkable, considering the state of the art at that time.

Realizing then the limitations of the mechanical methods, we had before us two alternatives for providing a large-screen picture. First (Fig. 3) the intermediate film method which consists in photographing the television picture reproduced on a small cathode-ray tube on to a film, which after rapid development, fixing, and drying can be projected as a standard film through the usual 35-mm projector. Second (Fig. 4) there was the cathode-ray-tube projection involving the stepping up of the normal television receiver of the home to a higher power basis, so that intensely brilliant images of a size approximately 6 inches in diameter can be projected by an efficient lens or

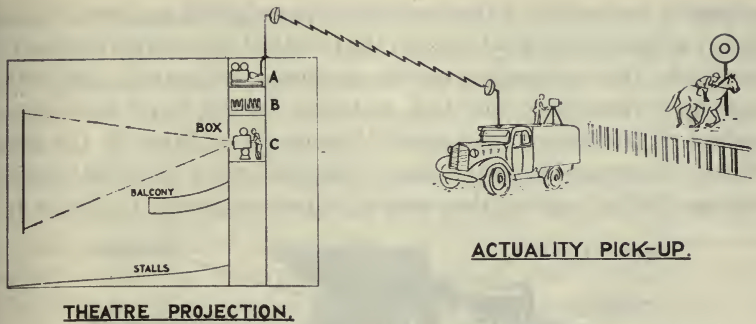

Fig. 3—Delayed large-screen projection by the intermediate film process. Television picture recorded on film at *A*. Film processed and dried at *B*. Film projected by normal projector at *C*. Delay, 5 minutes.

mirror system to the full cinema screen size. This problem of the use of one or other of these methods, or of both of them, still exists today.

First let us deal with the prewar studies of the intermediate film process, which was developed both in Britain and Germany, and demonstrated to theater audiences in 1935. This has the advantage that it is possible to provide the normal standard of brightness on the theater screen, because the processed film passes through a standard projector. The degree of definition achieved was reasonably good, but the method proved to be somewhat expensive, because of the high film costs incurred; and the attempt by our associated company, Fernseh A. G. in Berlin, to use a continuous loop of film, which was cleaned and resensitized in a continuous process in the intermediate film projector, was not attended with success. The 60-second delay in reproduction, due to the time of processing of the film, was not regarded as a serious defect. Such equipment in practice, however, needed a very high degree of supervision, and the maintenance of the

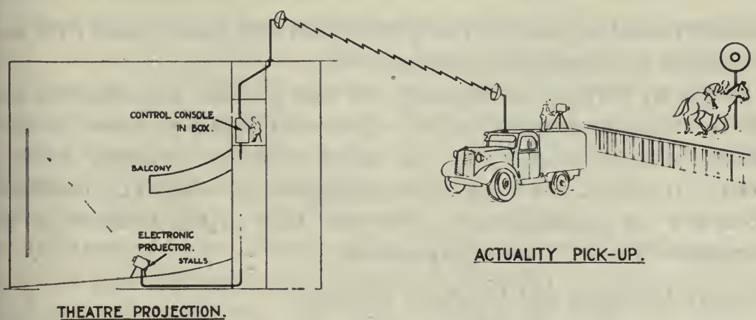

Fig. 4—Instantaneous electronic large-screen projection.

processing baths and of the mechanical parts of the projector was regarded as being somewhat beyond the practical limitations imposed by the day-by-day continuous service of cinema projection. Nevertheless, there were many who had, as many do now have, faith in this method of television presentation, because in addition to the possibilities of increased brightness and definition it has the additional advantage that by putting the received television picture on film, a per-

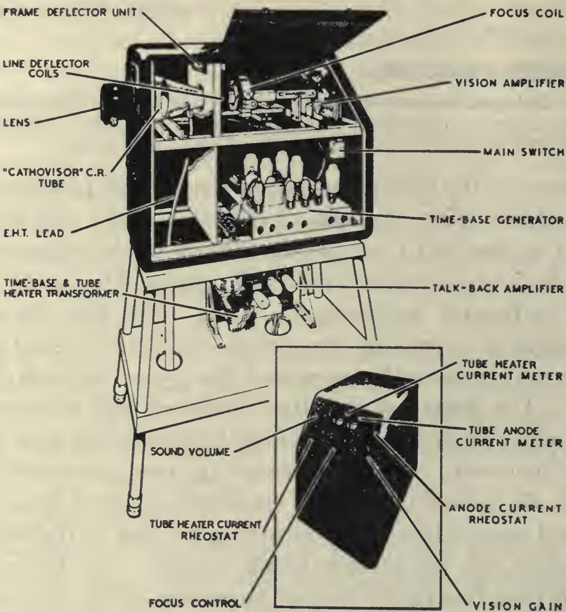

Fig. 5—1938 Baird cathode-ray-tube projector for the 10- × $7^1/_2$-foot screen in the Tatler Theater, London.

manent record is made in the theater and this can be used over and over again in subsequent performances.

However, further development of this process was dropped and efforts were concentrated on the cathode-ray-tube projection method, which appeared to offer the most scope for future practical development. It formed the basis of the equipment developed by the Baird Company for installation in 1938 and 1939 in the theaters of the Gaumont-British Picture Corporation.

Theaters Equipped and Programs Provided

Early in 1938, a small projector was installed in the Tatler

Newsreel Theater (Figs. 5 and 6). It housed a cathode-ray tube operating on 30,000 volts, and reproduced an intensely bright picture (3×4 inches in size) on the screen of the cathode-ray tube, which was projected by an $f/2.5$ lens on to a screen $10 \times 7^1/_2$ feet. The illumination on the theater screen was of the order of $^1/_4$ foot-candle, and the brightness, using a semireflecting screen material, of the order of $^1/_2$ foot-lambert; and demonstrations were given of various actuality programs transmitted on the 405-line basis by the B.B.C. These were mainly in the form of private demonstrations, and for a small theater of that type with a total seating accommodation for 650 people, the results were regarded as eminently satisfactory. The equipment was

Fig. 6—Projection in the Tatler Theater, London, 1938.

entirely of an experimental nature and could not be handled by anyone but a specialist.

These results gave encouragement for further work in larger theaters, and early in 1939 the Marble Arch Pavilion with a seating accommodation for 1290 persons was equipped with a higher power, dual cathode-ray-tube projector, using the pipe-shaped tube with metal-backed fluorescent screen, operating on 60,000 volts, with a Taylor-Hobson $12^1/_2$-inch $f/1.5$ anastigmatic lens. (Figs. 7–10.) This provided an illumination of $^1/_2$ foot-candle on a screen 15×12 feet with a brightness of 1 foot-lambert in the high lights. This equipment was used for special programs on a commercial basis for paying audiences, and we well remember a red-letter day in large-screen projection in February, 1939, when a much publicized boxing match (the Boon-

Fig. 7—1939 Baird twin cathode-ray-tube projector at the Marble Arch Pavilion, London.

Danahar fight) was reproduced to an excited and enthusiastic audience who had paid up to two guineas (ten dollars at that time) for their seats in this theater for this particular event. The audience stood up and cheered on the conclusion of this fight, which fortunately went the full distance. Not a single person asked for his money back! The success of the results achieved led to the Gaumont-British Picture Corporation (whose President then was Mr. Isidor

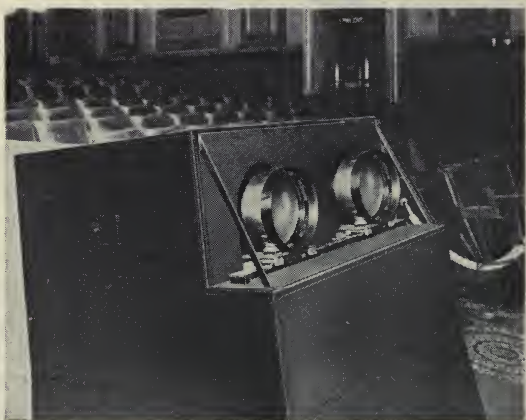

Fig. 8—1939 Baird twin cathode-ray-tube projector at the Marble Arch Pavilion, London. (Front view.)

Ostrer, a man of considerable vision, to whom we owe much for his encouragement of television in the early days), ordering twelve equipments for installation in the larger London theaters. By September, 1939, the following theaters had been equipped with these projectors.

Marble Arch Pavilion	1290 seats
New Victoria Cinema	2564 seats
Gaumont, Haymarket	1382 seats
Gaumont, Lewisham	3047 seats
Tatler Theater	650 seats

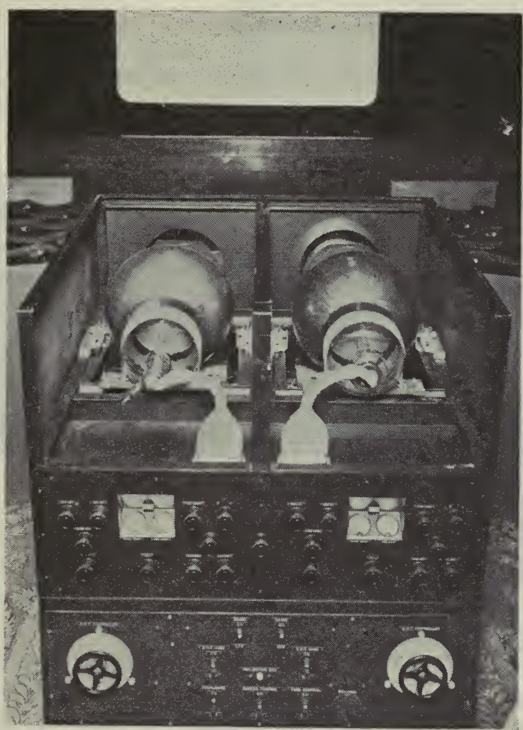

Fig. 9—1939 Baird twin cathode-ray-tube projector at the Marble Arch Pavilion, London. (Rear view of controls and cathode-ray tubes.)

The incidence of war prevented the equipping of other theaters and thus the plan to have selected television programs presented at twelve London theaters to a total audience capacity of approximately 22,000 was never realized.

At the same period Scophony, Limited, with its optical mechanical system with the supersonic light valve, equipped the Odeon Theater, Leicester Square, 2116 seats (Fig. 11), and certain news theaters, and were attracting full audiences for special programs.

III. Requirements for a Theater Service

Before continuing with the historical development since the war, I would like to discuss briefly the requirements for a theater television service.

The Complete Theater System

It is the ultimate aim of the television engineer to provide the entertainment industry with a complete television system which can handle

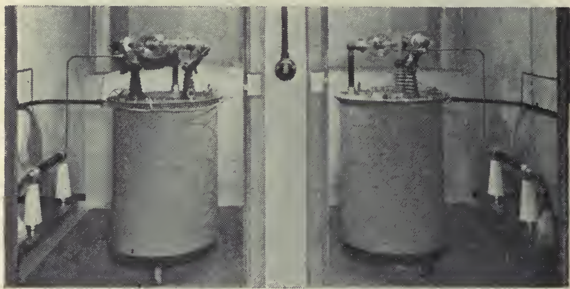

Fig. 10—High-tension units at the Marble Arch Pavilion.

and distribute all types of program material which will be of interest. The system and the equipment utilized therein can be conveniently divided as follows:

(a) Pickup equipment consisting of cameras and associated equipment for synchronizing control for interior (such as studio and dramatic presentations) and for exterior (outdoor scenes) together with the necessary sound pickup, lighting, and power supply.

(b) Film-scanning equipment.

(c) Control-room equipment, for the purpose of selection and routing of programs.

(d) Distribution network, utilizing special cables or high-frequency radio channels.

(e) Theater television projectors and loudspeakers.

Fig. 12 (a charter or ideal for British theater television engineers) indicates a possible system of pickup, control, distribution, and theater reproduction which is capable of dealing with events taking place mainly in the London area, and of distribution not only to theaters in London but also in the provinces. At the same time it comprises provincial program sources also.

Progress after the termination of the war has been concentrated under all the above headings, and will continue until there is evolved a satisfactory system which exhibitors will welcome as a valuable contribution toward their theater entertainment. The aim of the technician, who is primarily concerned with this aspect of television, will be to secure perfection independently in each of the divisions of work enumerated above.

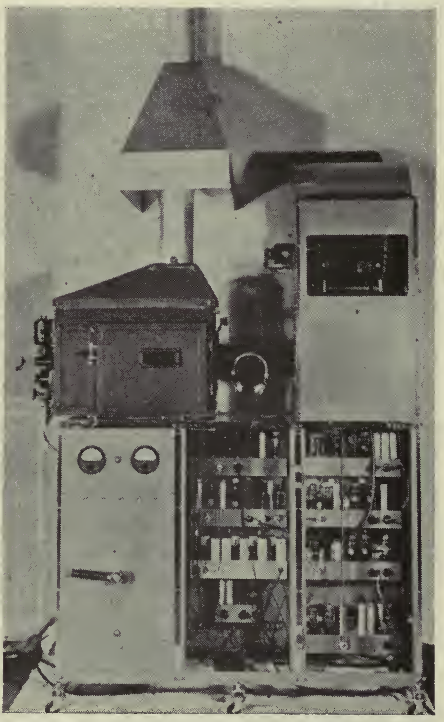

Fig. 11—Scophony supersonic light-valve projector installed at the Odeon Theater, Leicester Square, London, 1939.

Comparison with Film Projection

The overriding problem is, of course, the development of theater television projection to a form comparable to the present-day film projection.

Such a program of work can conveniently be visualized in two stages:

(1) The attainment of the utmost possible performance in each link of the 400- or 525-line system; alternatively the maximum possible to the 3-megacycle bandwidth limit.

(2) The full equivalent to film projection (say 1000-line basis or 20-megacycle bandwidth, or whatever it may be found to be).

Satisfying the Exhibitor

The exhibitor or promoter is our customer, and he presumably is capable of visualizing a true representation of what the public will require. It is our duty to satisfy him, if he wants it, by providing:

(1) Instantaneous projection in theaters, from a given distribution center, of items of entertainment, of interesting events and actualities.

(2) Delayed presentation from the distribution center. For example, daily films of local interest which are applicable to the theaters in a local area.

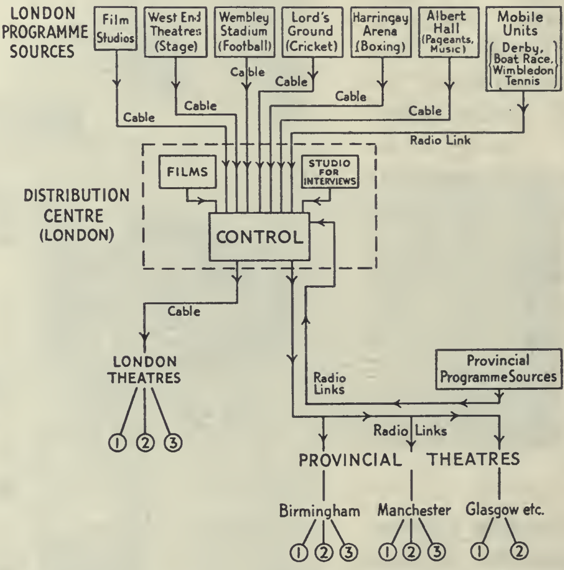

Fig. 12—Proposal for nation-wide theater television network.

(3) Delayed presentation in individual theaters where the program planning is impracticable to admit of (1), or requires re-presentation additional to that given by (2).

All these needs must be provided with the qualities of normal film projection.

There may be, there are sure to be, other requirements as well, but for the moment we, as technicians, have many problems to solve (even in black-and-white only), and they will take time. However, I must emphasize that the theater owners and exhibitors must also spend this period usefully in studying the possibilities and limitations of the application of television and in trying to decide how they want to use it as a means of entertaining, attracting, and even educating the public. There is no doubt that we are up against this problem of what to do with television in the theaters, and we are entitled to ask, and to receive, an answer to this question, while we are working on our purely technical problems, the solution of which is inevitable in the course of time. I should not, however, like to be too optimistic at this moment by saying that we have ready a system which we can present immediately to the exhibitor in the form suggested earlier in the paper. It may be three years or it may be more before we can provide the brightness and definition in the quality of the picture which will be necessary, for the exhibitor to mingle his television with his film program; but it may be that he will find it profitable to consider an intermediate step whereby the television program can stand on its own merit without achieving the full technical results of the film projection, and by segregating the television from the film program, or the television theater from the film theater, can give us an opportunity of gaining practical experience in the new technique.

It may well be, on the other hand, that the new art will not be constricted to such applications, but will break out, with success, in an entirely new medium of application, which we have so far not visualized.

I look forward to a more careful consideration of all the points by those who are responsible for the provision of public entertainment, and by such people who have the imagination and initiative to make practical use of the new tool which is now being forged.

IV. Postwar Development

Progress Toward Setting up a Theater Service

The keynote of the resumption of work on television in the autumn of 1945 was set by the British Government Television Committee, which issued a report in that year setting forth its deliberations regarding the reinstatement and development of the television service after the war, with special consideration given to (a) the extension of the service to the larger centers of population, (b) encouragement of research and development, and (c) guidance to manufacturers of equipment.

Although $2^1/_2$ years have elapsed, and very little has been done under (a), (b), or (c), I should say that the report was extremely good and showed that full consideration had been given by the Committee to the various aspects of television—technical, commercial, and political.

So far as it concerns us, I should like to quote a few sentences from the report. Thus, under the heading "Television in the Cinema," after stating that "The Committee had not been unmindful of the potentiality of cinemas for displaying television programs," the report went on to say:

"Before the war certain firms were interesting themselves in the production of apparatus for this aspect of television, and a few cinemas had acquired equipment capable of projecting a picture of large size on the screen from a position in the stalls. Such apparatus was used with some success on occasions when events of outstanding public interest were televised."

Then it goes on to say later:

"We are encouraged to believe that the cinema industry and the British Broadcasting Corporation working in co-operation and not as competitors in the exploitation of television, will achieve considerable results of a character beneficial to both."

And further:

"Although television in the home would compete with the cinema for the public's interest, the extension side by side of the two forms of entertainment should on the whole prove mutually helpful rather than otherwise, and home and cinema television are likely to have a stimulating effect on each other."

And, finally:

"We recommend that close attention should be given to the possibilities of the use of television by cinemas."

This report was accepted by the British Government and issued in the form of a white paper, but since that date no official pronouncement has been given indicating that these recommendations have been implemented in any way, or that any steps have been taken to give effect to them or to encourage the cinema industry in its work on these problems. I shall deal further with this point later on, but for the moment I should prefer to submit to you details of the work which has been done by commercial companies, and in particular by my own Company with the encouragement of Mr. J. Arthur Rank, and of the results achieved in the two years since we started thinking about television again in the autumn of 1945. During this period, we have seen the development and application of many new types of equipment which have an important bearing on our work; for example, new types of television cameras, of scanners for film and still pictures, new means of distribution by radio or by cable, and theater projectors either of the cathode-ray-tube type with lens and mirror systems or of the intermediate film type, or of the storage type.

Comparison with Cinema Standards

Before considering these in detail, let us consider five main headings (which possibly can be regarded as separate factors, but which in practice are all interlinked), to provide a basis of comparison with the accepted standards of the cinema.

(1) Picture definition, or detail of the reproduced picture.

(2) Picture quality or faithful reproduction of the tone values, from black through the half tones to white.

(3) Brightness of the reproduced picture, and its color.

(4) Freedom from interference, flicker, spurious patterns and effects, shading, and background noises.

(5) Cost of manufacture of the equipment and of its installation and maintenance.

Performance of Equipment

Let us now make a brief review of the various types of equipment already developed on both sides of the Atlantic, demonstrated in England, and also able to be manufactured.

(*a*) *Cameras.* You are quite familiar with the operation and characteristics of the various types of television cameras, so I need not go into them in detail, except to say that with the iconoscope we acknowledge its superiority in definition, but also its limitation in the production of undesired shading effects which cannot be controlled. The image iconoscope has the advantage of a little more sensitivity than the iconoscope and less shading troubles. The orthicon with its even field of picture rendering is free from shading, but loses detail; and the image orthicon with its enormously increased sensitivity, suffers, however, from background noise and great difficulties in manufacture.

(*b*) *Film Scanners.* There are those, like the Mechau continuous-motion mechanism, installed at the B.B.C., which use the iconoscope, and therefore also suffer from shading distortions of the picture gradation. There is the Farnsworth dissector film scanner which gives an even field, but is difficult to set up to avoid geometrical distortion of the picture. And finally, there is the cathode-ray-tube flying-spot scanner, which can give, under controlled conditions, as good a picture as you would wish to see, with excellent definition and quality, and free from shading.

(*c*) *Caption or Still-Picture Scanners.* The same remarks apply.

(*d*) *Means of Distribution.* By radio links, which can carry the full requirement of frequency range, which are flexible in setting up and operation, but which may be subject to interference.

By cable, with limited frequency band and high capital cost.

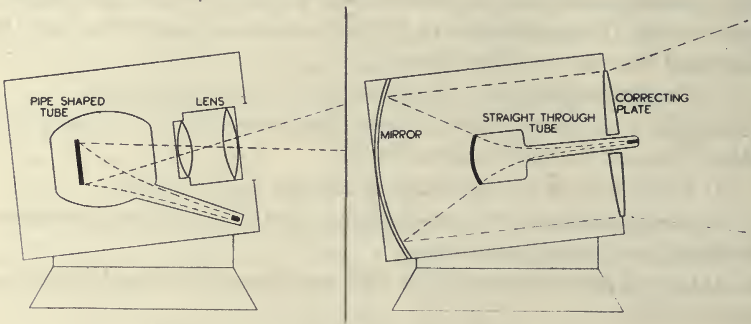

Fig. 13—Lens and mirror electronic projectors.

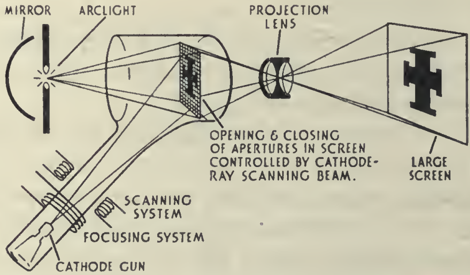

Fig. 14—Electronic storage projection system.

(*e*) *Projection.* Cathode-ray-tube projectors, either using a wide-aperture anastigmatic lens or a Schmidt-mirror system, with its great advantage. (Incidentally, I remember testing a Schmidt projection system in 1937.) (Fig. 13.)

Intermediate film projectors, in the operation of which much experience still is to be gained.

Storage projectors (described in principle in Fig. 14) of which only one type so far has been shown to be reasonably practicable, namely the AFIF system developed by Professor Fischer of Zurich. (Figs. 15 and 16.)

(*f*) *Screens.* Types of screens with higher reflection coefficients than the normal matte white screen, such as the established types of beaded or silver screens; new types of screens coated with material which is a combination of matte white and silver; and lenticular types of screens varying from the crudely stippled metal screens to the optically designed lenticular screens which project all the received light back into the audience seating only. (Figs. 17 and 18.) A screen

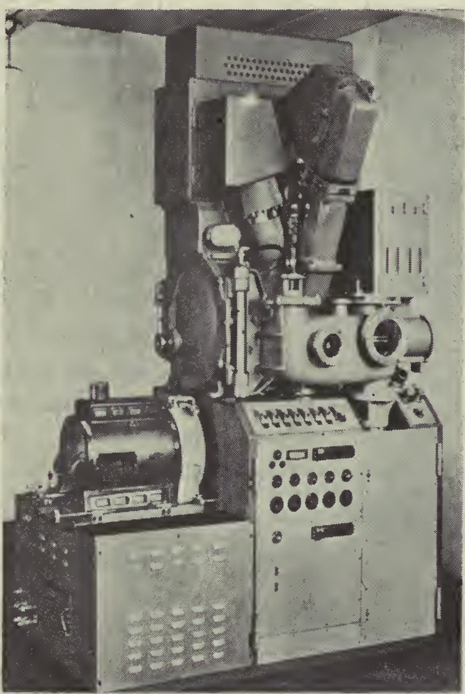

Fig. 15—AFIF storage large-screen projector.

having a reflecting cone with a vertical angle of 40 degrees and a total horizontal angle of 104 degrees would be ideal for the average theater. (Figs. 19 and 20.)

Arising out of the consideration of the qualities of the various types of equipment referred to (lack of time prevents me from going into a detailed study), we have in my Company evolved an experimental 405-line system which has already been the subject of practical tests, and which for the present consists of:

Telecameras
The image orthicon or image iconoscope.
Telecine
Cathode-ray-tube flying-spot film scanner. (Fig. 21.)
Telecaption
Cathode-ray-tube flying-spot still-picture scanner. (Figs. 22, 23, and 24.)
Teledistribution
Radio links operating with a few watts on a frequency of 480 megacycles at distances up to 12 miles.

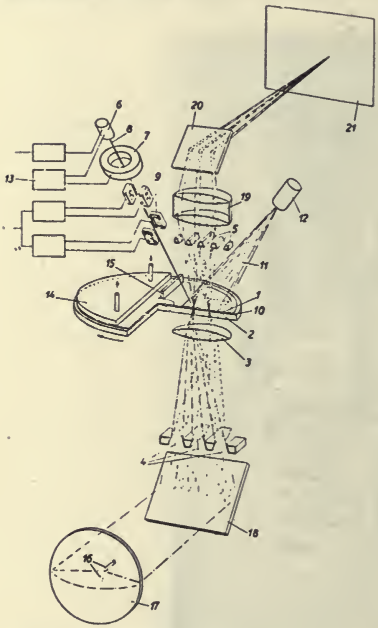

Fig. 16—AFIF storage projector.
16, 17—Arc lamp.
1—Eidophore oil film scanned in vacuum by the cathode-ray beam 8.
4,5—Heat-absorbing bars.
19, 20—Lens and mirror projecting the picture on to the screen 21.

Teleprojectors
A Schmidt mirror projector (Figs. 25 and 26) having a 27-inch diameter mirror, and an 18-inch diameter plastic correcting plate; with an aluminum-backed straight-through cathode-ray tube, operating on an anode voltage of 50,000; mounted in the stalls, or on the front of the balcony; remotely controlled from a console installed at the back of the stalls or in the projection box. (Fig. 27.)
Theater Screens
Of a type where the reflected light is concentrated into the area occupied by the audiences.

I must now state the practical results achieved in terms of the fundamental points of performance which I have specified above.

(1) The *definition* over the whole system is such that 3-megacycle vertical bars are resolved in the picture without any noticeable phase defects.

(2) The measured high-light *brightness* on a 14- × 11-foot stippled metal screen in the direction normal to the screen down the center line of the theater, is 5 foot-lamberts, compared with the accepted film standard of 7 to 14 foot-lamberts, and the measured black brightness is 0.1 foot-lambert; the average contrast range during a succession of pictures is 30:1. At 30 degrees off the center line the high-light brightness is 2.5 foot-lamberts. The output of light from the projector with no picture, and running at a brightness corresponding to the maximum usable high-light brightness for a good quality picture is

300 lumens. A new projector, almost completed, will provide a light output of 600 lumens, adjusted for conditions for good quality picture projection. By the time we get into the London theaters we hope to project 1000 lumens on to the screen. The color of the picture is off-white in the direction of cream. Fig. 28 indicates the progress of definition and brightness over the years, in comparison with the desirable results which are equivalent to the average characteristics of film projection in theaters. The important point about these curves is that the upward tendency continues and there is no sign yet of a slowing up of progress, which might be indicated by a flattening of the curves.

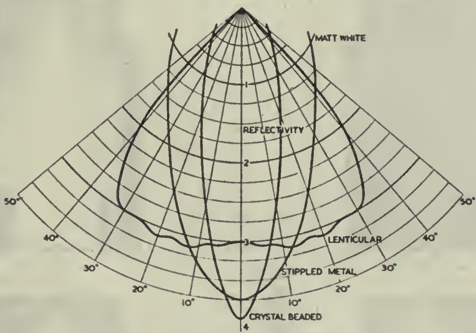

Fig. 17—Polar diagrams showing reflectivity of types of screens at various angles with the normal to the screen, compared with that of the matte white screen which is represented by the circle of radius 1.

(3) The estimated *over-all quality* curve is approximately linear over the range from black to two thirds the high-light brightness specified in (2) above, and flattens out above that figure. For example, we have measurements indicating a brightness curve for the projector as follows:

A gamma of $1/2$ in the shadows, caused mainly by scattered light.

A gamma of 2 over the greater part of the curve up to $2/3$ high-light brightness.

A gamma dropping to $1/2$ at the upper values of brightness due to electron-beam defocusing at high current, saturation in the fluorescent powder, and other causes.

This distortion, if measured correctly, can be mostly made good to provide an over-all constant-gamma condition.

(4) With regard to *freedom from interference*, I must admit that there

is much to be desired with existing standards, and with relatively uncontrolled local noises. Under the best conditions these can be a relatively unimportant factor, but on occasions the interference may be troublesome and cause annoyance to the spectator.

Proposals for an Experimental System for the London Area

The complete system described above, and which is in practical operation in an experimental form, and can be engineered in a form suitable for the production of a serviceable instrument, is, in my

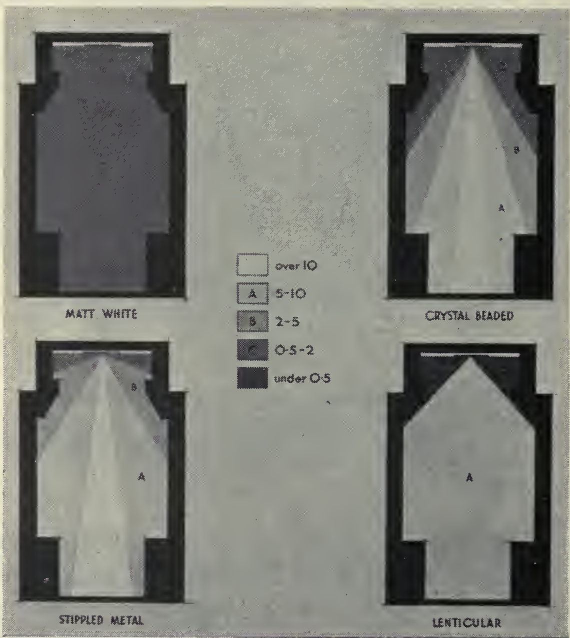

Fig. 18—Pictorial representation of screen-brightness distribution in a theater for various types of screen, subject to a given value of illumination.

opinion, a first practical solution which we can offer to the cinema interests. It is a long way ahead of the 1939 equipment. It is up to them to decide how, where, and when they can use it to advantage.

Our recommendation is to set up a sample system in daily operation for invited and paying audiences. Fig. 29 illustrates a plan of a proposed experimental system which we hope to work out during 1948 to give us this experience. You will see that programs are to be provided from three centers, the B.B.C. Studios at Alexandra Palace in the north of London, the Pinewood Film Production Studios of the Rank Organization to the west of London, and the Crystal Palace site

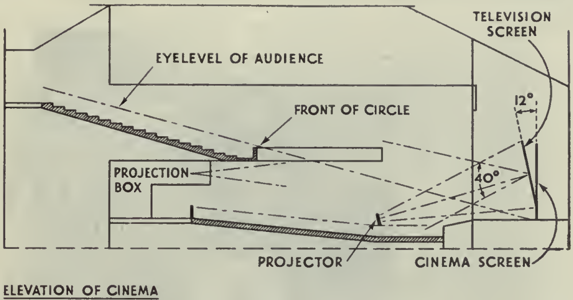

Fig. 19—Elevation of average theater showing the angle required for screen reflection in the vertical plane.

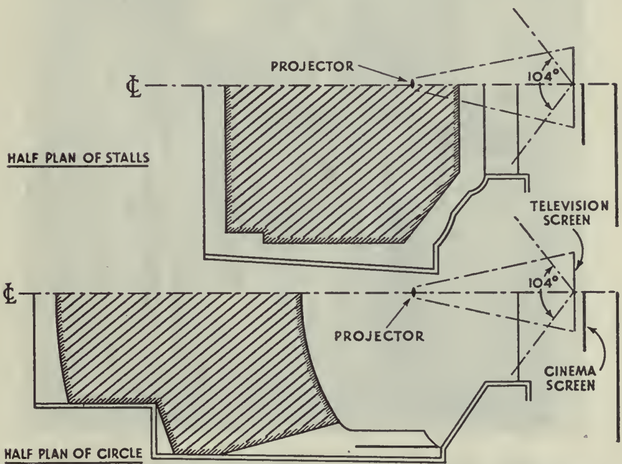

Fig. 20—Plan of average theater showing the angle required for screen reflection in the horizontal plane.

on the southern side overlooking London, where we shall set up a central receiving station and retransmitting station, and some local scanners for the transmission of films, interviews, and announcements. The radio links will be on frequencies just above and below 480 megacycles. Retransmissions will be beamed, from the Crystal Palace, with an angle of 10 degrees in the direction of certain theaters which are suitable for the installation of the projection equipment. We have in mind four West End theaters and two suburban theaters. One beam will suffice to cover the London West End cinemas and a selected northwestern suburban cinema, and another beam will cover a suburban cinema in the southeastern area of London.

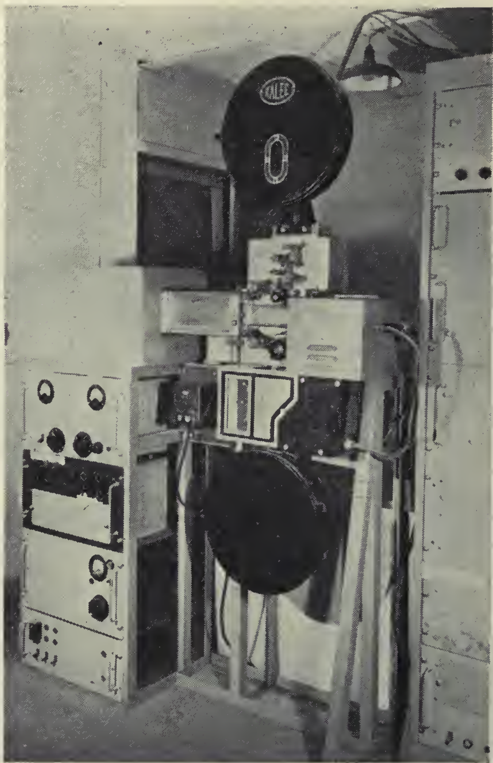

Fig. 21—"Cintel" flying-spot (35-mm) film scanner. (Scanning tube in left-hand box, optical system and gate in center, multiplier phototube in right-hand box.)

Figs. 30 and 31 are elevations of two of the selected cinemas showing our proposals for equipping them.

Audience Reaction

So far, nothing has yet been done, so far as I know, on either side of the Atlantic, which would give the exhibitor some practical figures and experience to gauge future public requirements. We badly need experience on public reactions to a regular service beyond the stage when television was just a novelty and used only on special occasions.

We recently invited a cross section of our employees to see a projected B.B.C. program (lasting $1^1/_4$ hours) in the cinema which we had equipped with the projection installation described above. These

Fig. 22—"Cintel" flying-spot caption scanner. (Scanning tube below, lens and phototube box in center, monitor tube above.)

employees had been working some distance away in other factories, and had not seen any large-screen pictures before. The entertainment value of the program projected happened to be poor. This was beyond our control, but we were surprised at the tone of the response to the questionnaire which was circulated to each employee afterwards, asking for impressions. The total number concerned was 264 and there was a good mixture of technical, clerical, and administrative

Fig. 23—Still picture transmitted on 405-line basis by "Cintel" caption scanner.

(nontechnical) staff, bench workers, wiring and assembly girls, and glass workers, and the following is the analysis of the voting papers:

Fig. 24—Still picture transmitted on 405-line basis by "Cintel" caption scanner.

AUDIENCE REACTION FIGURES

1. The picture was generally:	better than expected	129
	as expected	83
	not so good as expected	52
	total	264
2. The picture was:	adequately bright	165
	not bright enough	99
	total	264
3. The detail was:	just sufficient	79
	not quite enough	145
	not nearly enough	35
	nonvoters	5
	total	264
4. The picture caused:	some eyestrain	158
	no eyestrain	101
	nonvoters	5
	total	264
5. The picture:	is good enough	163
	is not good enough	96
	nonvoters	5
	total	264

to justify reproduction on large screens of certain events of general interest, i.e., the Boat Race, Test Cricket, football, etc., to paying audiences.

So much for what might be termed an average audience.

Now to come to an audience of enthusiasts, where there is no question at all regarding the practicability of utilizing large-screen television up to its present degree of performance.

We were invited at the beginning of the month to assist at the Conservative Conference which was held at Brighton on the south coast of England, in the large 3000-seater Dome, built in the oriental style, by King George IV in 1805. As an attendance of 4000 persons at the Conference was anticipated, room had to be found for an overflow meeting in the Dolphin Theater, a 1000-seater, and about 500 feet away from the Dome. We set up image-orthicon cameras, manufactured for us by the Du Mont Company, facing the platform in the Dome, one for the close-up of the speakers and the other for a general view of Mr. Churchill's Shadow Cabinet on the platform. The picture was reproduced on a 14- × 11-foot screen on the stage of the distant theater, on a 405-line basis, with a Schmidt projector operating on

40,000 volts, and giving a high-light brightness down the center of the theater of 4 foot-lamberts. To enable the delegates to study their agenda papers there was about $^1/_4$ lighting left on in the theater. We had accepted this invitation to gain experience, and we certainly did get that experience from the enthusiastic Party representatives, especially on the occasion when their Leader was speaking. Throughout the three days of the Conference, the theater was filled to overflow-

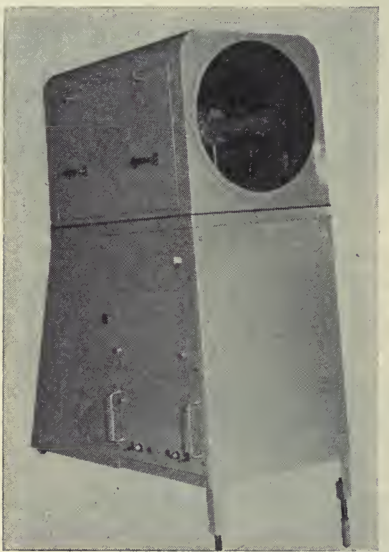

Fig. 25—"Cintel" mirror projector for 16- × 12-foot screen. (Front view.)

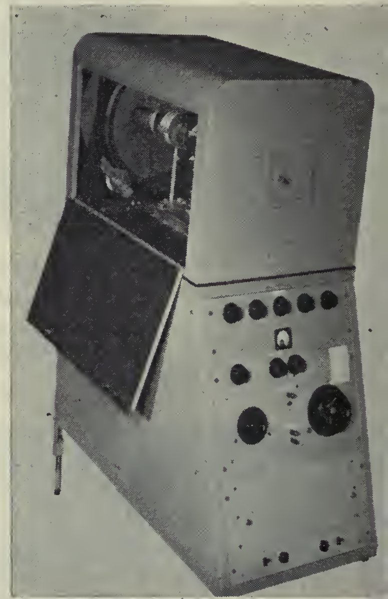

Fig. 26—"Cintel" mirror projector for 16- × 12-foot screen. (Rear view.)

ing, and many of the visitors preferred the close-up of the speakers on the large screen to the more distant view in the large Dome. On the last day, I sat at various points in the theater and took Leica snapshots, at exposures of $^1/_{10}$ of a second, using an $f/2$ lens and Super-XX film, of the large-screen results, and I am happy to be able to present some of the results here, and I am more than happy that they represent one who is, I believe, regarded throughout the world, and even in Britain also, as one of the greatest leaders of our time. (Figs. 32 and 33.)

Installation and Regulations

Finally, there is one factor not to be ignored; the installation problem, especially in relation to national or local regulations which, when originally framed, did not envisage the use of television in theaters.

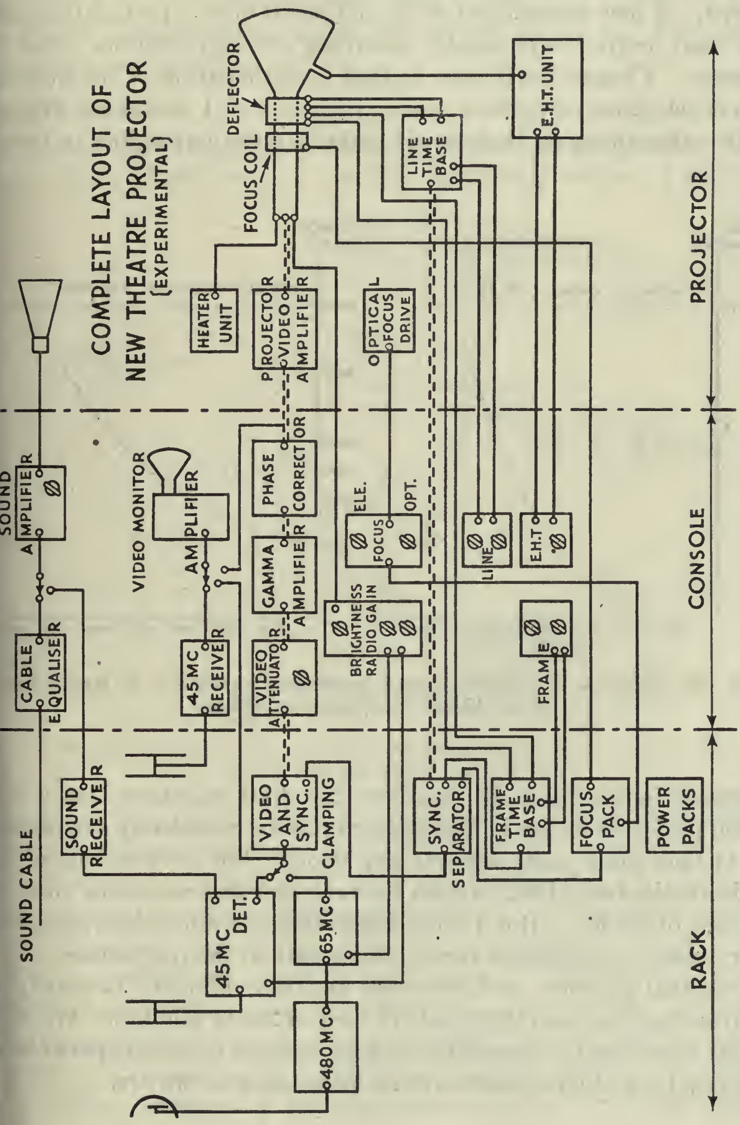

Fig. 27—Block diagram showing three main units of "Cintel" 1947 theater projector, capable of operating off cable input, and off 45- and 480-megacycle radio inputs.

In Great Britain the authorities are busy drafting more and more new regulations. Everything has to be regulated. The old original Cinematograph Act of 1909 (amended only once since that date in 1923 and before the advent of sound, and still legally in force) would close *half* the cinemas in the country if the letter of the law were observed. A new amendment of the old Act is now in preparation, and has been drafted, and would, according to the exhibitors, close *all* cinemas. Clauses have been drafted in anticipation of the installation of television equipment, and in such a form (I should say without malice aforethought) that would make it quite impossible to install

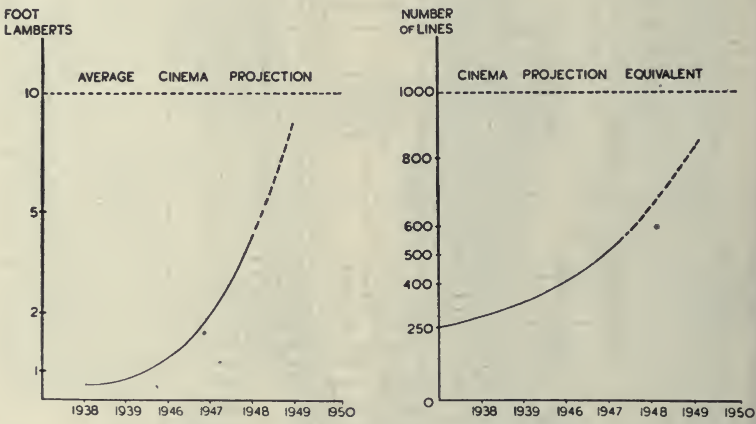

Fig. 28—Progress of brightness and equivalent definition in large-screen (16- × 12-foot) television projection.

television in cinemas. For example, the draft stipulates that a television projector set up in the theater must be completely surrounded by 14-inch brick walls without any doors. We have visions of the projectionist being built in with the projector and remaining there all the rest of his life. But I must admit that the authorities are, however, open to suggestions for improvements in the regulations.

In actual practice, we have never had any difficulty in satisfying local authorities from the points of view of safety and fire. We have found them most co-operative and as anxious to gain experience in the new type of equipment and its installation as we are.

V. Present Problems (Requirements for the Immediate Future)

I have dealt with the present state of the art in Great Britain. I may have painted, perhaps, too rosy a picture, but I prefer to be an optimist, recognizing that we still have a long way to go. Our present problems are as follows:

(*1*) *Technical*

We have to improve detail, quality, projection brightness, and freedom from miscellaneous minor but irritating defects. I prefer to

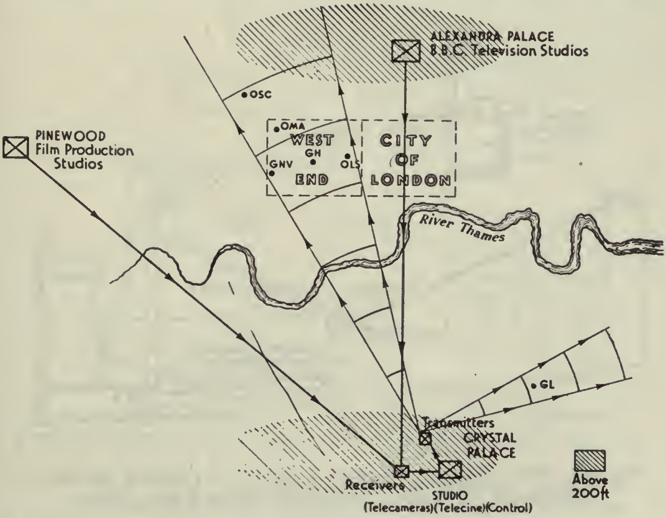

Fig. 29—Proposed experimental cinema-television-distribution plan in the London area. (For 1948.)

group all these points together and to refer to some of the fundamental problems associated with all of them.

(*a*) *Number of Lines for Theater Standardization.* We have seen many references to the 1000-line desirability. On the other hand, we have often heard that our 405-line system at its best is enough. That, of course, refers to a controlled local picture. Therefore, ignoring for the moment all the excellent work which so far has been done in trying to establish the minimum basis for either home or large-screen projection, we decided to start afresh and make a practical investigation with many observers, of the brightness-resolution—contrast relationship in projected pictures.

Some of the preliminary conclusions are given in Fig. 34 which show the result of observations made on line patterns of various dimensions exhibiting varying degrees of contrast and illuminated at various values of brightness. The curves in the diagram connecting brightness resolution and contrast should be taken as indicative of the order of magnitude involved where the unit of relative brightness represents the normal high-light brightness of a projected picture, say approximately 10 foot-lamberts. The number N of test lines per picture height is equivalent to the number KN of lines of television scanning, where the factor K lies between 2 and 3. Curve A indicates that the

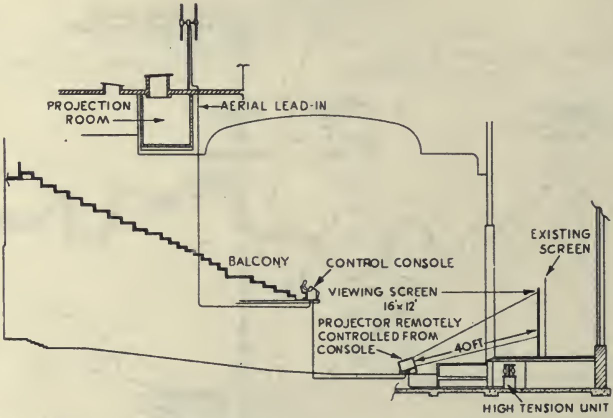

Fig. 30—New Victoria Theater, London. Proposed television installation with the projector in the orchestra stalls.

eye can appreciate up to something between a 950- and 1400-line picture at a brightness of 10 foot-lamberts; but in practice, according to curve D, the result of observations of projected films, it is satisfied with something between a 650- and 950-line picture at that brightness. Arising from this, it appears to be desirable that we should aim at a standard of something round about 900 lines for theater television, and up to 1200 lines, if we wish to record a picture on film which will provide prints equivalent to normal film practice.

(*b*) *Systems of Scanning.* We have got too much into the way of a tacit acceptance of double interlacing, based on a theoretical calculation of its advantages. I am not at all sure that practice has proved this.

At the recent Cannes Conference it was generally agreed that the time was ripe for a renewed investigation of sequential processes. In fact, all the authorities there admitted, as a result of their practical experience of results using interlaced scanning, that they would prefer a 500-line sequential picture at 50 frames per second to a 1000-line interlaced picture at 50 frames, 25 pictures a second.

The following defects are observed in interlaced scanning: line crawling, interline flicker, spurious pattern flicker, line breakup on movement, pairing or loss of interlace, unequal field brightness, irregularities and irritating effects on vision, and complexity of circuits and equipment.

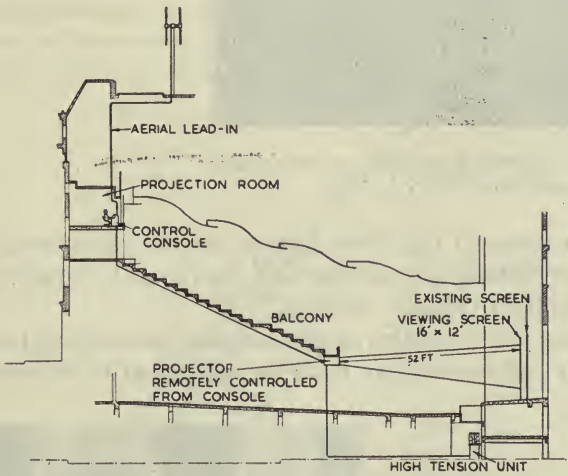

Fig. 31—Gaumont Theater, Haymarket, London. Proposed television installation with the projector on the front of the balcony.

Some of these also appear with sequential scanning, with the added disadvantage for a given channel bandwidth of greater "lininess" and lower definition.

The list of interlacing defects is formidable, and indicates the reason for disquiet as to the future of interlacing in improved television systems. The advantages, however, such as terms of improved definition, are not to be lightly disregarded. The final choice, to interlace or not, cannot be decided without further observational data.

A number of various comparisons can be made, but they all resolve themselves into a choice between either a loss of definition or the presence of flicker and stroboscopic defects. Other factors which will

Fig. 32—Mr. Churchill speaking by large-screen projection (14 × 11 feet).

require attention in this investigation are the compromise between vertical and horizontal resolution, and the value of artificial means for line broadening to reduce "lininess."

In drawing your attention again to sequential scanning, I should like to mention that recently we made an equipment to demonstrate the

Fig. 33—Mr. Churchill speaking by large-screen projection (14 × 11 feet).

principles of scanning a picture and reconstituting it, for the Science Museum in London, in connection with the Electron Jubilee Exhibition. We employed a scanning of 100 lines sequential, and the reproduced picture had a remarkable element of stability; in fact the rigidity of a lantern slide, and we were not unduly bothered by the limitations of definition due to the low number of scanning lines. In my opinion, in introducing interlaced scanning we have deliberately tried

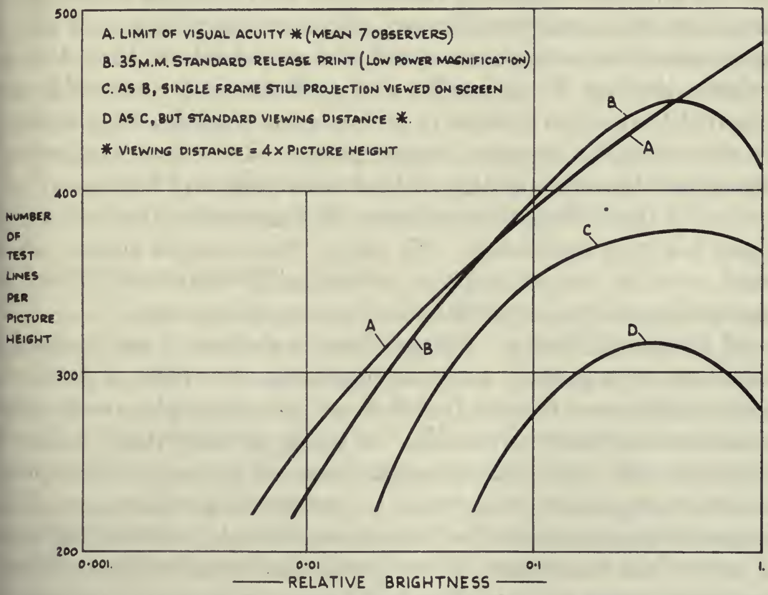

Fig. 34—Investigation of brightness-resolution—contrast characteristics. Data for center of field, with low-contrast test object. (Density difference 0.3, equal line width—line spacing.) Constant "average" brightness of picture.

to deceive the eye, and the eye will not stand to be deceived, and it is in this connection that we shall find advantages when we come to achieve any system of storage projection.

We have made some interesting tests, originally out of curiosity more than anything else, to compare the results of projecting, one after the other, an intermediate film picture and an interlaced electronic picture on the large screen, of the same subject scanned with the same number of lines, and we were remarkably surprised at the amount of irritation, as you might describe it, produced by the interlaced projected television picture on the eye, in comparison with the steady restfulness of the projected intermediate film picture. I have an idea that here we have a vital point regarding vision which needs much more study; and, furthermore, that an electronic sequential picture will occupy an intermediate place between the other two regarding the general stability and freedom from irritation (and from consequent headaches) desirable for large-screen projection.

(c) *Channel Bandwidth.* We have had to change our minds during the last two years regarding the amount of intelligence which can be carried on a 3-megacycle channel. Now we find that we are able to squeeze much more apparent detail and quality into a channel with a definite cutoff at 3 megacycles, and we have been remarkably surprised at the general increase of performance which has been achieved by correcting for response, phase, gamma, and other requirements throughout the whole system within this limitation of frequency. Up to now for the 1000-line transmission, the bandwidth of up to 20 megacycles has been mentioned. We believe that we shall achieve all we want to do by concentrating on obtaining the maximum value that can be obtained on a channel up to 12 megacycles only.

(d) *Quality of Picture.* We have been in the past, I feel, content to have seen occasionally, when all conditions were right, a picture of good quality, and then to feel that we had achieved a result which would be universally acceptable. It is only recently that a full study has been made of the component and over-all linearity of the system and that steps have been taken to correct errors in gamma. This process of gamma control, which ensures that the relative brightness of parts of the reproduced picture bear a linear relationship to the corresponding parts of the picture being scanned, is of vital importance in ensuring a picture of first-class quality. It is only when a system has been set up which complies reasonably well with this condition and registers an over-all gamma of about 1 that one realizes the enormous improvement in general quality of the picture. As regards projection, I am convinced that so far no projector of any type complies with this condition. As previously mentioned, there is a distortion of the gamma curve, particularly in the high-light region, and this must be corrected, first, by studying each element of the system in turn, and, second, by applying an over-all correction when each element has been improved as far as it will go.

(e) *Picture Brightness.* In the cathode-ray-tube projector the curve connecting brightness with anode voltage on the cathode-ray tube, and the curve connecting brightness with beam current, both show saturation, which begins at a certain high-light brightness on the viewing screen. The problem of extending the brightness curves is one of the most important that we have at the moment. This involves the following studies:

(i) The development of optical systems of the mirror type to even greater efficiency than the Schmidt.

(ii) The development of tube electronic characteristics so that defocusing is controlled with an increase of voltage and current.

(iii) The development of a fluorescent material and its application to the face of the tube, studying in particular the problems of high-current saturation, defocusing, and halation in the layer; and also its color and life characteristics.

(iv) The development of the viewing screen providing more economical use of the light projected on it, so that it is reflected back where it is required and not dissipated throughout the theater.

(2) Distribution Systems

Considerable study has been made of the relative advantages and disadvantages of cable and radio means of distribution. On behalf of the radio link, we find lower capital and running costs, more flexibility in operation, and against it the scarcity of channels, and interference; on behalf of cable, a clear and undisturbed channel (at least we hope so), and secrecy; against cable, the high cost of installation, resulting in high rental charges, and the length of time before the installation can be carried out, due to higher priority for installation labor. In Great Britain, both radio and cable links are controlled by the Postmaster General, and in the setup of a radio system of a permanent nature, such a system would most likely not be licensed for commercial operation, but would be taken over by the Post Office to operate in whatever manner it thinks fit. However, the exceedingly high charges for the rental of coaxial cables (something in the nature of £600 per mile per annum for a 3-megacycle cable has been quoted) with no definite date of availability promised within the next five or ten years, makes it imperative to provide experimentally a radio-link system, and the first steps in this direction already have been described. In the meantime, the first link in the provincial distribution system of B.B.C. television programs has been started. Work has commenced on a radio link between London and Birmingham to operate on 900 megacycles.

Although you are, for your own commercial cinema schemes, pressing for allocations of frequencies above 1000 megacycles for radio links, we are pressing for the 500- to 1000-megacycle band, because this range offers, in our opinion, advantages for wide-band television which may not be possible in the regions above 1000 megacycles.

(3) Program

Here we have many problems, the majority of which are outside our technical province. I have already referred to some of them. Others causing us much thought in England are as follows:

(*a*) *License to Operate Commercially.* Over two years ago we asked the government to consider giving us facilities to operate on a commercial basis between our studios and theaters. The permission is concerned with the means of transmission and distribution. In other words, we ask for a license to use the ether or the facilities provided by Post Office cables. In this respect we are dependent on the Television Advisory Committee (which has taken the place of the original Television Committee), and this Advisory Committee has been taking plenty of evidence during the last two years but has been very slow in making the appropriate recommendations to the Postmaster General who would present them, if he agreed, to Parliament for ratification.

(*b*) *Three-Cornered Interests.* It may be that although the report of the Television Committee advised that steps should be taken toward the encouragement and establishment of a television service for cinemas, the delay in the granting of a license to operate commercially has been mainly due to the difficulty of getting together in agreement the three interests who are mostly concerned:

(i) The B.B.C. and its home viewing audience.

(ii) The promoters of sporting events, some of which can be classified as being of a national nature.

(iii) The cinema interests.

Therefore, if these three could be got to work together in harmony, with full co-operation in the provision and exchange of program material, the authorization of a license which would give the cinema interests a start in commercializing television might be forthcoming. However, pressure in this direction is bound to come when technical results are obtained, which justify in themselves that a perfected invention of this nature should be utilized for the nation's benefit. In any case, as the price of home television receiving sets is for the time being higher than the purchase level of the majority of the population, is not television in the cinema the average man's way of participating in this form of entertainment?

(c) *Place of Television in the Theater Program.* What do theater interests intend to do with television? This is a question which, as mentioned before, needs very careful study of all factors by the entertainment industry. I have not yet heard a balanced and well-thought-out reply to this problem.

Are we wrong in assuming that large-screen television and cinematographic projection can be made complementary to each other?

Can we show them both in the same program?

On the long or very long view, the answer is yes.

But in the meantime, those who have financed its development must be thinking of some return. In which case, can we commercialize on an intermediate stage either by (i) provision of specialized television theaters; or (ii) provision of television in cinema theaters, but television and film each taking a separate and independent program period for itself.

(d) *Instantaneous Versus Delayed Action.* I am not at all clear as to the relative uses of instantaneous electronic projection of television in theaters, and the delayed-action presentation by using the intermediate film process. There are so many factors controlling the timing of programs in theaters that it would be extremely difficult to guarantee that all theaters taking a particular program would be standing by at exactly the correct moment. On the other hand, I cannot visualize the practical operation and maintenance of intermediate film equipment in individual theaters.

There is one thing of which I am quite certain. I have many times experienced the tenseness of an audience watching, as it is taking place, on the cinema screen, a national event, the outcome of which is unknown, and I am convinced of the enormous entertainment value of such an item. The satisfaction which I personally have experienced on such an occasion has been acknowledged also by all those present. The important point is that the event is being watched as it is happening, and half the entertainment value would be lost with delayed presentation.

I feel, however, that the best way out of this problem is not by writing and talking, but by setting out to obtain practical experience in both methods over a period of time; such work to be done in close cooperation between the technicians and the leaders of the entertainment industry, and it is only by facing this problem fairly and squarely that we can really get a solution that will satisfy future requirements in the provision and extension of the cinema television service.

(4) General Economic Problem

Although I am not qualified to discuss this subject, I feel that this is a matter which must not be left unmentioned in a general survey of this nature.

In looking ahead, as the technician must look ahead, toward the future of the entertainment industry and the impact of technical progress on it, we must attempt to visualize the various possibilities which may arise, so that we can provide information for those whose duty it is to study the economic trend in relation to the ever-changing needs and tastes of the public served by the industry. Here we have in large-screen television a new tool rapidly approaching the practical stage where it can be of value for entertainment and education. It is our duty to give guidance, as far as we can, so that it can be used to the best public advantage. I hope that this paper will, in describing past experiences, and in discussing present problems and future possibilities, make some contribution in this direction.

VI. Conclusion

Finally, I should like to put to you a few questions, based on my remarks, and eagerly await your considered replies:

(1) Do you agree that the presentation of large-screen television to the public should be made in two distinct stages?

Stage (i) on the 400- or 525-line basis, or the 3-megacycle bandwidth limit.

Stage (ii) the equivalent to film projection. Or should we wait until Stage (ii) is an accomplished fact?

(2) What do you regard as technical requirements for Stage (ii)?

- (a) Number of lines.
- (b) Sequential or interlaced.
- (c) Bandwidth.

(3) Should we really make a comparison with film projection? Should not public television develop as a different medium, and to a different standard?

(4) What will be the comparative practical uses for:

- (a) Film intermediary.
- (b) Instantaneous electronic projection.

(5) How will theater television be used by the entertainment interests?

ACKNOWLEDGMENTS

I must give credit and appreciation to the members of my team, who work with unequalled enthusiasm and unity of purpose in endeavoring to solve our problems: Messrs. T. M. C. Lance, J. D. Percy, T. C. Nuttall, L. C. Jesty, L. R. Johnson, K. A. R. Samson, E. McConnell, M. Morgan, J. E. B. Jacob, and many others; also to Dr. C. Szegho, now with the Rauland Corporation; and to Dr. Starkie of Imperial Chemical Industries (Plastics Division) who has carried out the optical work for projection; and Mr. Warmisham of Taylor Hobson for the optical work on the scanning side.

NOTE: Following the delivery of his paper, Mr. West showed a short film, divided into two parts: (1) the recording of B.B.C. programs with particular reference to faults encountered, and (2) the recording of pictures transmitted by "Cintel" film and caption scanners.

DISCUSSION

MR. FRASER: Was the film that was just shown a 16-mm film?

MR. A. G. D. WEST: Yes, reversal 16-mm film.

MR. FRASER: Has anyone attempted to count the number of scanning lines to see if there are 405 or $202^1/_2$?

MR. WEST: I think it is likely that there is quite a lot of pairing. As I have mentioned, we are concerned about the difficulties of correct interlacing. We have an idea that not more than 10 per cent of receivers interlace properly. Does that hold on this side of the Atlantic?

MR. SIEGFRIED: What is the greatest projection distance that Mr. West has employed with practical results, and what is the largest picture?

MR. WEST: The projection distance maximum is 40 feet from the screen. We have not been farther back than that.

MR. BEN SCHLANGER: There was one of the theater diagrams which you showed which had a television projector on the face of the balcony. It did seem to me as though that was one of the best locations. The projector did not seem to obstruct the view from any part of the audience. It seems to be the most practical job. Is that true?

MR. WEST: Yes. We fully agree with that. We should be very pleased to see theaters which had balconies coming out to, say, 50 feet from the screen. That would be the ideal position for the projector, but few existing theaters satisfy that condition. Most of them are 70 or perhaps 90 feet back.

MR. SCHLANGER: In contemplation of building a new theater, might that be the course to follow?

MR. WEST: Yes, sir. Obviously it would be preferable to have the projector back in the box which is the right place for it, but in determining the best position for the projector in the auditorium we are subservient to the economic cost. I believe that we could produce a large projector with a 40-inch mirror which could be put in the projection box, and would provide sufficient brightness, but it would be very expensive. The glasswork alone might cost about $16,000 and furthermore the production output would be very slow. I believe it is the same over here. It might take two years to produce one only. It, therefore, appears to be neither an economic nor a practical proposition.

We, therefore, have to compromise with a smaller mirror, smaller dimensions of projector, and a smaller throw distance to secure the brightness for a given size screen. If theaters are to be designed for the purpose of large-screen television, then the balcony should be designed so that the projector can be mounted on the front of it at a distance not more than 50 feet from the screen.

MR. PAUL J. LARSEN: I agree that the front of the balcony is a very nice position for the projector, but there is, in my opinion, a very much better place where the projector can be placed in theaters without disturbing the seating arrangements or anything else, and that is by hanging it from the ceiling. It can be supported there very rigidly and solidly, and projecting downward to the screen. In that way you could have your control box located in the projection room or in the balcony, and that would not be taking up any space in the orchestra stalls.

MR. WEST: That is an interesting point of view. I think that we are rather afraid that our roofs are not strong enough to support the equipment. There is the question of servicing the projector also.

MR. LARSEN: It could hang from the ceiling most of the time just like a chandelier, and it could be lowered to the floor by pulley rope when servicing is required.

MR. WEST: Would not roof vibration cause trouble?

MR. LARSEN: I do not believe that it would be serious. I do recall some tests made some time ago in projecting still pictures that way. Naturally you would not depend on a single rope but you may use a triangular rope arrangement which would hold it quite steady.

MR. SCHLANGER: Would not that be in the line of the film projection in the projection room?

MR. LARSEN: You would place it at an angle so that it would not be.

MR. SCHLANGER: That might require quite a steep angle from the television projector to the screen in order to get above the regular beam of the motion picture projector.

MR. LARSEN: It would not be any worse than trying to have it down in the orchestra and trying to project it up on to the screen.

MR. SCHLANGER: That position in front of the balcony that I saw in Mr. West's diagram was practically a straight throw.

MR. LARSEN: That holds true where a balcony is available, but where a balcony is not available, then the only place you have is in the orchestra stalls, and you have to project upward at quite an angle. With my suggestion you could project downward.

MR. SCHLANGER: Every theater will present a separate problem.

Auditorium Acoustics*

By J. P. MAXFIELD

Van Nuys, California

Summary—This paper presents a review of the factors affecting the acoustic properties of auditoria. Emphasis is placed upon not only having these factors meet the previously accepted requirements for technical excellence, but those factors which contribute to the esthetic or dramatic effect, particularly as regards shape of the auditorium and the diffusion of reflected sound.

The design of a theater or other place of amusement partakes of both the arts and the sciences. The final result must be "pleasing" and capable of permitting the performance to arouse, in the audience, a maximum of esthetic or dramatic effect. Herein lies the art.

The mechanisms by which these results are obtained, such as the acoustic properties, the clarity of vision, and others, represent the factors which are directly amenable to the methods of engineering.

Fortunately, the correlation between some of the objective factors and the esthetic value or "pleasingness" of the artistic result can be determined and then can be used to guide the engineer and the architect in the best use of the known objective factors.

The purpose of this paper is to review the acoustics of auditoria, with special emphasis on the motion picture theater, and to outline the best conditions for the dramatic and esthetic presentation of the program.

Professor Wallace Sabine laid the groundwork for the many later developments in architectural acoustics. He studied methods of controlling the reverberant characteristics of auditoria and the dependence of these acoustic properties on the nature and amount of sound absorption present in the theater.

The introduction of radio broadcasting, electric recording and reproduction of sound, and later talking pictures gave acoustical engineers considerable opportunity to study the requirements for "pleasing

* Presented October 24, 1947, at the SMPE Convention in New York.

acoustics." The "single-channel" transmission, as contrasted with normal binaural listening, tended to accentuate all acoustic effects, and therefore rendered them more amenable to detailed study.

The results of such studies indicated that "pleasing acoustics" resulted when the following broad requirements were met:

(1) The magnitude[1–3] of the reverberation time and its frequency characteristics[4, 5] must lie within reasonable limits.

(2) The first discrete reflections from surfaces close to the source must be carefully controlled and dispersed. They should reach the audience area from a number of relatively small splays rather than from a few large flat walls.

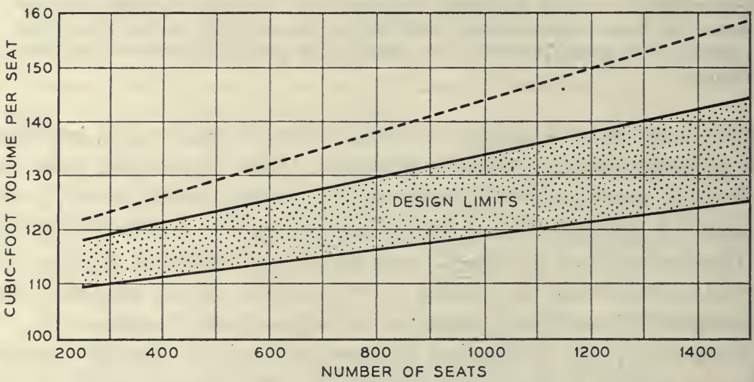

Fig. 1

(3) The decay of sound essentially must be logarithmic, but modulated by a large number of intensity variations brought about by the shifting interference patterns during decay.

(4) The reverberation should consist mainly of reflections which reach the listening position indirectly and with relatively long time lapses.[6]

The recent literature regarding requirement (1) is in reasonable agreement.

Requirements (2), (3), and (4) imply the use of means to direct and to disperse or diffuse the sound. Volkmann[7] and others have carried the idea of diffusion to an extreme by the use of a large number of polycylindrical surfaces.

In view of the work reported by Hanson[8] in 1931 and the experience supporting the desirability of essentially logarithmic decay, the question arises: Is there an optimum amount of diffusion from the point of view of "pleasing acoustics?" Hanson showed that a logarithmic decay devoid of fluctuations due to the shifting interference pattern did not yield a natural sound. If, however, he modulated such a decay with the intensity fluctuations of a shifting interference pattern, made up of a large number of small intensity variations, he obtained a sound which showed auditorium "character" and was "pleasing" to the listener.

It would seem, therefore, that the time has arrived to examine the control of the discrete first-order reflections, the amount and kind of

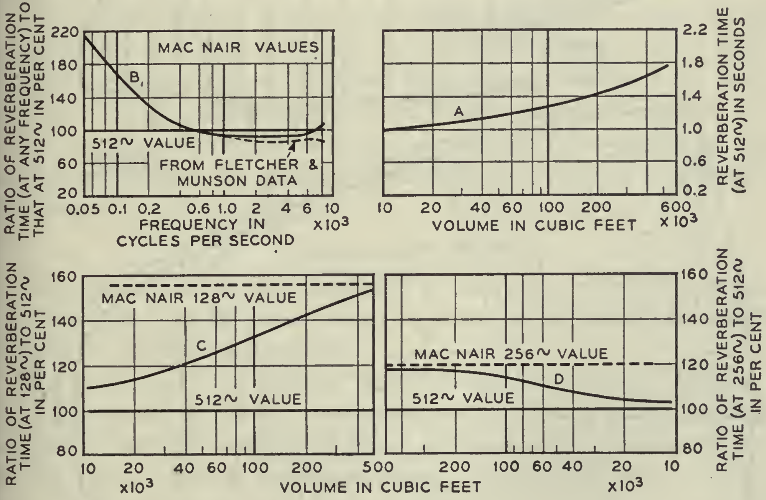

Fig. 2

diffusion, and the possible desirability of permitting a suitable amount of nonuniform distribution of energy among the natural modes of the theater to give "character" and "pleasingness" to its reverberation.

However, there are other important factors in theater design which must be considered in producing an esthetically satisfactory auditorium.

Four of the important factors in theater design are

(1) The basic shape, which deals with the general relationships between the length, the width, and the height.

(2) The volume or size, particularly in relation to the seating capacity.

(3) The general reverberation characteristic.

(4) The shape, size, and position of the individual internal surfaces to control the proper distribution and dispersion of the sound.

NOTE: The four broad requirements apply to the last two factors.

THE BASIC SHAPE

Frequently this is influenced by the size and shape of the land available as the site of the theater. Fortunately, the acoustic re-

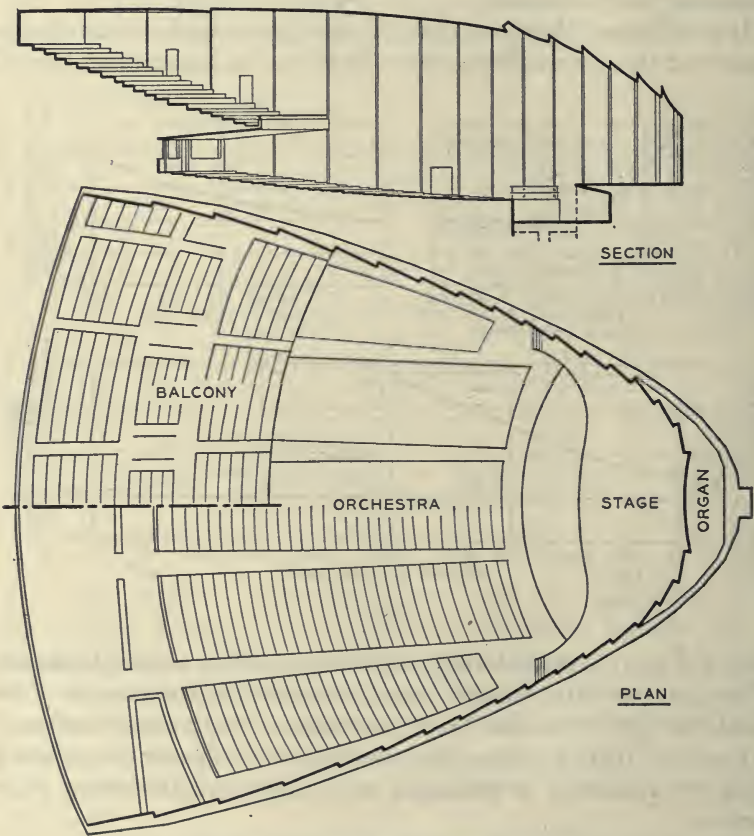

Fig. 3—New Kleinhaus Music Hall, Buffalo, N. Y.

quirements allow the architect a considerable leeway in the shape of the floor plan. Experience has shown that a ratio of length to width which lies between the limits[9] 2:1 and 7:5, when combined with proper internal surface design, will yield excellent hearing conditions.

Where the length becomes greater than twice the width the design tends to approach the so-called "shooting gallery" shape with the resulting difficulties of avoiding multiple reflections between the side walls and the high attenuation over the audience heads. On the other hand, a ratio of length to width of less than 7:5 approaches too close to a square, in which a number of the natural modes of the room tend to have nearly the same frequencies.

This statement of limiting ratios does not imply that the floor plan should be a rectangle but merely that its general average dimensions should lie within these limits. In general, it is desirable to avoid a rectangle.

The ceiling height is largely controlled by the choice of the number of cubic feet of volume to be allowed for each seat. However, for the 7:5 ratio of length to width it should not exceed one half the width, while for the 2:1 ratio it should be less than two thirds the width.

Having chosen the ratio of length to width and the volume per seat, as discussed later, the method of computing the height suggested by Rettinger[10] can be applied.

VOLUME PER SEAT

For the motion picture theater it is desirable to keep the volume per seat low in order to minimize the amount of acoustic treatment and sound dispersion necessary.

Fig. 1, from C. C. Potwin,[1] shows desirable limits of volume in cubic feet as a function of seating capacity. These values are based on controlling the sound reflections and hence the reverberation by proper shaping of the internal surfaces. Regarding Fig. 1, Potwin[1] says: "These limits have been developed as a result of empirical practice, and assume (1) the use of upholstered seats with a spring- or rubber-cushioned bottom and padded back, (2) fully carpeted aisles, and (3) furred construction of walls and ceiling for low-frequency absorption. The broken curve is considered generally from past experience to be a maximum practical limit for the auditorium structure. In most cases a small amount of acoustical material properly distributed will be required for these larger volumes."

Volumes greater than shown by the dotted line tend to result in large flat surfaces which must be broken to disperse the sound properly and lead away from economy in the planning of the theater.

GENERAL REVERBERATION CHARACTERISTIC

The literature covering this phase of design is quite complete and is, generally, in good agreement. Fig. 2 shows the reverberation times for various frequencies as a function of theater size. This figure summarizes the data published by Maxfield and Potwin.[5, 1]

INTERNAL SHAPING

In rectangular rooms or theaters the sound energy, during decay, tends to concentrate in certain well-defined modes of vibration.

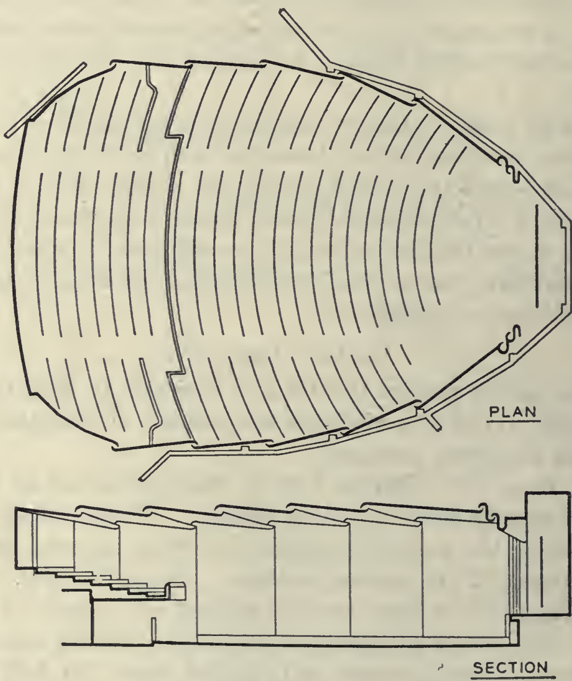

Fig. 4

While this tendency is less in nonrectangular shapes, some additional dispersion is necessary to cause a relatively smooth logarithmic decay. This additional dispersion tends to lower the mean free path, that is, to decrease the time interval between successive reflections.

The nature of the successive reflections determines the so-called "character" of the theater and the time interval between them is interpreted as "size."

It is generally recognized that when a theater has a "pleasing character," the esthetic value of the show performed in it is enhanced.

This is particularly true of musical renditions although it also applies to speech.

It follows, therefore, that an amount of diffusion which destroys this character may be undesirable since this excess diffusion or dispersion also causes a decrease in the time interval between successive sound reflections. Also, it acoustically decreases the apparent size of the auditorium. It has been the experience of the author that too much diffusion produces auditoria or theaters which are "characterless and cramped" and that such theaters are less pleasing as places of entertainment.

Fig. 5

Fortunately, this amount of diffusion is not necessary to obtain good definition for speech even when the reverberation time is sufficiently long for good music production or reproduction. By careful internal shaping to reflect the higher frequencies from numerous small-angled surfaces on the side walls and ceiling, the definition and "presence" can be maintained without using too low a time of reverberation.

Fig. 3 shows diagrammatically* a plan and elevation of Kleinhaus Music Hall in Buffalo, N. Y. The author and the late C. C. Potwin

* For this figure see *Arch. Acoust.*, Design reprinted from *Arch. Forum*, September, 1939.

believed that the amount of dispersion used in this design represents the maximum "sound break-up" consistent with maintaining good "character."

Fig. 4 shows similar diagrammatic sketches* of a motion picture theater to which this type of sound diffusion and control of first reflections has been applied (Normandie Theater, New York, N. Y.).

Where the internal shaping can be carried out as completely as shown above, for instance, in remodelling an old theater, effective diffusion can be obtained by distributing the necessary acoustic treatment in a random manner over the walls and ceiling. The use of small absorbing areas well distributed is superior to the use of a few large ones. Completely covering any one wall with absorbing material is bad practice.

Fig. 5 shows a studio† in which most of the sound diffusion was odtained by the intelligent random distribution of absorbing material.

* Also in same *Arch. Acoust.*, Design reprinted from *Arch. Forum*, September, 1939.

† See Fig. 4 of "The control of sound in theaters and preview rooms," by C. C. Potwin, *J. Soc. Mot. Pict. Eng.*, vol. 35, pp. 111–126; August, 1940.

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(9) C. C. Potwin, "Building Types Section," *Arch. Rec.*, July, 1938.

(10) M. Rettinger, "Applied Architectural Acoustics," Chemical Publishing Company, Brooklyn, N. Y., 1947, p. 75.

DISCUSSION

MEMBER: Does the slide that showed the volume per seat still hold?

MR. JOHN VOLKMANN: Yes, we still adhere to that. It is very desirable to keep the volume down, but not down too low. You want to obtain enough reflection from the walls and the ceiling to give an enveloping effect of the sound.

If you make the room too small, below 100 cubic feet per seat, you get the ceiling down very low. As was mentioned in the paper, you can get a room that is too long relative to the width of the room. You can also have a room that is too long relative to its height. Then a number of problems enter into the picture, not only the cutting down of the liveness of the room by making the volume per seat too small, but you get into the difficulty of projecting enough sound to the last rows of seats.

For all practical purposes, I believe that the analysis that was made from that original data still holds. It is a very acceptable guide.

MR. JOHN K. HILLIARD: It has been our experience where these so-called smaller theaters are being operated that there is this feeling of better over-all co-ordination of the sound and picture, and we feel that both from the production and reproduction standpoint, it is highly desirable to hold the volume down well within these shaded areas.

MR. NEILL WADE: There was a mention of smooth logarithmic decay of the sound in connection with the shape of the auditorium. It is still not clear to me whether the rectangular shape tends to cause this smooth logarithmic decay or whether it is the departure from flat walls which causes this type of decay; and second, is this smooth logarithmic decay accepted practice today, or do we find that we need something else—a departure from that—to get a pleasing result for the listener?

MR. HILLIARD: I think a departure from the rectangular room is necessary for the sake of diffusion; as Mr. Volkmann brought out, and as Mr. Maxfield indicated in his paper, it is necessary to provide sufficient random distribution of the sound so that reflection from any one surface is small compared to that coming from the loudspeaker at the screen. That gives us the so-called presence that we talk about and desire. In other words, restrict each individual flat surface down to an area where the total energy from this surface reaching the listener in the auditorium is small as compared to that directly from the loudspeaker.

COMMENT BY MAIL FROM AUTHOR: Mr. R. L. Hanson* has shown, some years ago, that a completely smooth logarithmic decay of sound is unpleasant. Experience in theaters has demonstrated, however, that the logarithmic decay modulated by a sound interference pattern consisting of a large number of low-intensity modulations produces the most pleasing effect.

MR. CHARLES LEE: A theater auditorium in which you have a patchwork series of absorbing and reflecting surfaces, such as that horrible looking example flashed upon the screen, would not be acceptable to the theater audience but it might be to the studio recording. I find it very difficult to follow the formulas in one theater after another that would yield the ideal results for the auditorium. We have had proposed, from time to time, a series of variegated surfaces, and if we did use them once or twice, you then are confronted with the architectural problem of not having complete repetition for every auditorium.

CHAIRMAN HARVEY FLETCHER: Are you asking how you can make the auditorium satisfactory when there is a small audience and also when there is a large audience?

* R. L. Hanson, "Liveness of rooms," *J. Acous. Soc. Amer.*, vol, 3, 1932.

MR. VOLKMANN: If possible, that means that we should try to keep down the variations in absorption in the room as the audience increases. The obvious thing is to get seats which are as absorptive as possible, so that when the occupant comes in and occupies the seat, he covers up about the same amount of absorbing material, you might say, as his clothing contributes to the room. That I think is the ideal procedure. That means getting seats that are satisfactory, i.e., that have an absorption value of about $3^1/_2$ Sabines. Then the 4.2 units of the person do not make a very great difference in the reverberation time.

CHAIRMAN FLETCHER: Some of you may have been in our little auditorium at the Bell Laboratories. When that is full, the characteristics are scarcely any different than when you have one person in it, and it is arranged so that the seats have the same absorption as the persons when they are sitting in them.

MR. P. B. ONCLEY: In defense of the last slide which was flashed on the screen —you didn't read the title at the bottom. That was the photograph of the studio before the installation of decorative covering material. It wouldn't have to look quite that bad.

MEMBER: There has been a tendency in the early history of acoustical design for theaters to be dictators of what the places are going to look like, and I think that is what has bothered Mr. Lee and many of us. I think as time went on we finally found out pretty much what that slide teaches us, that there are a lot of panels in a room. When seen together they certainly are ugly looking, but I think the successful method has been to cover them with an over-all masking whose appearance is up to the architect. This masking covers both the absorptive material and the nonabsorptive surface, so the layman does not know where the absorption is at all.

MR. W. E. MACKEE: We are building a number of theaters of less than 600 seats, 570 or 580, and our auditorium will be standard. The auditoria will be 50 feet wide. The actual seating capacity will be about 90 feet, height 27 feet. It is costing us, completely equipped, about 115 cents a cubic foot or $30.00 a square foot. We have to be careful with our seat spacing, and we are going to use 33 inches, and about 15 feet in the back for standing room.

I am checking up on my architect. I am just asking whether 50 feet wide and about 90 feet deep and 27 feet high is an ideal size for a theater of something over 525 seats, depending on the space between the seats.

MR. HILLIARD: According to rough calculations, he has 202 cubic feet per seat. An over-all average of 18,000 theaters in the United States shows 125 cubic feet per seat, so it looks as if you have a few more cubic feet than you need for the optimum performance.

MR. MACKEE: These are designed for exhibitors who will not do more than $1200 or $1500 a week. When we add one foot to the theater in length, it costs us about $6000. We have to watch carefully or the exhibitor will not be able to pay us, and we are going to have a theater on our hands. We want to cut it down to the limit, otherwise we shall be in the theater business, and we are in the banking business.

MR. E. J. CONTENT: According to Mr. Rettinger's figures, an ideal house for 600 seats would be a house about 48 feet wide, 88 feet long, with a ceiling 18 feet high average.

MR. MACKEE: You are talking about just the seating area? Is the lobby included?

MR. CONTENT: Not including the lobby.

MR. MACKEE: We are pretty near right then.

MR. CONTENT: You have too much ceiling height.

MR. MACKEE: These are one-floor theaters, and the projection room is up on a sort of balcony.

MR. CONTENT: You could drop it enough by proper study, to reduce the ceiling height sufficiently to obtain a reasonable cubic content per seat.

MR. MACKEE: I could knock off $10,000 or $15,000.

COMMENT BY LETTER FROM AUTHOR: The value of 200 cubic feet per seat is definitely too high for best acoustics in a motion picture theater. The author agrees with the comments from Mr. Hilliard and Mr. Content and believes that by lowering the ceiling height materially at the screen end of the theater, and properly designing its shape, the situation could be much improved. If the projection booth can be lowered, somewhat, without damaging projection, this would help.

MR. JAMES FRANK, JR: Mr. Volkmann made a remark about the absorption characteristics of the seats, that ought to be amplified. There is no question that the ideal seat should have the amount of absorption he stated, which I presume means a soft covering on both the seat and the back.

On the other hand, we have to be practical from the point of view of maintenance, and I imagine a very large majority of seats in theaters have an imitation-leather covering, at least on the seat portion. We know of course that in the smaller and less expensive theaters, they use plywood backs, but a good many people insist on imitation-leather covering on the seat. Some people have the habit of cutting the covering, and it is easier and less expensive for the theater to maintain its seats by recovering with imitation leather than with mohair or some other soft fabric.

However, that is a very definite factor in connection with the acoustical condition of the theater. Is it possible to give some relative proportion of a theater seat with soft covering on both the seat and the back as compared with an imitation-leather covering on the seat and a soft back?

MR. VOLKMANN: Any range from 1.8 to 3.5 does give fairly satisfactory conditions to meet that problem of variation of reverberation time with an audience. The figure of 3.5 I quoted was to obtain as near ideal as possible, with the type seats that are available. In other words, a very de luxe house does put in seats of that type, but the average is more nearly around 1.7 or 1.8, and in between there, 2.5 is another type of seat that is very common in a de luxe type of house.

CHAIRMAN FLETCHER: What is the absorption value of this imitation-leather seat, without the back being covered?

MR. VOLKMANN: Without the back of the seat being covered, but with a cloth upholstering on the back, the value is about 1.8 units.

With reference to the architect's prerogative of covering the absorbing materials, I believe that Mr. Maxfield probably deliberately left off the covering on that slide in order not to intrude on the architect's field. Further in regard to that, I believe the architect has all kinds of opportunities to express the artistic phases of his work, in doing more things with regard to these diffusing surfaces. There has been a tendency in the studio field, to arbitrarily accept a great deal of curve paneling of the cylindrical type, which from the fundamental basis is not the only shape that will give adequate diffusion for the reflection surfaces in the room, and I should like to make the appeal that the architects do a lot along the line of creating designs of conversely shaped surfaces for the diffusing parts of the auditorium.

The other point I wanted to bring out is that many of our calculations on the acoustics of the auditorium are based on the reverberation time, but we must not forget the echo problems in the room, and the one which gives us the most trouble is that the rear wall usually is the most offending surface from the viewpoint of echo, and echoes can be very localized to the degree where a few seats in the auditorium can be highly disturbed by echo, and the rest of the auditorium will be all right. I can think of a number of examples in the theater where we have had that kind of problem.

MR. CHARLES LEE: This touches on a very important item in connection with auditorium design, and that is that wherever a soft absorptive material is used below the height of five or five and one half feet, children attending the show frequently take delight in attacking these surfaces. Can the experts offer anything other than perforated material, such as we are getting tired of seeing, that will give us the reflection and the absorption in the spots that they believe are technically desirable, and give us a chance to get them out of the way of the young folks?

CHAIRMAN FLETCHER: Are you asking whether they get a new kind of material or a remedy for the children, preventing them from cutting it?

MR. LEE: I do not think we want either one. We should like to know how we can place these materials so we will avoid the reflective spots he cautions against.

MR. CONTENT: There is very little use in putting absorptive material any lower than five or six feet. The space above represents the largest absorptive surface in the entire auditorium. Absorptive material should be used on the walls above five or six feet and hard surfaces down below.

MR. P. H. THOMASON: I noticed that Mr. Maxfield's paper omitted the treatment of the rear wall, that is, backstage areas. Is not that very important to obtain good acoustics in an auditorium, where you have the reflection on the backstage, also the projection-room ceiling?

COMMENT BY MAIL FROM AUTHOR: It has been well understood for some years that the backstage requires some treatment. Frequently the nature of this treatment depends specifically on the type of sound system used and its position on the stage. Therefore it was deemed wiser to leave the specification of this treatment to the engineers responsible for the installation of the sound system.

MR. HILLIARD: There has been no question throughout a number of years about backstage treatment. To a person in the audience the sound coming from the loudspeaker should be high and the general reflected sound should be low by comparison. For that reason, it is almost 100 per cent necessary that the backstage wall be treated to a very large extent, depending upon the distance or relation of the loudspeaker to the rear wall. This avoids what we call slaps. If the loudspeaker were a part of the rear wall, then this damping would not be necessary. However, the farther out from it the speaker is placed the more drastic must be the treatment.

MR. WETHERELL: The speaker said that as the stage wall recedes from the loudspeaker, more acoustic treatment becomes necessary; as a general rule, smaller houses will just allow a little over four feet between the screen and the back wall of the stage to take care of the speaker unit. I was wondering whether that four feet is enough of a depth.

MR. HILLIARD: I should consider that some treatment would still be necessary. Others feel that this distance might be within the minimum not requiring any treatment.

MR. WETHERELL: Where you have suspended walls, is it not necessary to use some sound-deadening material in the back of those walls to keep the walls from vibrating?

MR. CONTENT: Sound-isolation construction?

MR. WETHERELL: No, furred walls and metal lath and plaster; where you have no intermediate supports, more or less a suspended wall, you might say, is it not necessary to treat in back of those walls with rock wool or sound-deadening material to keep the walls from vibrating?

MR. CONTENT: Ordinarily no, they do not vibrate to such an extent, because there is enough mass in the lath and plaster to prevent violent vibration. There may be some absorption, but it will not be too selective.

MR. ONCLEY: Mr. Maxfield pointed out that such construction added to the low-frequency absorption.

MR. JOSEPH J. ZARO: Could any of the experts comment on a practice which seems to be rather new, of using materials such as we have draped here in this auditorium, on furring strips or auditorium insulation, but without any other means of sound reinforcement behind the material itself?

CHAIRMAN FLETCHER: You are asking what effect that will have, or is it desirable to do it?

MR. ZARO: Do they have any figures or data on the acoustical value of using that material in that fashion?

CHAIRMAN FLETCHER: Such as this room, without anything back of it?

MR. BARONIK: Most installations of that type are not too good. The cloths that are hung are usually rather sheer, and the absorption that takes place is at the high frequencies only. This means that in many of these rooms, especially with parallel side walls, you get a booming effect. I do not know how heavy this particular material is. In many installations I have seen, you get a booming, barrel effect from that sort of construction, and if you want to preserve more uniformity, you should have a material which absorbs more uniformly with frequency.

MR. BEN SCHLANGER: In the paper given, and in past practice, there has been a desire shown by acoustical experts to introduce surfaces and forms near the screen which will reinforce the original sound source. This usually leads to a constricting opening at the picture, and does not allow for future expansion of whatever might happen at the screen end of the auditorium, that is, to get angular or concave surfaces that will reflect the sound out into the auditorium. You cannot help but have that go inward toward the optical center of the auditorium. Is this practice essential, and could something else be done so that the auditorium can be left as wide as possible at the screen end, with some other approach to the problem?

MR. CONTENT: I believe that much work remains to be done in co-operation between the acoustics engineer and the architect. The engineer himself cannot design a complete theater. He can only say what acoustic materials should go into the theater, and if it is not done in absolute co-operation with the architect, you do not end up with something esthetically as well as acoustically correct. We shall find, by working together with the architect, that we can open up the front end of the theater to provide the effect there.

UNKNOWN: I wonder why the architect would like to have a wide front in the auditorium. It seems contrary to my conception; it makes the screen look much smaller than it would look if the auditorium tapered down toward the screen. It does not provide for extra seats that are of any value.

MR. SCHLANGER: I agreed with you years ago, but the reaction from important clientele indicates, and I am beginning to believe it myself, that anything that tapers toward the picture makes you particularly conscious of the closure and gives a constricting feeling, and a more abstract effect is obtainable if you do not obviously point a funnel toward the picture.

The specific question was whether the surfaces that we have been introducing are absolutely essential to the amount of reinforcement we get out into the auditorium, whether that reinforcement is replaceable by other means which can be accomplished.

MR. VOLKMANN: In the case of sound motion pictures, I refer to Mr. Ryder's comments this morning; he advocated treating the whole front proscenium area with absorptive materials and making the live end of the room in the rear. In the case of sound motion pictures then, where you have amplification, you can eliminate the necessity for the side walls, if I have understood you.

MR. SCHLANGER: That is a new approach, because it has been in the other direction. For years we have been told to reinforce the sound at the screen end.

CHAIRMAN FLETCHER: May that not be an economic problem, if you have to use four or five times as much power to get the sound out there; if you put absorptive materials back there and do not have this reflection—you see that problem comes into it too. That is what you would have to do.

MR. HILLIARD: About ten years ago, there appeared in literature material in which considerable emphasis was placed on getting the architect to make the surface convex instead of the customary concave, and we still believe that this is a very potent factor. By making the surface adjacent to the screen diffusing, we can still build up the sound level in the auditorium, but we do not create the focal points that were present in some of the earlier types of construction where the curvature was concave. Since then many theaters have been built with the surface curved so as to diffuse the sound. We have had excellent results, and I believe that as an architect you will find that there are many, many ways in which you can accomplish this purpose and still maintain the objective that we are seeking. You can do it with small curves, large curves, and decorate it in a manner so that it does not look like a funnel. You can blend that in with the front part of the auditorium, so the audience does not appreciate that it is being done.

MR. ONCLEY: Most of the talk has centered around the motion picture theaters. This is a very special problem. However I think we might point out that in many of the music halls, especially the opera halls of Europe, you have good acoustics with stages as wide as the whole front of the theater, stages as deep as the whole body. I should not think it would be necessary, in fact, to have a narrow stage in the moving picture theater.

COMMENT BY MAIL FROM AUTHOR: The author notes with interest the remarks by Mr. Ben Schlanger. It is true that in theaters and auditoria in which no sound-reproducing or amplifying equipment is used, it is important to shape the stage end of the theater to aid sound reinforcement in the audience area.

There are two reasons why the author has recommended the narrow front, in the past, for motion picture theaters. First, it is of material assistance in obtaining a low value of cubic feet per seat. Second, he believed, as Mr. Schlanger says he once did, that the architects desired that form for esthetic reasons.

There is no definite acoustic requirement for narrowing the theater at the screen end where sound-reproducing or amplifying systems are employed, but it is highly undesirable to obtain this breadth by employment of front-wall surfaces which are concave toward the auditorium. Also, by the proper shaping of these end-wall surfaces it becomes unnecessary to use large amounts of sound-absorbing treatment on the walls immediately adjacent to the screen.

Theater Engineering Conference

Acoustics

Quieting and Noise Isolation*

By EDWARD J. CONTENT

Stamford, Connecticut

Summary—The purpose of this paper is to describe some of the objectionable noises, their causes, some of their remedies, and to point out that it is much easier to avoid these troubles in building a new theater than to rectify them in an old one.

Noise is any undesirable sound, but all sounds do not have the same effect on a person, and low tones, of course, are not nearly so objectionable as higher tones. Howard Hardy recently said in *The Frontier:* "A sound source of many component fragments will sound much louder than one of the same intensity which has a pure tone." Considerable confusion exists among inexperienced observers about the particular psychological factors with reference to noise. It has been shown that noise of a frequency below 500 cycles is not nearly so objectionable as noise consisting of high-frequency tones and harmonics.

The object in noise reduction in design is to shift the objectionable sound from high to lower frequency, as well as to lower its intensity. Loudness alone is not an indication of the annoying effect. People do not object to noisy machinery as much as to erratic and unexpected sources of sound. Such things as high-frequency screeches are definitely more disturbing than the low frequency of thuds or all the lower tones.

There is no doubt that high noise levels in theaters require the operation of the sound system at a higher level, and even though the audience does not realize that the sound level is higher than otherwise would be the case, it does put them under a nervous tension, and if the noise is extremely high, the sound level has to be so much higher to overcome the noise that it really becomes annoying.

There are several misconceptions that should be explained. Many

* Presented October 24, 1947, at the SMPE Convention in New York.

people do not differentiate between sound isolation and acoustical conditioning. Sound isolation fundamentally consists of two things—soundproofing of solid-borne noises such as shocks and machinery, and the sound insulation of air-borne noises such as is provided by thick walls and special construction, which prevent the sound from being transmitted from one point to another.

On the other hand, acoustical conditioning consists of three factors, the control of the reverberation time, controlled by the amount of sound-absorbing material used; the control of reverberation characteristics determined by the type of materials, and how they are used; and by the elimination of sound focal points and standing waves, which is done by the elimination of opposing parallel and concave surfaces.

As stated above, all of these faults are much more easily avoided in new construction than cured in old construction. Wherever a theater is to be built, a noise survey of the site is absolutely necessary to determine the noises in the surrounding area. Outdoor and traffic noises in some areas may reach 85 to 90 decibels above zero reference sound level of 10^{-16} watt per cubic centimeter.

The noise in the theater itself should be kept to a point where it is lower than the audience noise (a good value of audience noise is about 30 to 35 decibels), which means that the outside walls of the theater may be required to have an insulation value of 55 to 60 decibels, which if dependent upon mass alone, requires a brick wall two feet thick. Fortunately there are other ways of doing this by special construction which is much less costly than a two-foot brick wall.

There are some noises that are not under the control of the architect and engineer, such as street noises caused by automobiles, bus traffic, airplanes, railroad trains, streetcars, subway and elevated trains, and garbage and ash collectors.

Of course, there are audience noises about which nothing can be done, except hope for a quiet audience. There may also be noises from adjacent property—music, loudspeaker systems, juke boxes, hand trucks, factory operations, and about the noisiest source is a bowling alley.

Windows have no place in the theater, as they are always weak points in any wall which allow sound transmission. If there must be windows they should be fastened so they cannot be opened, to reduce sound transmission. In some cases, where there is noise on adjacent property such as floors above or below the theater, it may be necessary to construct isolated ceilings and floors, and even isolated suspended walls, as in broadcast-studio construction.

Of course, there must be fire-escape doors, which should be fitted tightly to provide as good sound isolation as possible. This also helps in the operation of the air-conditioning system.

A good example of noise isolation occurred at radio station WOR, with studios on the first floor, where there was a corridor at the rear which led from the street to the freight elevators. Many times during the day there were deliveries by hand trucks which were very noisy and interfering noises were heard in the studios. The solution was surprisingly simple. About an inch and a half of street-paving asphalt was laid on the floor of the corridor, which eliminated that noise in the studios.

There are a number of controllable noises in a theater. First there are the noises from the projection, the rewind, and generator rooms. The best insurance there of course is to specify and get quiet operating machines. As Mr. Hardy has reported in another paper, the acoustic problem is being thoroughly considered in the manufacture and design of projectors. The ceilings of these rooms should have noise-reducing treatment, such as fireproof acoustical tile, or some kind of fireproof treatment having as high a value of sound absorption as possible.

If the ceiling is high, acoustical absorbing materials should be used on the walls also; to four or six feet from the floor. The projection ports should be fitted with optical glass. However, as that represents another maintenance problem, another way that the noise can be retarded from getting into the auditorium is by lining the top and sides of the ports with acoustical tiles. The viewing ports should be fitted with plate glass which reduces the amount of transmission through these openings.

Another source of noise is noisy electrical equipment. The only precaution required is to buy good equipment, making sure that it is operated in the most efficient manner by engaging the services of an organization thoroughly competent in maintenance of sound equipment for the theater, to maintain the equipment. There are reliable organizations which provide that service.

Other noises originate in the lobby, the promenade, the ladies' and men's lounges, and the rest rooms. The ceilings of all these spaces should be treated with noise-reduction materials with carpets on all spaces except the rest rooms.

The ventilating systems are sources of noise such as motor or fan noises, which can be both air-borne and solid-borne. One airborne noise is the noise of the air itself in rushing through the ducts and grills, and the solid-borne noises can be caused by the vibrations being transmitted through the ducts.

The best insurance against these noises is to operate an air-conditioning system so that the air in the ducts flows at low velocity. At the registers, both supply and return, the air velocity should not exceed 250 or 300 feet per minute. Metal registers, where the metal is placed edgewise, are also a source of noise. At the higher air velocity the fins may begin to vibrate. It is best to use a flat punched register, with at least 50 or 60 per cent opening so the air is not constricted, and will not appreciably increase in velocity in the openings.

In one theater which had air noise in the ducts, the trouble was corrected by putting in sound baffle boxes, sound traps, in the branch ducts just before they went to the inlet registers. In this manner it was still possible to get a sufficient amount of air with the existing motor and fan.

In a new system, install low-speed, quiet operating fans because high-speed fans are prone to greater and higher frequency noises.

Another cause of noise is the water-supply system, such as knocking in the pipes when a faucet is turned on, and there may be vibration in the pipes, especially with copper and brass pipe. The proper way to prevent the knocking is to have the proper air cushions installed in the pipes and to make sure the valves seat properly.

Water lines can be fastened in shock-absorbing mounts so that vibration will not be transmitted to the theater structure. The troubles encountered in a hot-air system are very much the same as in ventilating. A hot-water heating system is like any other water system, but with steam heat, hissing valves should be replaced with quiet operating vent valves on the radiators. A big source of noise is steam systems is in the pressure-reducing valves. In one installation the noise was as high as 90 decibels within a foot or two of the valve. The valve and steam-pipe line causing the noise and vibration were isolated from the rest of the building to prevent transmission of structural-borne noises and covered with alternate layers of various materials to reduce the noise in the rooms where the pipes and valves were located. The pipes on both sides of the valve should be hung in shock-absorbing mounts for sufficient distance, so the vibration will not be transmitted to the rest of the structure.

The rest rooms should be separated from the auditorium by at least two walls, not necessarily two walls built together, but at least two walls separating the rest rooms from the audience.

Other sources of trouble are noisy reactors and transformers for fluorescent and cold-cathode lighting. Wherever these are noted, they should be corrected. Noisy electric switches cause clicks at times, which can be eliminated by replacement with mercury switches. Oftentimes vibrations are set up by different kinds of machinery, motors, pumps, forced-draft fans, oil burners; they should all be located on antivibration mounts to prevent the vibration from being transmitted to the building structure. Quite often this vibration will set up very serious noises in some other part of the building.

If there are any elevators in the same building, all the machinery, the hoist drums, the controllers, the contactors, the motors, should all be hung on vibration-isolation mounts, and the guide rails for the elevators should be mounted on antivibration mounts.

A certain amount of trouble is caused by concavity of rear walls in theaters. Oftentimes domes and other concave surfaces catch sounds and retransmit them to other points, sometimes louder than they were in the original location. The answer is to eliminate the use of concave surfaces if possible. If it is necessary to use concave surfaces, make sure that the distance from the focal point to the concave surface is either at least twice or less than one half the distance to the populated area of the theater.

In one theater the author collaborated with Mr. Schlanger in revising the acoustical treatment. In this theater having this trouble the dome was eliminated and replaced with a flat ceiling.

In conclusion two points should be emphasized for either new construction or for alteration; one, engage the services of a registered architect who has had experience in theater construction as there are points that the average architect will never encounter; two, always see that he engages the services of a competent acoustical engineer.

Discussion

MR. W. E. MACKEE: Seat men think the most important thing is a seat. The carpet man thinks carpet is most important. The man who sells lighting tells you how to light your theaters. The acoustical people say the most important thing is acoustics. I think you have forgotten the real purpose of a motion picture theater.

First you must understand that there is a different type of audience in the small motion picture theater today. Sixty per cent of these have less than 500 seats, and 74 per cent have less than 750 seats. What is a motion picture theater? Before the war the average audience was supposed to be 19 years of age and pictures were made for them. Then the war started, and exhibitors thought they would go out of business for our younger people were all going to war. As a matter of fact, we did more business. We got an entirely new audience; older people are going to the movies, discovering the movies. The average is 32 or 33 years of age. They go more often and they pay more, that is our audience today. Why do they go to see motion pictures?

They go primarily for two reasons, rest and recreation. They can stay home and listen to the radio; incidentally radio audiences have dropped, and motion picture audiences have increased. They are not staying home and listening to the radio. We draw these facts from the radio industry. The motion picture audience of today is composed of older people. They demand a different type of picture than we had before the war.

What comes out of the radio? Charlie McCarthy. Charlie McCarthy is not successful in motion pictures. One picture that brought all the people in is one you probably do not remember—"Mrs. Miniver." It was not designed for the 19-year-old audience. It was designed for older people. Just about that time, the audience aged. More people are coming in and they are staying in.

In the motion picture industry we have to bring them out of their homes. You have a nice living room, and you have your radio and your family, but you go a mile or five miles to a motion picture theater. Why do you do that, and pay real money for it? You do that because the modern theater today is just as good as your living room. The seats are very comfortable, and the most important thing in the theater is not sound. The most important thing is the picture image, going back to the fundamental purpose of the motion picture. Sound is secondary. In the pictures that come to us, too often sound predominates, but the audiences go for rest and recreation and a series of pictures flashed on the screen. Sound is just explanatory. Anything you can do to remove your noises is desirable, but do not forget that the motion picture basically is a series of photographic images flashed on the screen.

DR. RICHARD COOK: Recently in Washington the picture was flashed on the screen, but for some reason the sound did not come on. There were catcalls from the audience, "Where is the sound?" They wanted sound right away.

DR. E. W. KELLOG: All we try to do in the way of better sound is to improve the value of the theater for seeing the pictures.

MR. MACKEE: We do not want newsreels in the small theaters. The football pictures are full of sound and noise. We can do without a newsreel. We keep sound down as low as we can. Air conditioning, yes; and quiet, yes; and a nice comfortable theater. We do not say you should eliminate sound, but we definitely are finding out what these older people want, and that is the most important thing as far as dollars and cents in the box office are concerned.

MR. JOHN K. HILLIARD: Why is it, especially in a dramatic sort of picture, when the sound is low, the audience is sitting there listlessly, and if the sound is brought to the proper intensity, not necessarily loud, the audience immediately reacts and applauds a scene, where if the sound were below what it should have been, there is absolutely no reaction from the audience.

MR. MACKEE: If it is so low they cannot hear, they start to clap. If they can hear, we do not hear any comment. Some theaters have earphones. We could not understand why people would put on earphones when they are not deaf. We asked one or two, and they said it was because they can control the sound.

MR. LEONARD SATZ: Sound is so much a part of motion picture presentation that I do not see how you could improve one without improving the other. Maybe some prefer to call it intangible, but when a patron comes into the theater and sits down, it is primarily to enjoy himself. If the sound is not good, he will leave the theater. He does not want to strain to hear the words. We consider sound in the smaller theaters just as important as in the larger theaters.

MR. GONZALEZ: During the war, we operated 1200 theaters. We had upwards of 12 to 14 theaters in some installations. We put in proper acoustic material, with the proper absorption, and someone painted the material with oil paint. Where there was reverberation, the sound was distorted. We found that at these places where the sound was improper, the soldiers would walk a half mile or a mile to go to a theater that had good sound, and attendance at the improperly wired theater fell off, which proves that we needed good sound.

Mr. Content said that the recirculating velocity should be limited to 250 feet per minute, and that the duct be limited to 500 feet. That is rather expensive in design. We found that we could safely go as high as 1200-foot velocity without interfering with the sound system in the theater. So long as the duct was properly designed so that there were no abrupt changes of air to cause sound or air noises in the supply grills, we went as high as 600 feet velocity without any perceptible increase in the noises.

MR. WETHERELL: When I design a motion picture house one of my main interests is in the appearance of the finished product and its effect on the viewer. I wonder if there is not one point that has not been touched on concerning sound. Someone mentioned that sound is secondary. It seems to me it might be, to this extent. The aim of the acoustics and sound engineer should be to produce sound that is so natural it becomes the background of the picture. You come to the theater, you see the picture, the sound is woven around the action. It should be so natural and so keyed that you do not realize you are listening to artificial sound. It is not the aim to have sound so natural that perhaps it is secondary, but it is quite an art to produce sound that is natural and accurately follows in tone and volume the action.

MR. BEN SCHLANGER: I want to defend what the paper said about air noises. There are certain dramatic sequences where the words are spoken softly and during those periods air noises are very disturbing. Maybe in the louder sequences—I do not mean noise but higher levels and less dramatic—air noise may not be disturbing, but you have to design for the more particularized mood in the picture once in a while.

MR. E. J. CONTENT: There are parts in the picture where sound levels will reach as high as 80 or 90 decibels, and certain parts which will be of low intensity as low as 30 or 35 decibels. If you have noises masking the sounds, they are not producing the desired effect upon the viewer. The only way you can keep background noises to 30 or 35 decibels is to operate the air-conditioning system at low velocity as mentioned.

MR. D. G. BELL: We have the main trunk lines approximately 700 feet per minute in the lines to the outlets. The principal noise from the duct system usually originates in the fan, in the blower, and it has been necessary in many other cases to add an acoustic absorbent in the duct for ten or twelve feet after the blower in the duct, immediately after the blower; and using those velocities which are recommended by the American Society of Heating and Ventilating Engineers, we have kept the noise in the theater down to 30 and 35 decibels.

MR. SHEPARD: I believe the point that Mr. Gonzalez brought out may not have been followed perfectly. He wanted to show that by proper designing, you can have fairly high velocity without the introduction of noise which can be generated by any vibrating element in the system. It can be reduced by the proper construction, the proper handling of beams, and possible use of acoustical materials. In many of the installations in the theaters that I have visited where that was done, I do not know what the actual velocities were but they were fairly high, and the noises were not excessive; just where you would have to obtain the maximum velocity, I do not known.

MR. SCHLANGER: It is ridiculous to try to save a few dollars by using a higher velocity than you should when you have already invested so many thousands of dollars in a theater.

MR. SATZ: Do you have any special preference for slab cork for vibration eliminators, cement pit with cork, for heavy fans; would you say that one is more efficient than the other?

MR. CONTENT: That all depends on the weight of the machine, the frequency of the vibration, and other factors, such as the weight of the noise-making parts. The isolating material must be loaded to a point where the transmission of the vibration through the material is very low. It is possible to use vibration mounts where there will be more vibration transmitted than if there were no isolation at all. Each individual problem must be analyzed carefully.

MR. SATZ: Do you find that glass fabrics are any less suitable than cotton?

MR. CONTENT: I see no reason to condemn one as against the other. Sound will transmit through the glass fabrics, through the pores as well as through the cotton or other materials. Sound as we hear it is a movement of air, and it will get through the pores of the glass cloth just as well as the cotton.

MR. A. D. PARK: What is the recommended treatment for the rear wall of a motion picture theater?

MR. CONTENT: The best treatment for a rear wall is not to make it concave. Break it up. If you do that, you may not need sound-absorbing material. All you want to do is to prevent echoes which are reflected from the rear wall from reaching the audience. If that wall disperses sound sufficiently so it will not produce echoes, if it is a concave surface, you must use an absorptive material with a high coefficient, so that very little sound will be reflected back to cause trouble in the audience.

MR. JOHN VOLKMANN: It depends considerably on how far the rear wall is from the seating area, that is, the front of the room. In certain seating regions, it is possible where, in addition to shaping the walls, you have to put a lot of absorptive material on it too. I know of cases where we have had a lot of absorbing material on it, and we had to angle the rear wall down, as well as treat it, purely because the surfaces which, as I say, were treated with rock wool, perforated and paneled and cloth-covered on top of that—they were so disposed that they were on a curved surface, and because they were so disposed, they tended to concentrate the sound into localized regions and not until we angled them forward did we get rid of the concentration effect.

Theater Engineering Conference

Acoustics

Behavior of Acoustic Materials*

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Summary—Theater architects and engineers need accurate data on the performance of acoustic materials, which are used to control the acoustics of theaters. Descriptions of prefabricated materials and acoustic plasters are given. The mechanism of the sound-absorption process in porous materials is briefly described. There are two commonly used absorption coefficients, the "random-incidence" coefficient, and the "normal-incidence" coefficient. The experimental methods used for measuring the two coefficients are described. The significance and limitations of these coefficients in theater design are pointed out, and it is concluded that, at the present time, the random-incidence coefficient is more useful in auditorium design. Recommendations for painting acoustic materials are made, and illustrations of the results of painting are included.

The control of the acoustics of auditoriums and theaters, and the quieting of noisy rooms, both require the installation of acoustic materials. By an acoustic material is usually meant a sound-absorbent substance which is fastened in flat patches to the walls and ceiling. Recently, however, some absorbers have been fashioned in the form of cylinders, cones, and spheres, and have been suspended at a distance from the walls and ceiling of the room.

The principal function of acoustic materials is to absorb sound energy which originates within the room. Only incidentally do they prevent the transmission of sound energy from one room to another. Such transmission is better prevented by other techniques.

Architects and engineers are faced with the problems of deciding what material should be used in an auditorium to secure the proper amount of sound absorption, and deciding what is the most economical absorbent to quiet a noisy location. It is clear that they must have accurate data on how acoustic materials absorb sound. Such data have been available for many years.[1] However, the special uses to which a material is put will in general require more detailed

* Presented October 24, 1947, at the SMPE Convention in New York.

information than can be obtained from the results of routine laboratory tests. Nevertheless, the results of such tests are of great importance to the theater engineer, and he should understand their significance and limitations.

II. Description of Materials

There are two main kinds of acoustic materials. One kind is prefabricated, a familiar example being the one-square-foot tiles which are commonly used in many public places. The other is the kind which is manufactured, so to speak, at the moment of application, and includes acoustic plasters and sprayed-on fibrous materials.

There are various types of the prefabricated kind. A common type

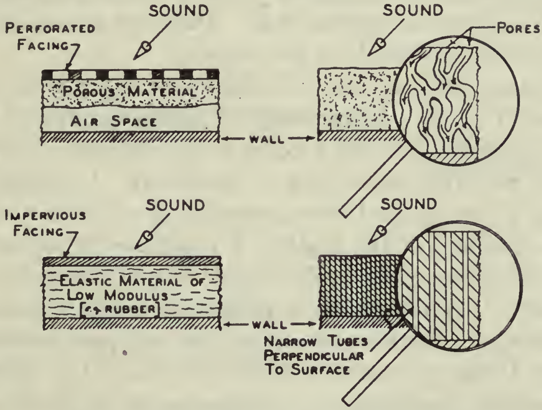


Fig. 1.—Some types of acoustic materials.

is the homogeneous porous absorbent consisting of wood fibers, or glass fibers, or granulated material, held together with a suitable binder. Another common type is the porous material having a hard, nonporous surface which is perforated (Fig. 1) so that the sound waves can pass into the porous region and be absorbed. The perforations might be regularly spaced slots, or circular holes, or irregular fissures. Another type is the porous material installed in blanket form, such as glass wool or rock wool, and protected by a perforated surfacing of wood, metal, or asbestos cement board. The principal advantage of the prefabricated acoustic material lies in the uniformity of the product. The manufacture can be carefully controlled, and in general there are relatively small variations in the absorption coefficients for a particular type.

Several different types of acoustic plasters are available. Some consist of granulated inorganic substances which are mixed with a foaming agent and a suitable binder, and are applied with a trowel. Sometimes the plaster is stippled (in order to improve the absorption of sound) before it has set hard. Other types consist of fibrous material, usually rock wool or asbestos, which is mixed with a binder and sprayed directly on to the wall by means of special equipment. Acoustic plasters are generally difficult to handle, and careful control must be exercised when they are applied. Occasionally, however, there are economic advantages in favor of plaster and sprayed-on materials.

A third kind of acoustic material has been used in Europe, and consists of sponge rubber having a low modulus of elasticity, and covered with a thin impervious skin. Such absorbents do not seem to be commercially available in this country.

Acoustic materials can also be classified by the way in which they absorb sound (Fig. 1). A knowledge of the mechanism of absorption is important, especially if one is going to be faced with the problem of painting the material, or keeping it decorated. In almost all cases, the absorber is porous, and the absorption of sound is due largely to the viscous damping of the motion of molecules of air in the pores. Sometimes the absorption process is aided by vibration of the porous material itself. In addition, the propagation within a porous material is influenced by the tortuousity of the channels (see the sketch to the right in Fig. 1) and by thermal effects. In fact, it is difficult to say which absorption mechanism predominates in a given porous absorbent without conducting a complicated investigation as to how sound is propagated through a material. The sponge rubber described earlier absorbs sound by frictional damping in the rubber. Oddly enough, some very soft and porous fibrous materials, after being covered with an impervious layer of paint, behave like sponge rubber. As a general rule, however, it is very important to preserve the porosity of an absorbent. This makes painting difficult, a point which will be discussed later.

III. Measurement of Absorption Coefficient

A number of elements are important in the choice of an acoustic material. The user is interested not only in sound absorption, but is also concerned with light reflection, fire resistance, appearance, strength, and paintability, all of which are important. However, we shall discuss only the measurement of sound-absorption coefficients, and the influence of painting on acoustic properties.

Suppose a beam of sound waves is incident upon an acoustic material. The beam carries power. The absorption coefficient is the fraction of the power which is absorbed. For example, if a material absorbs 65 per cent of the sound power incident on it at 512 cycles per second, the absorption coefficient at this frequency is 0.65. An important point is that the absorption coefficient depends not only on the physical properties of the material, but also on how it is mounted. As a general rule, an air space between the absorbent and the rigid wall on which it is mounted enhances the absorption.

Physicists and engineers have struggled long with the problems of how to define better and how to measure the absorption coefficient

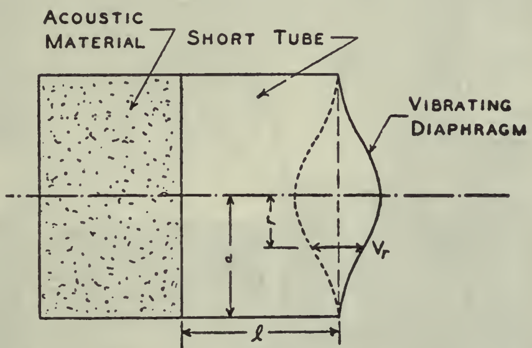


Fig. 2—Impedance tube for measurement of normal-incidence absorption coefficient.

of a material. In Fig. 2 is shown a technique for measuring absorption when sound is incident normally, i.e., perpendicularly, to the surface. The source is a vibrating diaphragm located to the right in the diagram. The acoustic material is to the left. By measuring the sound pressure at the center of the surface, we can deduce, from a knowledge of the amplitude of vibration of the diaphragm, what the absorption coefficient is for sound at normal incidence. Variations of this technique have been used. Sometimes the standing-wave pattern in the tube is explored with a probe tube and microphone. The important thing is that the general idea is always the same, namely, we measure the absorption coefficient when sound is incident perpendicularly on the surface. The coefficient obtained in this way is called the "normal-incidence absorption coefficient."

The basic idea of the other technique which is extensively used for measuring absorption is to have the sound incident on the material from all possible directions. To achieve this, the material is placed on the wall or floor of a large, highly reverberant room. Sound of the desired frequency is introduced into the room, and the distribution of sound energy is "randomized" by any one of several ingenious methods. This means that sound rays strike the surface equally from all directions. When the sound field has become thoroughly

Fig. 3—National Bureau of Standards reverberation room. Used for measurement of random-incidence absorption coefficient.

randomized, the source is turned off, and the rate of decay of the sound energy is measured with microphones and a recorder. The absorption can be deduced from the measured rate of decay. The coefficient obtained with this technique is called the "random-incidence absorption coefficient."

In Fig. 3 is shown the 15,000-cubic-foot reverberation room at the National Bureau of Standards. The sample, which is usually 72 square feet in area, is on the floor. The loudspeakers which supply the sound are on the vanes. The vanes rotate while measurements are being made, and help to randomize the sound field. The microphones which pick up the sound are not shown.

The important question is, how significant are the normal-incidence and random-incidence absorption coefficients in practice? As was pointed out earlier, the principal use of an acoustic material in an auditorium is for control of the reverberation time. Many years of experience seem to show that the reverberation time can be computed correctly if the random-incidence coefficient for the acoustic treatment in the auditorium is used in the calculations. On the other hand, it is not really necessary to design a motion picture theater for optimum reverberation time. The loudspeaker system can supply ample acoustic power, and hence large amounts of absorption can be, and usually are, installed in a motion picture theater. Even though

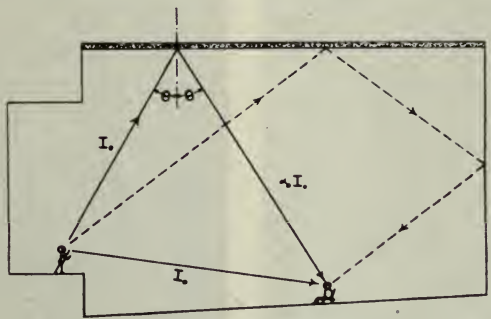


Fig. 4—Simplified geometrical acoustics of an auditorium having a sound-absorbent ceiling.

the normal-incidence absorption is more easily determined in the laboratory, it is still difficult, and in some cases it is impossible, to deduce the random-incidence behavior from laboratory measurements with normally incident sound. On the whole, the conclusion at the present time is that the random-incidence absorption coefficient is more useful in auditorium design.

Some of the difficulties involved in deciding how to measure sound absorption can be appreciated by referring to Fig. 4. The sketch shows that the listener receives sound which is non-normally reflected from the acoustically treated ceiling. If one wishes to compute the intensity of the reflected sound, neither the normal incidence nor the random incidence coefficients can be used! To make matters worse, the angle "θ" of the reflected sound is different in different parts of the auditorium. The object in pointing out these things is to indicate the limitations on the absorption coefficients when an acoustic material is being chosen for a theater.

IV. Paintability of Acoustic Materials

Since the majority of commercially available acoustic materials depends on porosity for sound absorption, it is clear that painting will present a problem. There is always the possibility that excessive painting will clog the pores and prevent absorption of sound.

In the case of porous materials having a mechanically perforated or

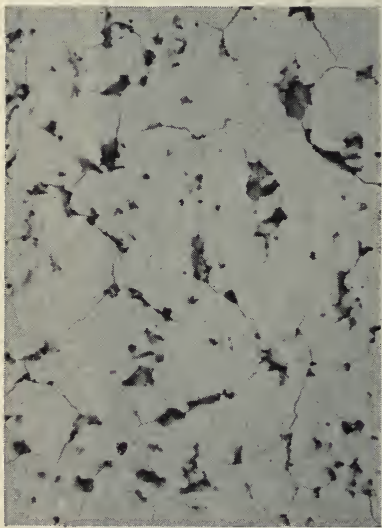


Fig. 5—Fissured surface of a porous acoustic material.

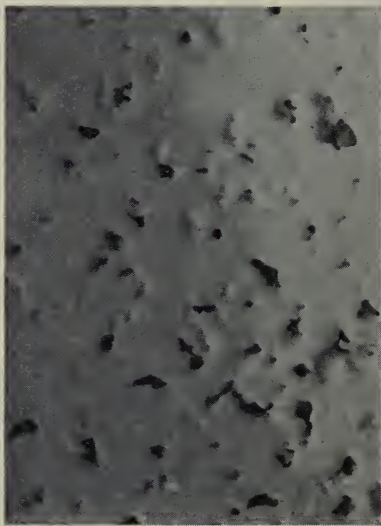


Fig. 6—Same material as in Fig. 5 after application of four coats of brush-applied paint.

fissured facing, there is no serious difficulty. Paint can be applied so long as the perforations and fissures remain open.

The painting of a porous material without large holes or fissures is more difficult. The paint must be applied as thinly as possible, preferably with a spray gun. If it is brush-applied, care must be taken to thin the paint and to get it on the surface without closing the pores.

The nonporous rubberlike materials can be painted, provided the paint does not substantially increase the weight of the facing. Too much paint will reduce the absorption of sound at high frequencies.

The effect of painting on some typical porous materials can be seen from the following data obtained from a paper by Chrisler.[2] Fig. 5 shows a fissured material which had a noise coefficient of 0.55 before painting. The noise coefficient is here defined as the average of the random-incidence absorption coefficients measured at frequencies of 256, 512, 1024, and 2048 cycles per second. Fig. 6 shows the same material after it was brush-painted four coats. The noise coefficient fell to 0.45 after painting, which is not a serious reduction. The reason for the success of the brush painting is that the material was fissured. The fissures which lead down into the porous material

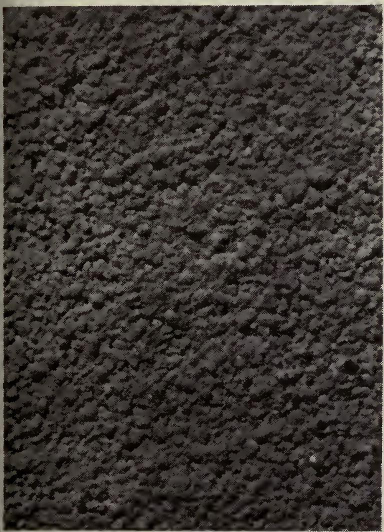


Fig. 7—Granular surface of a porous acoustic material.

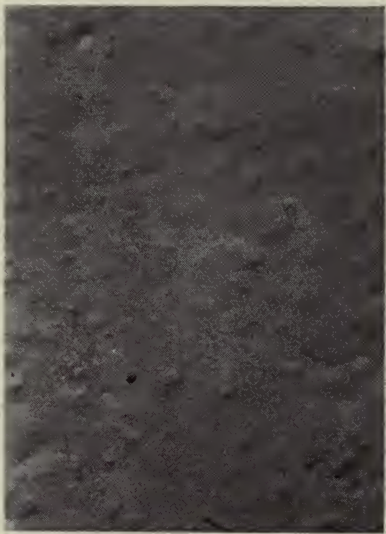


Fig. 8—Same material as in Fig. 7 after application of five coats of brush-applied paint.

were not covered over, and a considerable amount of sound absorption remained after painting.

Fig. 7 shows a porous material consisting of organic and inorganic granules held together with a binder, and having a granulated surface. Before painting, the noise coefficient was 0.60. Fig. 8 shows the same absorbent after five coats of brush-applied paint, when the noise coefficient fell to 0.25. This is a too-familiar horrible example of bad treatment of an acoustic material. The method of painting in this case should have been either with a spray gun, or with a thinned paint carefully brushed on so as not to close the pores.

REFERENCES

(1) The results of tests made at the National Bureau of Standards have been published in its Letter Circular LC-870, "Sound Absorption Coefficients of the More Common Acoustic Materials."

(2) V. L. Chrisler, "Effect of paint on the sound absorption of acoustic materials," *J. Res. Nat. Bur. Stand.*, vol. 24, p. 547; RP 1298, 1940. Reprints may be secured for 10 cents from the Superintendent of Documents, U. S. Government Printing Office, Washington 25, D. C. (stamps not accepted).

DISCUSSION

MR. WETHERELL: What difference in effect do you obtain with varying percentages of opening, or holes in the surface? The area of the holes forms a very small percentage of the total area. What is the difference in efficiency for different percentages of opening? How does that work out?

DR. RICHARD COOK: So long as the area of the slots or holes is ten per cent or more of the total available area, there will be no significant effect except at high frequencies where the absorption might be reduced a little if the area of the holes is reduced. It depends on the spacing of the holes. The openings should not be spaced more than, say, half an inch or so apart.

MR. WETHERELL: I cannot visualize whether that would be true.

DR. COOK: Most people cannot.

CHAIRMAN HARVEY FLETCHER: It works out that way mathematically.

DR. COOK: I have an explanation. The sound wave comes up to a hole; the particles of air move faster as the sound goes through, and it then spreads out on the other side without appreciably reducing the amount getting through the hole. If you listen through a perforated screen, you can hear almost as well as when the screen is not present, which shows that the sound gets through without any difficulty.

DR. LEO L. BERANEK: Some materials are designed to make use of those holes in reinforcing the absorption in a certain given frequency region. If the layer that is placed on the front of the material has a given thickness—if it is not a really thin layer, which is what Dr. Cook was thinking of—but if it has appreciable thickness, then the shape of that hole, the thickness and the diameter, may combine with properties of the material and the air space behind it to give an enhanced absorption at some frequency. That effect makes material like Celotex a good absorber in the region of 500 cycles per second.

I wish to mention three kinds of materials touched on lightly or not mentioned at all. First let us consider a plywood surface. If one takes two sheets of plywood, either eighth-inch or quarter-inch, and bonds them loosely together by, say, spots of glue and places them in a room either in the form of curved surfaces, or a flat layer spaced away from the wall, then you will find that you get quite large low-frequency absorption out of such a combination. We built a small studio recently at the Massachusetts Institute of Technology, and the reverberation without the introduction of any absorptive material was around five tenths of a second, and fairly constant with frequency.

CHAIRMAN FLETCHER: Without any absorption?

DR. BERANEK: Except the plywood panels, and it was fairly constant up to

2000 cycles per second. Such panels generally become quite reflective above 1000 cycles per second. You have to depend on the people in the room to provide the high-frequency absorption. So if you have cases where you want both diffusion of sound and you want absorption at low frequency, then these plywood surfaces can be very effective.

The rubberlike material which was mentioned, with an impervious facing on it, can absorb sound very effectively at low frequencies. At high frequencies it becomes reflective, and you have to depend on other means to provide absorption of sound.

There are sound-absorbent cones and spheres but the cones are the only ones I have seen manufactured. They consist of a pair of cones back to back, hollow inside, made of half- or three-eighths-inch fiberboard of some kind. They are hung in the room. We have tried them and have had quite good results. My own opinion is that they are most useful in a room with a high ceiling, where if you put on the usual material, say inch-thick tile on the ceiling, you do not seem to get so much effect out of it. Sound bounces back and forth between the parallel vertical walls, and by hanging these absorbers in the room, it is possible to get a great improvement in the acoustic results over those obtained by covering the ceiling only. Of course, they look peculiar. We put some up in some of the M.I.T. lecture rooms recently. We put them up in the Boston Art Museum and there was quite an article about "What Is New in Art Museums."

MR. ZARO: Dr. Cook, in showing your slides, you showed the slides where you had brush-painted surfaces. What painting material did you use? Did you use a casein paint or a light mixture of linseed oil and oil paint?

DR. COOK: The paint was an oil paint which was applied in such a way as to hide a black stripe painted on the surface. The application was not, shall I say, scientific. We wanted to get an idea of what might be expected from routine painting of the material.

MR. ZARO: Would you care to project any recommendations as to the use of casein paint as against oil paint on such surfaces?

DR. COOK: According to experiments made in our Sound Laboratory at the National Bureau of Standards, it seems that there is less tendency for a casein-type paint to fill up the holes of a porous material. It is quite safe sprayed on, but one must also be right after the painter to make sure he does not try to cover the fine holes due to porosity.

MR. C. W. LUHRMANN: On the sprayed sample you had, was that sprayed asbestos or sprayed wool? I am familiar with sprayed asbestos and it loses very little sound absorption on painting.

DR. COOK: Of the two slides I showed, neither referred to a sprayed-on or plastic-applied material. What you say is true. One still gets appreciable absorption from some such materials after painting.

MR. LUHRMANN: We recently put on a material of sprayed asbestos, and the architect was skeptical about paintability. He said, "I still think that it will not stand paint appreciably and still hold its sound absorption." So he requested that we paint that material as often as he desired, and we kept painting it, always using a spray coat until the paint began to drip off the ceiling. We had no equipment for absorption measurement there, but you could not detect any loss of sound absorption after the painting.

DR. COOK: I should not wish to comment on this unless I had seen the material. So much depends on the manner in which the material is applied, upon the density of application, and upon the painting.

MEMBER: There is another commercial material on the market that does not seem to fit into the pictures that you had. It is called Kimsul, and consists of sheets of paper, held together very loosely, and it is faced with a sheet of loosely woven muslin. Is there some theory to explain its action?

DR. COOK: I know the material you have in mind. That would probably come under the category of the rubberlike materials mentioned earlier.

MR. E. J. CONTENT: Dr. Cook, do you think that you can apply any kind of paint on the surface of materials other than those that have perforations, and not change the absorption characteristics in any way as a function of frequency?

DR. COOK: No, even for the rubberlike materials, repeated application of paint progressively reduces the absorption.

MR. DUNBAR: Was the paint applied all at one time, or was it allowed to dry between coats?

DR. COOK: The paint was allowed to dry a day or two between coats.

MR. BEN SCHLANGER: Dr. Cook spoke about convex-faced material and said he was going to tell us more about it.

DR. COOK: I was referring to spheres, cylinders, and cones. Yes, I did promise to say something about them. The sound can, so to speak, hit the material from all directions, whereas, when it is on a wall, the sound comes only from a hemisphere of directions. It appears that the greatest absorption obtains in the case of spheres, for a given material.

MR. SCHLANGER: I do not favor materials that have to be painted, but during the war we could only get white acoustic materials, that is, factory-fabricated, and we did not want white. So what I did, instead of painting with a brush, was to use a dry-brush application, so there was no flow of material, and I continued to apply the dry-brush stipple effect, until sufficient coat-covering was achieved.

MR. COLE: Dr. Cook, at what frequencies were the coefficients taken that you quoted with regard to the fissured material and the one following that?

DR. COOK: Those were average coefficients, usually referred to as the noise coefficients.

Continuously Variable Band-Elimination Filter*

By KURT SINGER

RCA Victor Division, Hollywood, California

Summary—A band-elimination filter continuously variable within a range from 30 to 9000 cycles has been developed. This device has proved extremely useful for the elimination of interference frequencies in the production of sound for motion pictures.

At the request of one of the Hollywood motion picture studios, a continuously variable band-elimination filter has been developed which is capable of suppressing a very narrow frequency band anywhere in the range from 30 to 9000 cycles. The immediate need for such a device was occasioned by the necessity to eliminate arc whistles from film recordings of one of the latest Technicolor productions. The arc whistles had been caused by commutator ripple modulation of the carbon arcs which were used for set illumination and had been picked up by the microphone. Because of the magnitude of the sets, such a great number of arc lights had to be employed that the series reactors, usually employed for arc-whistle suppression and which are connected between the motor-generator sets and the arc lights, became so badly overloaded that their attenuation was considerably reduced.

The members of the Sound Department were aware of the problem, but since it was impossible to correct the condition at the time, they went ahead and recorded anyway, leaving the solution of the problem to be worked out during the re-recording, when various expedients could be tried.

When the re-recording of the picture was started, tests with various types of filters were made in an attempt to eliminate the arc whistles; however, it was found that conventional filters did not cut sharply enough to permit elimination of the arc whistles without deleterious effects on recording quality. Since the only solution was to eliminate the disturbing whistles electrically, we were asked whether it would be feasible to develop, on short order, a device suitable for the elimination of arc whistles in the neighborhood of 700 cycles. We

* Presented October 24, 1947, at the SMPE Convention in New York.

were also told "if we would be in a position to do not only this, but at the same time could elaborate on such a device and make it suitable for the elimination of deleterious noises anywhere in the audio spectrum, then really we should be doing something for them and the film industry in general."

The device which was finally developed to fulfill the studio's requirements is shown and explained in the accompanying illustrations. A zero-gain amplifier was used which consisted of four amplifier stages. A three-terminal adjustable Wien bridge was used as the coupling circuit between the second and third amplifier stages. Twenty-six decibels of feedback from output to input of the four stages narrows the bandwidth at cutoff frequencies. Fig. 1 shows the input transformer, the secondary of which is terminated in a voltage divider which permits adjustment of the amplifier to zero gain. This transformer is connected into the grid of a pentode-connected 1620 tube which is resistance-coupled to another 1620 tube used as a triode. The plate of this second stage is fed back to the cathode of the first stage. This was primarily done to lower the impedance of the second 1620 tube sufficiently to present a very low generator impedance to the three-terminal Wien bridge which follows. This expedient was necessary in order to prevent gain changes caused by impedance variations of the Wien bridge. It can be seen easily that as the generator impedance approaches zero, the generator in this particular case is the plate impedance of the second stage, no gain change caused by impedance change of the Wien bridge will be experienced. Conversely, if the load impedance into which this Wien bridge works is very high as compared to the impedance of the Wien bridge itself, again no gain change will take place.

Following this second stage is the Wien bridge which is a more or less standard three-terminal configuration. The audio spectrum from 30 to 9000 cycles is divided into five bands. This is accomplished by changing the capacitance arms of the Wien bridge but keeping the variable range of the resistance arms the same for all five bands. By means of this arrangement, it is possible to cover approximately a 3-to-1 frequency range in the four bands from 60 to 9000 cycles and slightly better than a 2-to-1 range from 30 to 68 cycles. The output of this Wien bridge is fed into the grid of another 1620 tube, pentode-connected, which in turn is resistance-coupled to a triode-connected 1620. The plate of this fourth stage is connected to a suitable output transformer and a portion of the output voltage

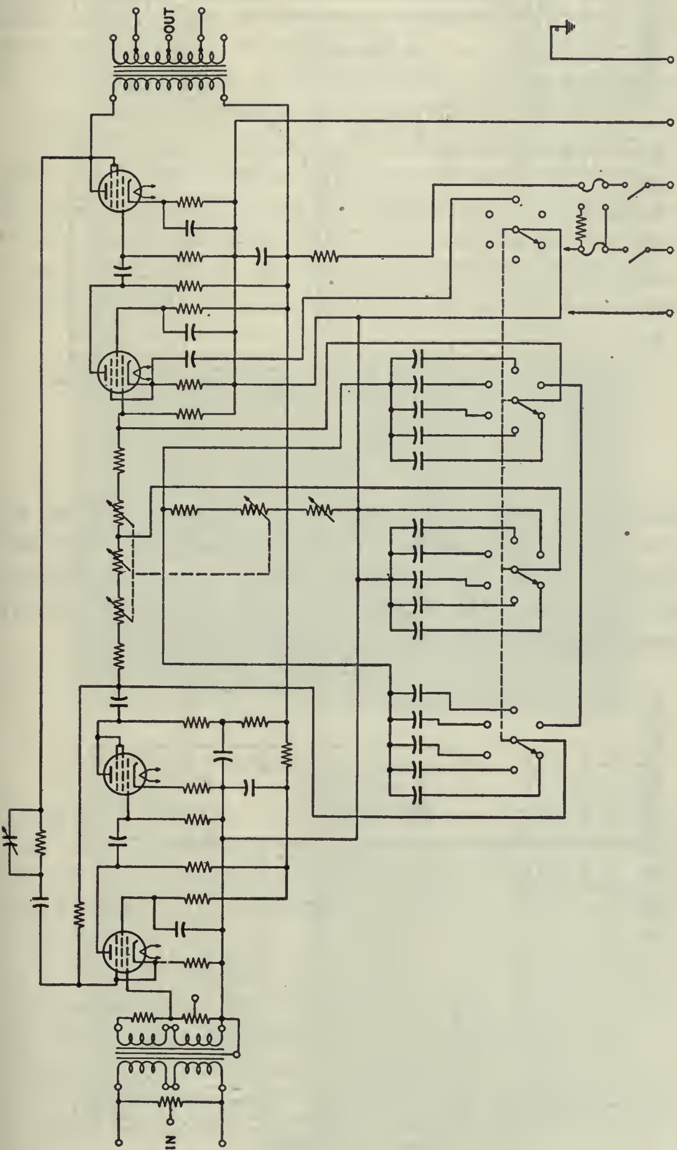


Fig. 1—Schematic.

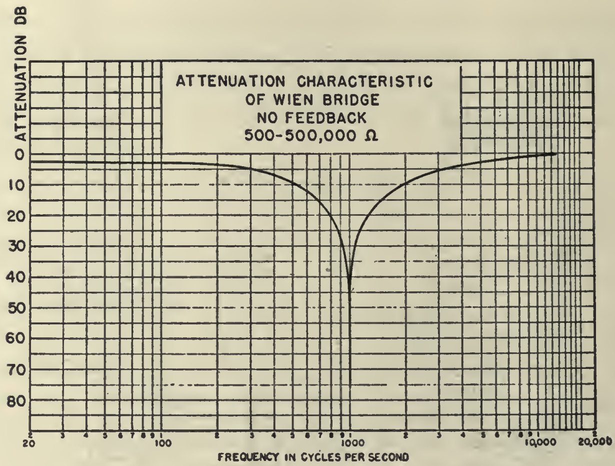


Fig. 2

is fed back, 180 degrees out of phase, to the cathode of the first stage. This over-all feedback results, first, in a considerable decrease of over-all amplifier distortion. Second, since it corrects for frequency-response variations within its limitations, it narrows the bandwidth of the band which is eliminated at the cutoff frequencies.

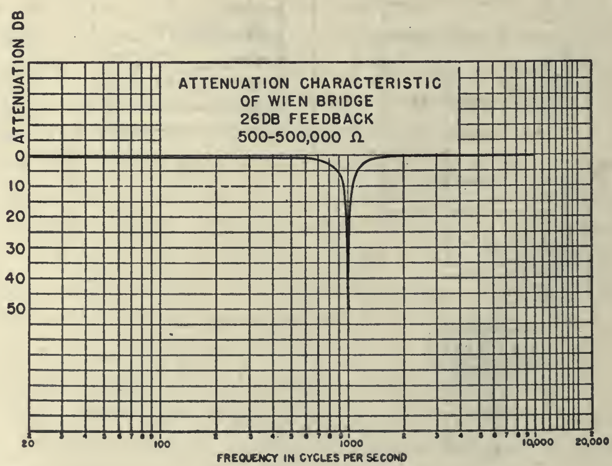


Fig. 3

Figs. 2 and 3 give a better picture of what is meant by narrowing the bandwidth. Normally, a Wien bridge when used between two amplifier stages attenuates rather gradually and the slope becomes progressively steeper. With the use of over-all feedback around the Wien bridge, the biggest part of this gradual region is eliminated and the sides of the eliminated band are made considerably steeper. Two variable, vernier resistors in the Wien bridge permit obtaining an exact null. Fig. 4 shows a front view of the filter panel. The large center dial permits selection of any frequency within the specific band which is selected by setting of the rotary switch directly below. The two smaller dials to the left and right of this large dial are the two verniers, which assist in obtaining an accurate null. There is

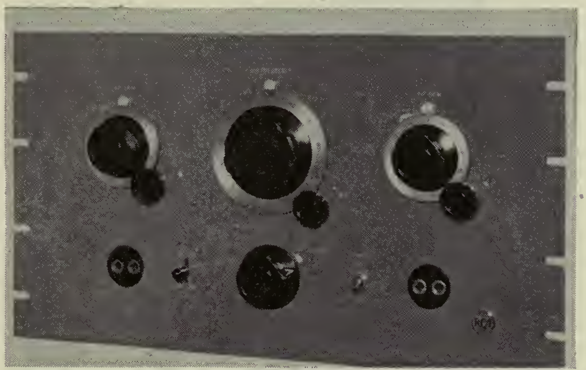


Fig. 4—Front view.

an "on-and-off" switch to the right and an "in-and-out" switch to the left. This "in-and-out" switch permits removal or insertion of this filter in the recording line at the operator's discretion. No click or other disturbance is created when this filter is switched in and out of the circuit.

Fig. 5 shows the interior of the device and Fig. 6 shows the frequency characteristics as obtained with various settings of the dip-control dials. The bandwidth of the rejected frequency band is approximately 15 per cent at 6 decibels attenuation and 3 per cent at 30 decibels attenuation as referred to the peak-attenuation frequency.

The practical operation of the filter takes place in the following manner. Usually, one determines the exact frequency of the interference by beating it with an oscillator. Then the band-elimination filter is connected into the recording circuit and the same frequency as the interference is injected into the recording channel directly from the oscillator. The frequency derived from the oscillator is eliminated by means of the proper dial adjustments on the filter. This is first done by ear and the ultimate and lowest setting is obtained by means of high-gain volume indicators. The minimum attenuation of the interference frequency which can thus be obtained is 50 decibels. After the proper setting of the filter has been determined, the oscillator is disconnected and the recording channel repatched for normal operation with the band-elimination filter in the circuit. If the in-

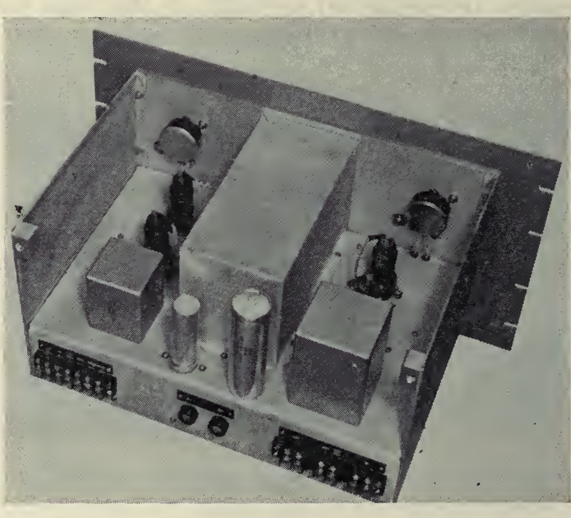


Fig. 5—Chassis view.

terferences consisted of a single frequency only, this frequency has been eliminated. However, if there were higher-order harmonics present they, of course, have been retained. How objectionable these harmonics are, depends upon their magnitude. In the case of the previously mentioned arc whistles, it was possible to eliminate them completely by the use of this filter just by eliminating the fundamental.

It has also been found possible to find further use for this filter by using it for the elimination of camera noise and motor-generator noise. Some added explanation might be in order. Camera noise, is, as the name implies, generated by the motion picture camera. Most studios use blimps, that is, soundproof housings over the camera which are supposed to remove camera noise completely. Some blimps, however, are not so good as others and under certain conditions it is impossible to use blimps. Then one has to rely on low-noise cameras which are not always low noise, the noise being a function of maintenance and wear. While camera noise does not consist of only a single frequency, it has been found possible to reduce its objectionable effects almost completely by the use of this filter by eliminating the predominating noise frequency.

Motor-generator sets used for lighting current on location are usually quite noisy since they employ gasoline motors. While an attempt is usually made to keep them as far from the microphone as

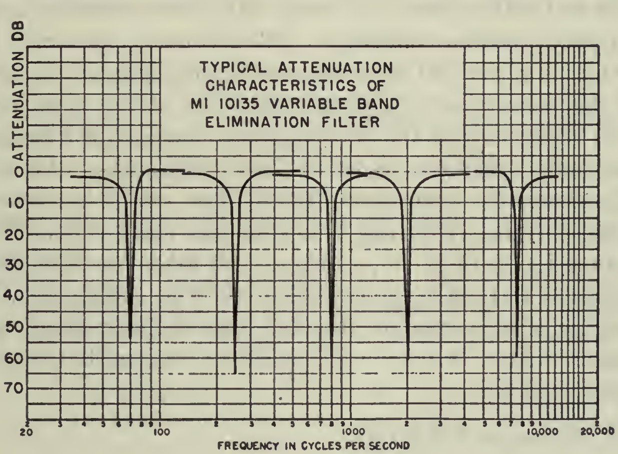


Fig. 6

possible, there are practical limitations to this distance, with the result that some studios have motor-generator-noise interference on a number of their location shots. There again it has been found that the elimination of the predominating noise frequency is sufficient to attenuate the generator noise satisfactorily.

In conclusion, the summary of the electrical characteristics of this band-elimination filter are as follows: The gain of the filter is zero decibels, the input impedance is 600 or 250 ohms, and the output impedance is 600 or 250 ohms. Zero gain is maintained whether the 250- or 600-ohm input or output connections are used. The filter operates from a heater supply of 6 to 12 volts direct current and B supply of 250 volts direct current. Four RCA 1620 Radiotrons are employed. The maximum input level that can be applied is −2 dbm.* The distortion at an input or, for that matter, output level of −2 dbm without the frequency-selective circuit, is about 0.15 per cent from 50 to 8000 cycles. With the frequency-selective bridge in the circuit, it is somewhat difficult to express distortion in terms of percentage of fundamental frequency, if the fundamental frequency lies in the attenuation band, since the ratio of fundamental to harmonic is determined primarily by the attenuation of the fundamental frequency. However, for fundamentals which are outside the attenuation band, the distortion is not any more than 0.15 per cent. The peak rejection frequency is continuously adjustable between 30 and 9000 cycles. At least 50 decibels rejection is obtained at any peak rejection frequency. The frequency spectrum from 20 to 9000 cycles is divided into five overlapping bands. A sixth position on the selector switch permits removal of the frequency-selective Wien bridge so that the device may be operated as a flat zero-gain amplifier which sometimes is useful if one wants an isolation amplifier.

The mechanical construction of this filter, which is known as the MI-10135, permits mounting in a standard relay rack. The front panel dimension is 19 × 10$^1/_2$ inches. All tubes are nonmicrophonically mounted and the frequency-selective Wien bridge, as well as the entire wiring, are completely shielded against electrostatic and electromagnetic fields. A dust cover, which is removable from the rear, is also provided.

* Decibels with respect to 0.001 watt.

DISCUSSION

MR. GEORGE LEWIN: Is there any noticeable effect whatever on the quality of voice or music with this filter in operation?

MR. E. E. MILLER: I do not believe the effect on voice or music through the insertion of this filter is any more than that you will notice in a studio on the scoring stage where you move the microphone an inch and a half wavelength at any particular frequency to pick up the peak or null of a standing wave that exists in that studio. I do not believe you will find this is any more than that.

DR. HOWARD C. HARDY: I do not have so much enthusiasm as the speaker had for the fact that you could take out the noise of a motor generator or camera by this filter; certainly the spectra of some of those instruments are very wide bands, and no peak usually exists that is over 60 or 70 decibels above the whole main spectrum. At the most, you could eliminate 60.

MR. MILLER: I think the author makes that very clear. He pointed out that if a high order of harmonics exists, we can remove the fundamental but not the harmonic if it is of a high order.

Society Announcements

Czechoslovak Film Standards

As of July 1, 1948, the standard projection speed for 35-mm sound film in Czechoslovakia will be 25 frames per second rather than the American Standard of 24 frames per second. Mr. Frantisek Pilat, president of the Filmovy Technicky Sbor (Czechoslovak Motion Picture Engineering Committee), reports that this change was made because of the increased use of synchronous motors in theater projectors in that country and also because of the 50-cycle power-line frequency that is in common use in most European countries. With synchronous drive, speed-regulation problems cease to exist as long as the line frequency is constant, and, according to Mr. Pilat, practical tests proved that the resulting higher pitch of the reproduced sound created no practical problems since it was not observed by spectators.

International Scientific Film Congress

The second congress of The International Scientific Film Association will be held in London from October 4 to 11, 1948.

The Association was constituted last year in Paris by delegates from 22 countries who had accepted the joint invitation to the inaugural congress from The Scientific Film Associations of Great Britain and France. The primary aim of the Association is:

> "To raise the standard and to promote the use of the scientific film and related material throughout the world in order to achieve the widest possible understanding and appreciation of scientific method and outlook, especially in relation to social progress."

This year's congress is being convened by The Scientific Film Association of Great Britain, with the help of The British Film Institute, and invitations have already been issued to countries throughout the world. The congress will open with a formal reception to the delegates on October 4 and the following three days will be devoted to business meetings of The International Scientific Film Association. On October 8, 9, and 10 there will be a Festival of Scientific Film when it is hoped to show many contributions from all the participating countries to members of the general public. The congress will close with a general assembly of the delegates on October 11.

The widespread public interest in England in the scientific film as evidenced by over 10,000 members of local scientific film societies, the introduction of scientific films and other visual aids into the educational program in that country and, in particular, the many pioneer activities of The Scientific Film Association with its country-wide membership make it particularly appropriate that this congress should be held in Great Britain. Visitors from overseas will have an opportunity of studying the many contributions which England has made by the use of films to the "widest possible understanding and appreciation of scientific method and outlook."

Further details may be obtained from The Scientific Film Association of 34 Soho Square, London, W.1.

64th Semiannual Convention

Hotel Statler, Washington, D. C., October 25–29, 1948

—PAPERS PROGRAM

Preparations are being made for the Fall Meeting of the Society which will be held at the Statler Hotel in Washington, D. C., October 25 to 29, 1948, inclusive. Authors desiring to submit papers for presentation at this meeting are requested to obtain Author's Forms from the Vice-Chairman of the Papers Committee nearest them. The following are the names and addresses:

Joseph E. Aiken
225 Orange St., S. E.
Washington 20, D. C.

E. S. Seeley
250 West 57 Street
New York 19, N. Y.

N. L. Simmons
6706 Santa Monica Blvd.
Hollywood 38, Calif.

R. T. Van Niman
4431 West Lake St.
Chicago 24, Illinois

H. L. Walker
P. O. Drawer 279
Montreal 3, Que., Canada

Author's Forms and summaries of papers must be in the hands of Mr. Aiken by September 1.

—PRELIMINARY CONVENTION PROGRAM

Present plans for the 64th Convention Program include a number of special features that will be of interest to all Society members. There will be a symposium on High-Speed Photography now being organized by Mr. J. H. Waddell, Chairman of the SMPE Committee on High-Speed Photography, and it is expected that a large group of interesting and related papers on the subject will be presented.

—BUSINESS SESSION

The annual Society Business Meeting is scheduled for 3:00 P.M., Tuesday, October 26. All members planning to be in Washington should attend this session since there will be important items of business to be discussed and voted upon.

—AWARDS

Annual presentation of Society awards is planned and recipients are now being determined by the SMPE Committees on Journal Awards, Fellow Awards, Samuel L. Warner Memorial Award, and Progress Medal Award. Also, the newly elected Society officers will be introduced to the members.

PRELIMINARY PROGRAM

Monday, October 25, 1948

9:30 A.M.	REGISTRATION Capitol Terrace Room
12:30 P.M.	GET-TOGETHER LUNCHEON Congressional Room
3:00 P.M.	TECHNICAL SESSION Presidential Ballroom
8:00 P.M.	TECHNICAL SESSION Presidential Ballroom

Tuesday, October 26, 1948

9:30 A.M.	REGISTRATION Capitol Terrace Room
10:00 A.M.	TECHNICAL SESSION Presidential Ballroom
2:00 P.M.	TECHNICAL SESSION Presidential Ballroom
3:00 P.M.	BUSINESS SESSION OF THE SOCIETY Presidential Ballroom
3:30 P.M.	RESUMPTION OF TECHNICAL SESSION Presidential Ballroom
	OPEN EVENING

Wednesday, October 27, 1948

9:30 A.M.	REGISTRATION Capitol Terrace Room
10:00 A.M.	TECHNICAL SESSION Presidential Ballroom
	OPEN AFTERNOON
8:30 P.M.	64TH SEMIANNUAL BANQUET Presidential Ballroom

Thursday, October 28, 1948

	OPEN MORNING
2:00 P.M.	TECHNICAL SESSION Presidential Ballroom
8:00 P.M.	TECHNICAL SESSION Location to be announced later

Friday, October 29, 1948

10:00 A.M.	TECHNICAL SESSION Presidential Ballroom
2:00 P.M.	TECHNICAL SESSION Presidential Ballroom
5:00 P.M.	ADJOURNMENT

—*LADIES' ACTIVITIES*

The Ladies' Reception Hostess and Mr. W. C. Kunzmann are arranging a most interesting program for ladies who plan to attend the Convention or to visit Washington during Convention week. The Potomac Room at the hotel will be ladies' headquarters; further information about the special program will appear in the September issue of the JOURNAL.

—*RESERVATIONS*

Excellent accommodations at the Hotel Statler have been arranged for by the Convention Committee. Members of the Society will receive reservation cards, which they will be requested to fill out and mail directly to the hotel in Washington. Each member must arrange these accommodations directly with the hotel; be sure to mention the SMPE Convention if you are writing on your own letterhead. Reservations should be made by September 15.

Book Reviews

Magic Shadows, by Martin Quigley, Jr.

Published (1948) by the Georgetown University Press, Washington, D. C. 161 pages + 14-page appendix + 8-page bibliography + 7-page index. 24 illustrations. $6^{1}/_{2} \times 9^{1}/_{2}$ inches. Price, $3.50.

Film historians, recording the origins of the motion picture, seem impelled to begin their studies with the Altamira cave paintings and then, working up slowly through Leonardo, Rogêt, and Plateau, they finally come to Muybridge, Marey, and the Edison prescreen experiments. Actually, the relationship of their historic discoveries and devices to the history of the film itself is more than a little remote; Mr. Quigley has quite properly removed this chapter from the film histories and expanded it into a book that has its own validity. "Magic Shadows" carefully traces the slow accretion of scientific knowledge, the sudden acceleration in the mid-nineteenth century as early principles found practical application, and finally the simultaneous rush to the screen in France, England, Germany, and the United States in 1895–1896. Through it all Mr. Quigley stresses the internationality of the sources, the innumerable individuals who contributed to the scientific study of optics, and the universal appeal, not merely of films today, but of the more basic urge to project the shadow of reality. An elaborate chronology at once traces the growth of prescreen knowledge and emphasizes this multiplicity of its sources.

That same multiplicity is further revealed in the extensive bibliography that Mr. Quigley has appended to his book. Working intermittently on it since 1936, he has had opportunity to examine original sources both here and abroad, has covered printed material in Latin, French, German, and English, and translations from Greek and Arabian. But "Magic Shadows" is no mere compilation. The main lines of the study were laid down by the veteran film historian, Terry Ramsaye. In following them, Mr. Quigley has produced a study that is as readable as it is useful, as thoughtful as it is informative.

John E. Abbott
Webb and Knapp, Inc.
New York 17, N. Y.

Photographic Facts and Formulas, by E. J. Wall and Franklin I. Jordan

Published (1947) by the American Photographic Publishing Company, 353 Newbury St., Boston 15, Mass. 353 pages + 10-page index + vii pages. 18 illustrations. $6^{1}/_{4} \times 9^{1}/_{4}$ inches. Price, $5.00.

This book is literally crammed with a multitude of both facts and formulas. The new revision represents a minor modernization of the 1940 edition to include references to recent developments such as coated lenses and the new color processes. The material for the most part is presented in a clear and readable fashion with a continuity of subject matter that was not evident in the 1924 and earlier editions. The publisher's claim, however, that it is a practical handbook of directions for all photographic operations in common use is not strictly valid. The increasingly important field of color photography, for example, is glossed over in twenty pages, less than half the space allotted this subject in the 1940 edition. On the other hand, the preparation of lantern slides, which is currently something of a lost art, is allotted sixteen pages, and a process as obsolete as the making and toning of printing-out papers is treated in exquisite detail.

Black-and-white photography is quite fully and capable handled, and the experimental photographic hobbyist will be delighted at the practical working approach to such subjects as image toning; the sensitizing of leather, fabrics, and wood; oil, bromoil, and other transfer processes; gum-bichromate printing; and carbon processes. There is a tendency, particularly in the chapter on "Photomechanical Processes," to pile up formulas and working directions without any real description of the process involved. In general, the material appears to have been drawn from a variety of sources without too careful an effort to unify it.

Such important fields as reversal processing and tropical processing are only sketchily treated, and there is a regrettable tendency to retain obsolete terminology in some of the older formulas—such as boracic acid and carbonate of soda.

Despite these objections, the book is a sufficiently useful compendium of photographic information to be a worthy adjunct to the photographer's library. However, full-scale revision rather than mere deletion and addition is overdue. In view of the enormous amount of pertinent photographic material available to the compilers, there is not space in a photographic handbook of modest size for an entry on "How to Make Marine Glue" or for five pages on "How to Resilver Mirrors."

Howard A. Miller
Eastman Kodak Company
Kodak Park, Rochester, N. Y.

FORTY YEARS AGO

Political Subjects Desired

A correspondent of the "St. Louis Post-Dispatch" says: "I should like to ask through your columns why the moving picture show companies do not make arrangements for a reproduction of the proceedings of the Republican and Democratic national conventions that are to be held soon? It would be very interesting and instructive, and millions who are unable to go to the convention halls would like very much to see it. And other notable gatherings should be reproduced."

—*The Moving Picture World, June 13, 1908*

Section Meeting

Midwest

George W. Colburn, secretary-treasurer of the Midwest Section, presided at the May 13, 1948, meeting, which was held on the sound stage of the Atlas Film Corporation. Ninety-two members and guests were present.

The first paper, "The DM-2 and DM-4 Developing Machine," was presented informally by R. Paul Ireland, president, Engineering Development Laboratories. Mr. Ireland described the physical setup of the machines and elucidated on the features of roller design and the principles of physics involved.

"The RCA Six-Position Re-Recording Console" by Everett Miller of the Radio Corporation of America was read by Frank Richter, sound engineer, Atlas Film Corporation. The installation described by the paper was inspected after the final presentation.

Erik I. Nielsen, senior organic chemist, Armour Research Foundation, gave a talk entitled "Recent Developments in Plastics." This subject dealt with plastics as applied to optics and covered the problems involved in mass production of high quality plastic lenses.

The meeting adjourned at 10:00 P.M. and was followed by an inspection of the developing machines described in the first presentation, the re-recording console described in the second paper, and a general tour of the Atlas Film Corporation's facilities.

Correspondence

It is highly desirable that members avail themselves of the opportunity to express their opinions in the form of Letters to the Editor. When of general interest, these will be published in the JOURNAL of the Society of Motion Picture Engineers. These letters may be on technical or non-technical subjects, and are understood to be the opinions of the writers and do not necessarily reflect the point of view of the Society. Such letters should be typewritten, double-spaced. If illustrations accompany these contributions, they should be drawings on white paper or blue linen and the lettering neatly done in black ink. Photographs should be sharp and clear glossy prints.

Please address your communications to

MISS HELEN M. STOTE, *Editor*
Society of Motion Picture Engineers
Suite 912
342 Madison Avenue
New York 17, N. Y.

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

29, 4, April, 1948

Television Field Opens for Cinematographers (p. 120) E. Tow

Progress on 8-mm Synchronized Sound (p. 135)

29, 5, May, 1948

Extremely Wide Angle Lens for Aerial Mapping (p. 154)

Appreciating the Motion Picture (p. 163) C. Loring

International Projectionist

23, 4, April, 1948

Theater Television: A General Analysis (p. 21) A. N. Goldsmith

More on "Quality" vs. "Pleasing" Sound Reproduction (p. 30)

23, 5, May, 1948

Optical Efficiency in Projection (p. 5) R. A. Mitchell

Screen Data: Types, Sizes, Illumination for 35- and 16-mm Film Projection (p. 8)

Handling, Storing Cine Film (p. 12)

Theater Television: A General Analysis (p. 15) A. N. Goldsmith

Tele-Tech

7, 6, June, 1948

Sound Measurements in BC Studios (p. 38) W. Jack

Audio Engineering

32, 5, May, 1948

Loudness Control for Reproducing Systems (p. 11) D. C. Bomberger

Factors Affecting Frequency Response and Distortion in Magnetic Recording (p.18) J. S. Boyers

Horn-Type Loudspeakers (p. 25) S. J. White

British Kinematography

12, 4, April, 1948

Metals in Kinema and Related Equipment (p. 109) A. B. Everest and F. Hudson

Back Projection and Perspective. 1. Interlocking and Film Steadiness (p. 127) G. Hill

La technique cinematographique

19, April 1, 1948

Trente années de technicolor. (Thirty Years of Technicolor) (p. 133) W. R. Greene

Procédés d'enregistrement sonore sur film. (Procedure of Recording Sound on Film) (p. 135) P. Jacquin

Radio News

39, 6, June, 1948

The Recording and Reproduction of Sound. Pt. 16 (p. 65) O. Read

Modern Television Receivers. Pt. 3 (p. 71) M. S. Kiver

EMPLOYMENT SERVICE

POSITION WANTED

CAMERAMAN: Experienced in 35-mm and 16-mm cinematography, color, black-and-white. Active member SMPE. Three years' overseas experience as Official Army Photographer World War II. Will consider offer anywhere in U.S.A. References available. Free to travel part time at least. Write Charles Arnold, P. O. Box 995, Peoria, Ill.

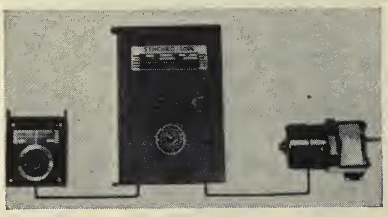
New Products

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.

Synchro-Link, Pulsing Drive, and Dyna-Link

Yardeny Laboratories, 105–107 Chambers Street, New York 7, New York, recently put on the market their Synchro-Link, Pulsing Drive, and Dyna-Link.

The Synchro-Link is an inexpensive remote-positioning servo control, which will position one or several distant motors, according to the setting of the master-control dial. The accuracy is independent of the load.



This equipment works on the principle of a self-balancing electronic bridge, and will control the speed adjustment on variable-speed transmissions, the setting of motorized valves, volume dampers, engine throttles, pumps, machine tools, and special machinery.

The master-control dial can be located any distance from the Synchro-Link controller up to several thousand feet. Only 3 wires of light gauge passing small control currents connect the master control to the Synchro-Link controller.

The Pulsing Drive is a new device for controlling electrical motors when accurate positioning is important. It responds to the operation of a single knob, and when this knob is rotated in one direction, the Pulsing Drive closes selectively one of two circuits for very short periods of time repeated at a rate dependent upon the speed of the knob rotation. It is suited for controlling all standard types of electric motors or magnetic valves.

The Dyna-Link is an electronic control device, designed for industrial applications of variable-speed power transmission. It consists of a master control calibrated in revolutions per minute, the Dyna-Link controller, and a speed-measuring generator. When the operator sets the master control to the desired speed setting, the Dyna-Link controller energizes the pilot motor in the proper direction for adjusting the speed changer until the actual output speed corresponds to the master-control setting. If the drive slows down because of an increase in the load, the Dyna-Link controller automatically detects the difference in speed and corrects the adjustment.

Film Counter, Audio Compensator, and Phase Converter

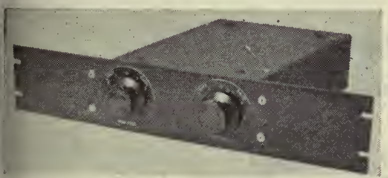
A Film Counter, Audio Compensator, and Phase Converter are three new products which are now being produced by **Arlington Electric Products,** 500 W. 25 St., New York, New York.

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.

The Film Counter is designed for use in motion picture viewing, dubbing, recording, and narrating, wherever footage and cuing information are desired.

The unit can be located remotely from a projector, recorder, or dubbing head and will read elapsed time in minutes and tenths of a minute and in feet of film that have passed through the film machine. The counter can be wired to start automatically with the projector or dubbing head and can be stopped and started any number of times during a thousand-foot reel.



The Audio Compensator is used where audio equalization is required, and is applicable in film recording, disk recording, and general broadcast-studio work. Equalization characteristics available consist of three steps each lowering or raising low frequencies and lowering or raising high frequencies. Each channel contains a two-stage resistance-capacitance amplifier employing Type 1620 tubes. Power and audio connections are made through multiple plugs.

The Phase Converter is designed for use where it is necessary to operate cameras or recording machines with three-phase driving motors from a single-phase source of power.

The converter is portable and does not use electronic tubes or rotating machinery. The converter input is 115-volt, 60-cycle, single-phase alternating current, and the output is 220-volt, 60-cycle, three-phase alternating current of sufficient power to run one motor properly. A motor running from this converter will have the electrical characteristics identical to that of commercial three-phase power and will have a speed synchronous to the single-phase line frequency.

FORTY YEARS AGO

Washington, D. C., Wants Picture Machines Inclosed

Fire Chief Belt has recommended to the Commissioners that moving picture machines used in the five-cent theaters and the regular theaters of the District be inclosed in fire-proof boxes.

—*The Moving Picture World, May 9, 1908*

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Journal of the Society of Motion Picture Engineers

VOLUME 51 SEPTEMBER 1948 NUMBER 3

Subscription to nonmembers, $10.00 per annum; to members, $6.25 per annum, included in their annual membership dues; single copies, $1.25. Order from the Society's general office. A discount of ten per cent is allowed to accredited agencies on orders for subscriptions and single copies. Published monthly at Easton, Pa., by the Society of Motion Picture Engineers, Inc. Publication Office, 20th & Northampton Sts., Easton, Pa. General and Editorial Office, 342 Madison Ave., New York 17, N. Y. Entered as second-class matter January 15, 1930, at the Post Office at Easton, Pa., under the Act of March 3, 1879.

Report of the President*

THIS REPORT of the President is the story of the Society of Motion Picture Engineers, its activities during the last six months, and what takes place at the New York Headquarters' Office 3000 miles from this, the 63rd Semiannual Convention.

I am proud of that "63rd" figure and the continuity of activity which it represents. Few people realize that for $31^1/_2$ years this Society has served this industry. Few people realize that much of the early world-wide standardization for silent pictures was worked out by SMPE members. As of this date this industry has established more standards with the American Standards Association than any other United States industry. This is important, for our market is world-wide and dependent upon the existence and the retention of standards under which our product can be played. The Society is still active and a look into the future would indicate that television will bring more and greater problems in standardization. It is important to note that the economic value of this standardization increases rapidly with complexity of equipment, and even to one familiar with television it is complex.

The 62nd Convention of the Society, which was held in New York last October, included a Theater Engineering Conference and Equipment Exhibit. It brought into our circle many theater people and their technical contributions along with an appreciation on our part of their problems. The good which has resulted from that convention will be of lasting value.

The period following the New York Convention has been marked by great technical changes. Television has grown from the ten-inch image of a home receiver to a reality on the theater screen. This is a milestone in motion pictures. It may bring about even greater changes than occurred with the advent of sound.

Our progress has not been limited to any one field. New color processes are now in commercial use and the thinking which has taken place is the forerunner to the great program of color papers at the 63rd Convention. The completeness of this color coverage is not an accident. It is the result of a realization on the part of our engineers that color offers an outstanding technical advantage which the motion

* Presented May 17, 1948, at the SMPE Convention in Santa Monica.

picture industry has and can use in meeting the competition of television broadcasting to the home.

Magnetic recording has arrived at a state of development where it is now finding its place as a tool for the broadcast and motion picture industries. The papers presented at this convention and the work of our Standards Committee will aid in the best use of this noteworthy scientific development. There are other fields in which there has been marked advancement and I say with pride that these advancements are well recorded in the JOURNAL of the Society.

Over the years the Society has progressively and solidly grown into a large and businesslike organization. Our Headquarters' Offices are located in the Canadian Pacific Building at 342 Madison Avenue, New York 17, New York. We have a paid staff of eight persons under Mr. Boyce Nemec, the Executive Secretary. The work which they do is the background of all Society activity—world-wide. Our sections are located in New York, Chicago, and Hollywood, with a Student Chapter at the University of Southern California. All of our membership records, business administration, and the publication of our JOURNAL are handled by the New York Office. The New York Office and the personnel in that office are there to serve you, the members of this Society. Please visit the office when you are in New York or write whenever we can be of assistance to you.

The records as of March 31, 1948, show that our membership has now reached 2787 members. For the year 1948 we anticipate a revenue and an expenditure of approximately $95,000.

In making a study of our membership we find that it has not grown as anticipated. This seems to be largely due to the complexity of the system of admitting new members. Steps have been taken at the Board Meeting of May 16 to rectify this condition. All persons interested in the art of motion picture making are eligible for Associate membership. We want their affiliation and we want to advance their status when, as, and if their qualifications and activity justify such advancement.

I want you to know that we, the Officers of the Society, are appreciative of the excellent support which we have received from the membership. I want the sustaining members to know that their support is sincerely appreciated and valued.

Respectfully submitted,
LOREN L. RYDER, *President*

Historical Sketch of Television's Progress

By L. R. LANKES

Eastman Kodak Company, Rochester 4, New York

Summary—This is a brief review of published material and, in its original form, was an introductory part of a symposium on the various aspects of television which will affect the photographic industry. It is not an attempt to answer directly the question, "Who invented television?" for, as Waldemar Kaempffert, Science Editor of the *New York Times,* has already pointed out, Professor William F. Ogburn in his "Social Change" has listed 148 major discoveries and inventions which were made simultaneously and independently by at least two workers in the particular field concerned in each case; and if the list were to include developments of secondary importance, it would undoubtedly have grown into a volume at least as large as an unabridged dictionary. Rather, then, it should be construed as an attempt to convey a general understanding of the subject by considering how it was pieced together.

Of all the pursuits to which one can turn his attention, perhaps none has aroused a higher degree of curiosity, enthusiasm, and hope than the development of television. It has been said that television holds the promise of being the medium that can bring the peoples of far places emotionally face to face with one another's manners, customs, and problems, and thereby make them understand that they are all essentially human. It could be said that the motion picture also holds this promise since television is essentially motion pictures with radio as the means of conveyance. However, there may be advantages in television's claim to immediacy: namely, that what is being viewed at the receiver is occurring *now* at the transmitter.

Contrary to general opinion, the concept of television is not a twentieth-century product. Even in Biblical times abstract thinkers predicted that it would be possible to develop the ability to see events occurring beyond the horizon. However, the crystallization of specific inventions which led to television as we know it today, began with the transition of the eighteenth to the nineteenth century. The first items are Alexander Volta's electric battery, the voltaic pile; Professor Berzelius' isolation of the element selenium; Oersted's discovery of the principle of electromagnetic induction; and the efforts of Ampere, Ohm, and Faraday.

The middle of the nineteenth century might be said to have borne the infant, television, for in 1842 Alexander Bain,[1] an English physicist, first proposed a device to send pictures from one place to another by electric wires. Bain's plan was so correct basically that it embraced the fundamentals of all picture transmission, having recognized the particular problems posed by the need for synchronization between transmitter and receiver. In 1847, Bakewell[2] devised a "copying telegraph" employing an elementary scanning device. Specifically, this was an instrument for transmitting writing or drawings in the form of nonconducting shellac ink on tin foil. The foil was then wrapped around a cylinder which rose as it rotated, thereby tracing out a spiral with a fixed metal needle pressing against the foil. At the receiver, a similar cylinder was covered with chemically treated paper. In 1862, Abbe Caselli[2] transmitted the first electric picture from Amiens to Paris.

The latter part of the nineteenth century saw the groundwork for the construction of the present video industry. The light-sensitive properties of selenium were discovered in 1873 by a telegraph operator named May.[3] In a terminal station for the Atlantic cable on the coast of Ireland, May observed the effect of sunlight falling on selenium resistors in some of his circuits. This indicated that light values can be converted into equivalent electrical values. In 1875, G. R. Carey, in Boston, and Ayrton and Perry, in England, proposed to build a large mechanical eye using a plate of tiny selenium cells as the retina.[3] Each cell would be connected by wire to a corresponding spot on the receiver. Electromagnets connected to each of the small sections of the receiver plate were to regulate the amount of light on each section. Many other suggestions, all very similar in principle, were advanced through this period. These were followed by Sir William Crookes' discovery of cathode rays in his famous vacuum tube. In 1880, Leblanc[2] developed the complete principle of scanning wherein a picture is divided into lines and each line into tiny segments. Hertz,[4] in 1886, confirmed Maxwell's theories of electricity and discovered the photoelectric effect in 1887, when he noticed that a spark could be made to jump over a gap more readily if one of the electrodes were illuminated than if the event occurred in darkness. The German

Hallwachs[4] later studied the photoelectric effect systematically and concluded that light set free electrical particles from the electrode surface. Sir J. J. Thompson identified them as electrons and Einstein announced the theory of the photoelectric effect. The practical side was advanced by Elster[4] and Geitel[4] who, as early as 1890, built practical photoelectric cells. Thus the method was defined by which a television camera would turn a picture into electricity.

As a noteworthy aside, Thomas Edison[5] filmed his first motion picture in 1889; and Marconi,[6] in 1895, sent and received his first wireless signals across his father's estate.

Coincidental with these latter developments came the invention, in 1884, by the German Nipkow[4] of the rotating scanning disk. This disk made use of the very significant technique, previously suggested, of dissecting the scene to be transmitted into points of light which would then be measured on a time scale in orderly fashion. Nipkow's work ranks high in the history of the medium because he realized so early a system which was not improved upon, basically, for nearly fifty years.

In 1890, the Englishman Sutton[4] proposed a system for a television receiver which ranks in importance with Nipkow's system for the transmitter. Sutton's apparatus used a scanning disk and a light source controlled by a Kerr cell. This method of reassembling the image was likewise remarkable in that it was used widely in practical television systems for nearly forty years.

At the turn of the century, Sir J. J. Thompson,[7] in his work to determine the charge-to-mass ratio of the electron, showed that the cathode ray was in reality a beam of high-speed electrons. His methods involved the application of both electric and magnetic deflecting forces. At about the same time, Professor Braun[8] built a cold-cathode-ray tube. With it he could show the effect of magnetism on electron beams in tracing their paths on a fluorescent screen. From the viewpoint of television, this was to be the means of scanning control for Crookes' cathode rays. Amplitude control, on the other hand, was to come later.

By the end of the first decade of the twentieth century, Professor Boris Rosing[2] had patented a television system, using a receiver resembling the modern set, based on the Braun cathode-ray tube. In 1911, A. A. Campbell Swinton,[3] a man of great imagination and foresight, saw the possibility of television communication with variations of Rosing's cathode-ray tubes at both transmitter and receiver.

Recent years have shown that Swinton actually predicted television apparatus as used today, having developed the theory of a cathode-ray-tube camera. Meanwhile, Knudson[2] had sent the first drawing by radio.

Only a few of the early discoveries and inventions are directly employed in modern television. However, the original work and inventions gave impetus to experiments in demonstrating that light could be converted into electrical impulses which, in turn, could be transmitted and later reconverted. Fortunately for television, the development of the radio and electrical arts coincided with the advanced phases of research in the fields of optics and vision.

World War I delayed progress universally, for the next important date is 1923 when Zworykin filed patent application on the first electronic television camera tube, the iconoscope, wherein the means for scanning control, as well as for picture signal-amplitude control, were all self-contained on a completely electronic basis. While the idea had been proposed early in the art, this was the first practical means of achieving it.

At this time J. L. Baird[4] in England, and C. F. Jenkins[4] in the United States, working independently, produced and demonstrated systems of television based on mechanical scanning through the use of the Nipkow disk or something similar to it. The disk carried holes along a spiral in such a way that a scene, when viewed through a portion of it, would be broken into parallel lines or arcs, thereby providing the means of measuring light values along the short time-base which represented the frame interval. The pictures were mere shadowgraphs at first, but Baird soon demonstrated television transmission of half-tone pictures as well as infrared television.

This method of scanning, having serious limitations in definition, is not in use today, nor is the receiving system that reconstructed the picture by reversing the process. While the low-definition (less than 60-line) images of those days may seem to have little bearing on techniques which produce present-day, continuous-tone pictures in a 525-line system, much of the theory which makes present equipment possible was proved during this mechanical era.

In 1927 the Bell System demonstrated the transmission of television over substantial distances; between Washington and New York over wire line, and between Whippany, New Jersey; and New York over radio link. With this was published an analysis, thorough for the time, of the transmission problems facing television, particularly the frequency bandwidth requirements which have become so characteristic of the art.[9]

The decade 1925 to 1935 produced many developments in steady succession. These began with the National Broadcasting Company's first radio network and Warner Brothers' "Vitaphone" sound-on-disk system synchronized with motion pictures. Concurrently, Congress established the Federal Radio Commission; progress continued with Bairds' first trans-Atlantic television picture and his first crude systems of color and stereoscopic television; Farnsworth's system and Zworykin's system of all-electronic television were introduced employing special cathode-ray receiver tubes called kinescopes; Bell Laboratories demonstrated television in color, delivering a picture of postage-stamp size; theater television was shown on screens as wide as 10 feet; two-way-wire television-telephone demonstrations were made by Bell; improved photoelectric cells and electronic tubes were introduced; an extensive program of field tests by the Radio Corporation of America was initiated starting with 240-line all-electronic television employing radio relay, to continue right through the period of commercial operation; and, finally, the 1935 announcement of the principle of frequency modulation by Edwin Armstrong.

Through the efforts of men like Zworykin, Engstrom, and Goldsmith of RCA; Farnsworth; Ives and others at the American Telephone and Telegraph Company; Alexanderson of General Electric; Dumont; and Goldmark of the Columbia Broadcasting System, well-planned and well-executed programs made public participation in the United States possible in 1934.

The Philips Company of Holland built the first iconoscope in Europe in 1935. Television transmitters appeared in places such as the Eiffel Tower and Stockholm. As the advance continued, A. T. and T. successfully demonstrated the capabilities of coaxial cables in 1936. Such cables were laid from New York to Philadelphia, from Paris to Bordeaux, and from Berlin to Nuremberg. The first patent on coaxial cable was granted in England at this time and cables were laid from the British Broadcasting Corporation transmitter to Buckingham Palace and Victoria Station for the first direct televising of coronation-procession street scenes.[10–12]

In 1938 television signals from London, on ultra-short waves, were picked up on Long Island, although badly distorted.

The point was reached wherein one saw the telecasting of plays from theater stages, the New York World's Fair, major-league baseball, and professional football. Meanwhile RCA introduced an improved television camera tube, the orthicon. It is beyond the scope of this paper to enumerate the many developments from that point to date.

The lack of uniformity in choice of number of lines for the picture structure was never satisfactory to the nontechnical observer who was quick to compare television with motion pictures. Because of this, and in keeping with the steady advances, "definition" was standardized at 343 lines in 1935. Later this was raised to 441. In 1940 it was increased to 525 where it remains as today's standard.

Although World War II brought an apparent period of inactivity, an abundance of knowledge and technical personnel grew out of government-sponsored radar and guided-missile programs. Accelerated research and development produced items such as the high-sensitivity image-orthicon and phosphors to withstand the bombardment of highly accelerated electron beams, for brighter pictures.

The highly controversial issue of color versus black-and-white television brought the industry to a virtual standstill. After this was settled early in 1947 in favor of black-and-white, the prospective broadcaster, the equipment manufacturer, and the receiving-set purchaser appeared ready to invest in the fast-growing business. By December 31, 1947, the score totaled 12 cities with television service; 18 stations operating and 55 licensees; 287 sponsors; 142,400 receivers in private homes; 27,600 receivers in public places; 195,000 total receiver production; and an estimated audience of 1,200,000 with assurance of nationwide networks in the reasonably near future.

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Report of SMPE Standards Committee*

THE BYLAWS OF OUR SOCIETY wisely provide that the chairmen of committees "shall not be eligible to serve in such capacity for more than two consecutive terms." The first of this present year constituted that limit for the writer's service as chairman of the Committee on Standards, and so made appropriate this final reporting of the events of that period. At the same time it is hoped that this review, including as it does a description of the terminal status of the various standardization projects which were being conducted under the writer's general direction, may be of service to the new chairman and members of the Committee on Standards. Then too, the accelerating influence of the wartime period on standardization activities has stimulated a good deal of thinking with regard to the development of sound peacetime practices in this field, so that I have ventured to include a certain amount of philosophizing in that connection.

The prewar pace of the Committee on Standards was quite a leisurely one, determined in part by limited secretarial assistance from the Society office, but conditioned also by the general feeling that such a pace was altogether appropriate. In the 10-year period prior to Pearl Harbor, the parent Committee held an average of about three meetings a year. During the war the pace slackened to only one or two meetings a year, and it has continued at this reduced rate to the present time. The most important reason for this slackening of activity during the war was the establishment through the War Production Board of a number of War Committees of the American Standards Association, which operated at an unusually high rate of speed and effectiveness in the development of War Standards in specific fields defined by joint committees of the Armed Forces. The subcommittees as well as the parent War Committee on Photography and Cinematography, Z52, were staffed in large measure with members of our Society, and with members of our Committee on Standards in particular. This war committee considered a total of 72 proposals for standardization, of which 61 were completely processed as War Standards in a two-year period ending with the termination of the project

* Presented May 17, 1948, at the SMPE Convention in Santa Monica, by F. T. Bowditch, retiring chairman.

in February, 1946. This high rate of activity may be compared with the long-time prior achievement of 44 SMPE Recommended Practices, of which 33 had been advanced to American Standard (Z22) just prior to the organization of the Z52 War Committee in December, 1943.[1]

It was altogether proper that this high-priority war project should absorb all the standardization talent and energies of our SMPE membership during these busy years, and it left us with a heavy portfolio of postwar projects for consideration as American Standards. Thus it was that in a meeting of ASA Sectional Committee on Motion Pictures, Z22, held in October, 1945, 22 projects were referred to the Committee on Standards, calling for the most part for revision of prewar American Standards in view of the many changes found necessary in the preparation of the corresponding War Standards. This comparatively large task, judged by the prewar speed rate, could not be handled effectively by the parent committee sitting as a whole, and so was assigned to six subcommittees. These subcommittees, as always, were appointed for the length of time necessary to complete their assignments, and since they are still active but now under the direction of a new Committee on Standards, the following detailed report seems in order.

SUBCOMMITTEE ON CUTTING AND PERFORATING RAW STOCK

A Subcommittee on Cutting and Perforating Raw Stock was established on November 8, 1945, under the chairmanship of Dr. E. K. Carver with Messrs. F. L. Brethaner, A. W. Cook, and D. R. White as members. This subcommittee was asked to review the following five American Standards from the standpoint of (a) method of presentation and (b) possible tightening of the limits for 16-mm film.

Z22.5-1941, Cutting and Perforating Negative and Positive Raw Stock (16-Mm Silent)
Z22.12-1941, Same—(16-Mm Sound)
Z22.17-1941, Same—(8-Mm Film)
Z22.34-1941, Cutting and Perforating Negative Raw Stock (35-Mm Film)
Z22.36-1941, Cutting and Perforating Positive Raw Stock (35-Mm Film)

Four of these projects have since been completed, and were finally approved by the American Standards Association on July 16, 1947. The remaining one, Z22.34, was given preliminary approval by the subcommittee but was then held open at the request of the Research Council of the Academy of Motion Picture Arts and Sciences, and has since been reassigned to the subcommittee.

The Subcommittee on Cutting and Perforating Raw Stock now has two projects of critical importance on its agenda. One of these has to do with a consideration of dimensional standards for 32-mm film, first, with regard to the reconciliation of conflicting practices with regard to the location of the perforations, and second, with regard to the effects produced by inaccuracies in slitting, such that the resulting 16-mm film is edge-guided erratically in projection. On account of the critical effects on sound quality so produced, this project is being jointly considered with the Committee on Sound.

The other project is a more extensive review of the Z22.34-1941 standard on cutting and perforating 35-mm negative raw stock, in view of the difficulties pointed out by the Research Council in securing accurate registration between Standard Positive and Negative film in the printing of color motion pictures. Because of the new fields of interest thus disclosed, Dr. Carver's subcommittee has been enlarged by the addition of Messrs. E. A. Bertram, A. F. Edouart, E. Fehnders, A. M. Gundelfinger, and W. E. Pohl. This group has been doing an excellent job, and I want to express my sincere appreciation to them, and, in particular, to Dr. Carver, who is always a tower of strength wherever standardization accomplishment is needed.

SUBCOMMITTEE ON PHOTOGRAPHIC DENSITY AND SENSITOMETRY

This subcommittee was appointed, under the chairmanship of Dr. D. R. White, to review the following ASA standards:

Z22.26-1941, Sensitometry
Z22.27-1941, Photographic Density

Messrs. R. Kingslake, G. A. Mitchell, and M. Sweet constitute the other members of the subcommittee. The Density project has been successfully processed, and was approved September 26, 1947, by the American Standards Association. The Sensitometry project ran into greater difficulties, but Dr. White is presently optimistic with respect to an early agreement. In view of this one remaining project, this group is now titled the Subcommittee on Sensitometry.

SUBCOMMITTEE ON FILM SPLICES

This committee, under the chairmanship of Mr. W. H. Offenhauser, Jr., was asked to revise the following ASA standards:

Z22.24-1941, Film Splices—Negative and Positive (16-Mm Silent)
Z22.25-1941, Film Splices—Negative and Positive (16-Mm Sound)

Messrs. E. A. Bertram, M. R. Boyer, T. R. Craig, A. W. Cook, C. E. Ives, L. E. Jones, M. W. Palmer, Lloyd Thompson, M. G. Townsley, and E. H. Unkles are the members of this subcommittee. A good deal of preliminary work has been done, leading to the publication of a very complete report[2] in the Society's JOURNAL in July, 1946. Comment accumulating as the result of this publication is to form the basis of the subcommittee's final action.

SUBCOMMITTEE ON 16-MM AND 8-MM PROJECTOR SPROCKETS

Under the chairmanship of Dr. Otto Sandvik, a subcommittee consisting of Messrs. H. Barnett, J. A. Maurer, L. T. Sachtleben, and M. G. Townsley has been assigned the task of revising the following American Standards:

Z22.6-1941, Projector Sprocket (16-Mm Film)
Z22.18-1941, Eight-Tooth Projector Sprockets (8-Mm Film)

It was agreed that the 8-mm and 16-mm fields were so different from the 35-mm field, covering as they do a wide range of performance quality in both amateur and professional equipment, that this project could not be handled most effectively by the existing subcommittee on 35-mm sprockets. It was agreed that the 1941 standards specified dimensional values which might better be left to the originality of individual designers, and that the new standards might therefore specify a design practice insuring good performance with film. With this objective in mind, Messrs. J. S. Chandler, D. F. Lyman, and L. R. Martin did a very fine piece of work which resulted in the preparation of a paper[3] published for comment in the JOURNAL. However, basic differences of opinion in the subcommittee have so far prevented the recommendation of a standard, the situation being substantially identical to that described in a report of the Committee on Standards[4] submitted by Dr. Carver over ten years ago. It is there stated that "Many members feel that the Committee should not standardize sprockets of any sort but that their design should be left to the projector and camera designers to achieve the best results with standard film." That argument still rages, and has recently precipitated a good deal of basic consideration as to the proper field of industrial standardization, a subject which this present report will discuss later on. In the meantime, the Subcommittee on 16-Mm and 8-Mm Sprockets is endeavoring to determine whether that part of the original project essential to the interchangeability of film can be recommended for standardization. The suggestion has also been advanced that a method of test for the film-handling ability of a sprocket might be standardized, leaving full freedom for individual design, but permitting the consumer to evaluate it on a sound basis.

SUBCOMMITTEE ON PROJECTION REELS

This subcommittee, under the chairmanship of Dr. D. F. Lyman and including Messrs. H. Barnett, L. W. Davee, John Forrest, Lee Jones, M. G. Townsley, and R. T. Van Niman, has been assigned the task of reviewing the following ASA standards.

Z22.4-1941, Projection Reels (35-Mm Film)
Z22.11-1941, Projection Reels (16-Mm Film)
Z22.23-1941, Projection Reels (8-Mm Film)

It was suggested that these standards should be rewritten in the style employed in the dimensional aspects of the American War Standard Specification for 16-Mm Motion Picture Projection Reels and Containers, Z52.33-1945. This war standard recognized certain desirable design considerations not included in the 1941 standards, such as the ratio of core-to-flange diameters, the specification of a flange diameter great enough to hold the rated film length with safety, and the specification of a flange separation which will neither hold the film too tightly nor permit lateral wandering. Difficulty is being experienced in reconciling these requirements with the characteristics of equipment presently on the market, since no manufacturer is anxious to vote for the obsolescence of his present goods and production equipment. This, then, is another instance of the basic difficulties encountered in design standardization, particularly in a well-developed field where many individual design practices are well established. Perhaps here too the solution will be found in the specification of a test method. Certainly this is to be preferred over a design standard which does no more than specify the range of present trade practices.

SUBCOMMITTEE ON 8-MM AND 16-MM CAMERA AND PROJECTOR APERTURES

This subcommittee consists of Mr. J. A. Maurer, chairman, with Messrs. M. G. Townsley, L. T. Goldsmith, H. J. Hood, W. C. Miller, and L. T. Sachtleben, and has been assigned the task of reviewing the following ASA Standards:

Z22.7-1941, Camera Aperture (16-Mm Silent)
Z22.13-1941, Camera Aperture (16-Mm Sound)
Z22.19-1941, Camera Aperture (8-Mm Silent)
Z22.8-1941, Projector Aperture (16-Mm Silent)
Z22.14-1941, Projector Aperture (16-Mm Sound)
Z22.20-1941, Projector Aperture (8-Mm Silent)

It was suggested that consideration should be given to war standards procedures in this field, since these went much farther in defining good engineering practice and in explaining the reasons for certain dimensional choices. The subcommittee has held several meetings and at present is hopeful of an early successful conclusion of this assignment.

In addition to the six subcommittees working on ASA assignments growing out of wartime standardization, the Committee on Standards has two other active subcommittees, and a number of projects now under preliminary consideration. These are as follows:

SUBCOMMITTEE ON THE PHOTOMETRIC CALIBRATION OF CAMERA LENSES

This very able subcommittee is under the chairmanship of Dr. R. Kingslake, with a membership consisting of Messrs. F. G. Back, E. Berlant, J. W. Boyle, L. E. Clark, C. R. Daily, I. G. Gardner, G. Laube, E. B. Levinson, J. A. Maurer, A. E. Murray, J. Thompson, M. G. Townsley, and G. C. Whitaker. This project was suggested by the need of cinematographers for a lens transmission calibration of some sort which could be used in combination with set-lighting information to determine proper film exposures. The present *f*/number markings are not sufficiently indicative of the light transmission of a lens, particularly since the advent of lens coatings. In joint meetings with the Research Council, it was agreed that SMPE would study this problem from a calibration method and apparatus standpoint, while the Research Council and the American Society of Cinematographers would continue their already active program of practical evaluation of proposed calibration methods.

Dr. Kingslake has aggressively prosecuted this work to the point where a proposed calibration method and system of lens markings has been agreed to by the Eastern members of his committee, and these are now under review by the West Coast studio group. An early agreement is hoped for, which will constitute a very real technical service to the motion picture industry.

Subcommittee on 35-Mm Projection Sprocket Design

This subcommittee has Dr. E. K. Carver as chairman, with a membership consisting of Messrs. H. Barnett, M. H. Bennett, M. R. Boyer, L. W. Davee, J. L. Forrest, C. F. Horstman, L. B. Isaac, and H. Rubin. They have completed a very creditable job[5] with respect to the standardization of a larger sprocket diameter (0.943-inch instead of 0.935-inch) which results in greatly reduced film wear, an item of substantial economic benefit to the trade. American Standard Z22.35-1947, was finally approved on July 16, 1947, incorporating this finding. At the same time, the ASA-Z22 Committee has recognized that other aspects of this standard are also in need of revision, so the subcommittee is being retained to extend its study of this sprocket.

At the first of the year, therefore, the Committee on Standards had eight actively functioning subcommittees working on projects of interest to the industry. The following additional projects were in the status indicated:

Proposed Standard for 35-Mm Flutter Test Films

After their publication for comment,[6] these two proposals were recently presented to the Committee on Standards by the Committee on Sound, through the chairman, Dr. F. G. Frayne. Following their consideration (in December, 1947) in a meeting of the Committee on Standards, these proposals were returned to the Committee on Sound with suggestions for minor changes. A formal ballot on the recommendation of these proposals for final standardization is anticipated soon.

16-Mm and 35-Mm Daylight Loading Spools

It has been suggested that the field of "16-Mm and 35-Mm Daylight Loading Spools" is in need of standardization. The Engineering Vice-President, Mr. J. A. Maurer, has agreed that this is a proper subject for study, and has undertaken to secure the co-operation of a firm to carry the chairmanship burden of a subcommittee on this project.

35-Mm Film Cans

Present 35-mm film cans are of varying diameter and embossing, so that they do not stack conveniently nor otherwise handle to advantage in processing laboratories. The need for standardization is indicated and the Staff Engineer is conducting a preliminary survey to define the task better before assigning it.

Film-Cuing Marks

Film-printing laboratories, particularly 16-mm, have indicated the need for a uniform system of film-cuing marks, and it has been suggested that a representative group be organized to collect and analyze suggestions from the various laboratories. This project was pending in this form at the end of the year, and possibly should be assigned to the Laboratory Practices Committee.

16-Mm Print Lengths and Reel Sizes

The Division of Motion Pictures and Sound Recordings of the National Archives has suggested a need for the standardization of a limited number of print lengths and reel sizes to facilitate storage. This project is presently under review by the Staff Engineer.

35-Mm Sound-Track Dimensions

A request has been received for the consideration of the five different types of sound tracks from the standpoint of possible standardization. This has been referred by Mr. Maurer to the Committee on Sound for first consideration.

Film Preservation

A proposal has been made that a standard procedure for the preservation of film for historical purposes should be worked out. An early proposal from the Motion Picture Project of the Library of Congress is anticipated, and this will be studied by the Engineering Committee on the Preservation of Film for recommendation to the Committee on Standards.

Glossary of Motion Picture Terms

In 1943, Dr. John Andreas of the Technicolor Motion Picture Corporation, submitted to the Engineering Vice-President a very extensive Glossary of Motion Picture Terms. A number of copies was prepared, and these were circulated to members of the Committee on Standards for consideration as standards. This informal procedure gave rise to a great many comments as to the detail of the wordings, and in the submission of new terms for consideration at a rate faster than we were able to secure agreement on the definitions for the old ones. After trying several procedures, each dependent upon the donation of a great deal of individual and member-company effort, largely of an uninspiring routine nature, it was recognized that the project could only be advanced at a satisfactory rate with the aid of considerable organizational supervision by the Society office. The project was thus transferred to the Engineering Secretary in 1946, and removed from the agenda of the Committee on Standards at that time. Since then, it has been decided that the estimated cost in time and money required to complete the Glossary is greater than can reasonably be assumed at this time in view of other commitments. This project is thus altogether inactive at present. It is mentioned here so that the following suggestion may be presented for general consideration.

Assuming that some sort of standard format could be agreed upon, the Glossary project could be established on a permanent basis through the formation of a Glossary Subcommittee in each Engineering Committee of the Society. These might be correlated through a subcommittee of the Committee on Standards, the membership of which would consist of the chairmen of the other subcommittees. Since a Glossary is not a fixed thing, but changes from year to year as new arts and new usages develop, Glossary subcommittees would always be in existence, although the personnel would be subject to change with each new term of the appointing officer.

CONCLUSION

This leads naturally into the concluding section of this report, which has to do with suggestions for a more effective Standards Committee procedure, based upon both the achievements and the disappointments of the past. These comments have been arranged numerically, in an order determined by the development of the ideas presented for consideration.

1. The membership of the retiring Committee on Standards was chosen in an effort to secure a wide representation of technical ability in all fields of engineering interest so that competent subcommittees could be formed within the Committee membership. This led to the formation of a large, unwieldy parent committee, consisting for the most part of key members of the other Engineering Committees. Subcommittees of the Committee on Standards were thus barely distinguishable from the associated Engineering Committees, so that it came to be realized that a needless duplication of organizations was occurring.

As a matter of principle, therefore, it was agreed that it is in general unwise to form a subcommittee of the Committee on Standards in a field served by another Engineering Committee. If the Committee on Standards agrees that a technical study is needed in a particular case, the project should be assigned to the appropriate Engineering Committee, unless there is some good reason to believe that its completion will be unduly delayed in this way. Since all major fields of interest are served by Engineering Committees composed of the top experts in their respective fields, the existence of an active group of such committees would require the formation of very few subcommittees of the Committee on Standards.

2. The Committee on Standards should therefore be chosen primarily as a policy-making group, to determine the type of study which each proposal for standardization is to receive. This will require the careful preparation of a preliminary analysis of each project, setting forth the nature of the present art, and discussing frankly the economic factors which may determine conflicting viewpoints. For instance, in a great many cases, present practices cannot all be conducted within a single standard, so that compliance is certain to cause hardship to whoever is outside any final agreement, while a performance standard is naturally opposed by those who wish to operate in a highly competitive amateur market rather than in the higher quality professional field. In full recognition of such factors, it should then be the primary duty of the Committee on Standards to decide either (a) that the advantage to the industry is sufficient to require the preparation of a standard, (b) that a further study is desirable in order to define the advantages of the proposal and the area of disagreement better, or (c) that the proposal is not a proper one for present consideration. As a matter of general policy, it is suggested that matters having to do strictly with interchangeability, nomenclature, and methods of test properly belong in the first category. On the other hand, a performance specification should be approached with considerably greater caution.

3. The task itself should then be assigned to a presently functioning Engineering Committee, if one exists in the field of interest. Only where this is not the case should a special subcommittee of the Committee on Standards be established. As has already been indicated, this is because the personnel best suited to the task likely are already members of the appropriate Engineering Committee, and needless confusion exists if these persons are asked to serve in two capacities. At the same time, it is fruitless to attempt to interest the diverse representation required of the entire Committee on Standards in the

details of a proposition confined to a single technical field, nor can a sound conclusion be reached in such a way.

4. The task group thus established should be charged in accordance with the policy decision reached by the Committee on Standards. If the determination of a standards recommendation is decided upon, then the task group should be given the authority necessary to resolve controversial discussions. A two-thirds vote rather than a substantial unanimity might be established as the determining factor in such a case. If only a study is to be made the primary duty of the task group should be the preparation of a detailed report, completely defining all controversial aspects, with a majority recommendation with respect to further action. If, in the course of this study, substantial unanimity is reached with respect to a definite standards proposal, this can then be considered by the Committee on Standards. If no such proposal is made, then the Committee on Standards should decide whether (a) the new facts justify a policy decision that a standard should be established, or (b) that the task group report be given suitable publicity as defining the present state of the art for the guidance of the industry.

5. The Committee on Standards should seldom if ever attempt to review the details of a task-group recommendation; only the broader implications as to the benefit of such a standard to the industry as a whole should receive consideration. Nothing is so discouraging to a capable task group as to have its hard-won compromises discarded, and its recommendation rejected because the same old arguments flare up in the parent committee. The chairman should be in a sound position to refuse to reopen these arguments through assurance that all viewpoints have already had their day in court in the task group. This, of course, requires the formation of a truly representative task group, which is essential to a worth-while result in any case.

6. Finally, if such an ideal routine should become operative, the Committee on Standards would be in the very desirable position of devoting most of its energies to the development of a sound philosophy in the field of standardization. Viewpoints such as many of us have recently been expressing in correspondence would be exchanged around a conference table, and a basic policy developed which could be specially adapted to each proposal for standardization. Such an opportunity should result in the development of a sound attitude which would gain for the Society the respect and compliance of the industry in so far as standardization authority is concerned.

It is realized that the foregoing is not all new, nor is it all my own. It merely represents present ideas of a good program for the future, based, as has been said, both upon the achievements and the disappointments of the past. As ex-chairman of the Committee on Standards, my complete lack of authority in this field is fully recognized; and I hope that these suggestions will be considered simply for whatever good may be derived from them in setting up a more definite and aggressive program for the future, in keeping with the splendid growth, not only in the size, but also in the technical responsibilities of our Society.

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Standards Committee 1947

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Errors in Calibration of the *f* Number

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Summary—The present system of marking the diaphragm stops in terms of the geometric *f* number is subject to serious deficiencies so far as uniform performance for lenses set at the same marked stop opening is concerned. Decisions regarding the proper exposure time to use at a selected stop opening may be in error by ±10 per cent for a lens whose surfaces do not have antireflection coatings, and by even greater amounts for a lens whose surfaces do have antireflection coatings. These errors arise from differences in the reflection and absorption losses in the lens elements themselves, departures of the measured from the nominal focal length, and departures of the measured diaphragm openings from the nominal diaphragm openings.

A method is described whereby a lens can be calibrated by a light meter in terms of an ideal lens so that the variation in axial illumination in the focal plane need not exceed ±2 per cent in using different lenses set to the same calibrated stop opening.

Preface

In problems of photography where the accuracy of lens markings is critical in determining the proper exposure, the various errors to which these markings are subject is of considerable interest. The present report gives the magnitude of such errors that were found to exist in a representative group of 20 lenses having focal lengths that range from $^1/_2$ to 47.5 inches. In addition, the results of calibration of these lenses by a photometric method that permits compensation of light losses resulting from absorption, reflection, and scattering are given. Values of lens transmittance for these lenses are shown. A method of plotting results of nominal, true, and calibrated *f* numbers is given that permits quick evaluation of the magnitude of the over-all error in terms of fractions of a stop.

I. Introduction

With the advance of photographic technology, a need has developed for more precise information on the light-transmitting characteristics of photographic objectives. In particular, a specific need exists for a more accurate means of marking or calibrating the lenses which employ a variable stop for adjusting the lens speed. The usual method, at present, of calibrating a lens is to inscribe a scale of *f* numbers on the diaphragm control. These *f* numbers are based upon certain geometric properties of the lens, and neglecting errors of marking, provide a satisfactory means of varying the speed of the particular lens by definite integral steps. Unfortunately this system of marking takes no cognizance of differences in light-transmitting properties that occur among different types of lenses and in addition those differences that result between lenses of the same type when the surfaces of one have been treated to reduce reflection losses.

This problem has been under vigorous attack for the past ten years and numerous methods [1–11] have been devised for the rating of lens speed with respect to some standard. These methods differ in such matters as type of light source, comparison lens or standard aperture, and type of light-registering device. The theoretical aspects of the problem have been discussed by McRae[8] and by Gardner[1, 2] who proposed several possible methods for calibration of a lens. In the present article, one of the methods described by Gardner is verified experimentally. The experimental technique is described and the variations in performance for 20 lenses, having focal lengths that range from 0.5 to 47.5 inches, are shown. Attention is given to sources of error in the existing marked *f* number. Lastly, a process is described for determining the transmittance of a lens from data obtained in the source of calibration.

II. APPARATUS AND METHOD OF MEASUREMENT

The apparatus consists essentially of a broad uniform source of white light, a sensitive light-measuring device, and a holder which can be used interchangeably either for mounting the lens under test or one of a series of standard diaphragms, each of which has a centrally located circular opening of known diameter. The arrangements of these elements is the same as that suggested by Gardner.[1, 2] The relative lens speed is determined by a comparison of the quantity of light flux transmitted by a lens with that transmitted by a circular opening. By making an appropriate series of measurements and by proper interpretation of their significance, the lens can be calibrated in terms of an "ideal" lens having 100 per cent transmittance.

1. *Procedure for a Lens*

A lens is mounted in the holder and its axis is aligned with the center of the broad uniform source and the center of the small circular opening in the baffle covering the sensitive element of the light-measuring device. The front of the lens faces the light source and the distance separating the rear nodal point of the lens and the baffle covering the light-sensitive element is adjusted to equality with the equivalent focal length *f* of the lens. The opening in the baffle does not usually exceed 1 mm except for some lenses of very long focal length in which cases it is kept under 0.01 *f*. All parts of the equipment are shielded so that only light from the source that passes through the lens can reach the light-sensitive element.

Readings of the light meter are taken at each of the marked stop openings. To minimize error arising from backlash, readings are taken both for the condition of the setting at the marked *f* number being made with the diaphragm ring of the lens moving in the closing direction and with the diaphragm ring moving in the opening direction.* The readings from these two sets of observations are averaged and this value is taken as the accepted reading of the light meter at a given marked stop opening.

2. Procedure for the Standard Diaphragms

The lens is replaced by one of the series of standard diaphragms which have centrally located circular openings with known diameters. The reading of the light meter is taken and the distance *D*, from the diaphragm to the baffle covering the light-sensitive element, is measured. This operation is repeated for several of the standard diaphragms so selected that readings of the light meter are obtained throughout the same range of readings that were observed for the various marked apertures of the lens. The brightness of the source and the sensitivity of the light meter are kept unchanged throughout both parts of the experiment. To ensure constancy of brightness of the source, a constant-voltage transformer is used to maintain a constant voltage for the lamps that illuminate the broad uniform source. To minimize error, two sets of data are taken for both the lens and the series of standard diaphragms so intermingled that random fluctuations in the brightness of the light source and in the sensitivity of the light meter can be neglected.

Ideally the diameters of the standard diaphragm openings should be so chosen that the same series of *f* numbers are present in both phases

* Ten lenses (Nos. 10, and 12 to 20, inclusive) were calibrated in this manner. The remaining ten lenses were calibrated with the diaphragm ring moving in the closing direction only in accordance with the recommendation contained in Report No. 6 of the Subcommittee on Lens Calibration of the Society of Motion Picture Engineers on November 6, 1947.

of the experiment. Too, the distance D should equal the equivalent focal length f of the lens. In practice, however, it has proved to be more convenient to let D differ from f and to place more reliance upon the ratio D/A, where A is the diameter of the circular opening in a standard diaphragm. When a wide variety of lenses is being calibrated, as is the case in this experiment, it is simpler to compute the f number of the standard diaphragm from the ratio D/A and to determine the performance for the conventional series of f numbers from the curve of light-meter reading versus f number than to attempt to reproduce the conventional set of f numbers by appropriate selection of values of D and A.

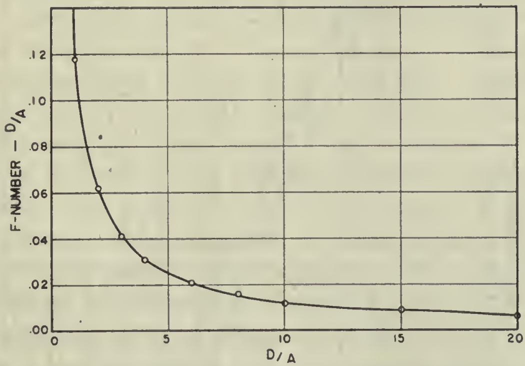

Fig. 1—Calibration curve for computing f number of standard diaphragms when the value of D/A is known.

The f number for a lens is defined by the equation

$$f \text{ number} = \frac{1}{2 \sin \alpha} \tag{1}$$

where α is the angle between the axis and the extreme ray of the circular conical bundle transmitted by the lens. In the case of the standard diaphragm, the relation connecting the measured quantities D and A is

$$\frac{D}{A} = \frac{1}{2 \tan \alpha}. \tag{2}$$

Accordingly the values of the f numbers for the standard diaphragms can readily be computed from the known values of D/A. A sufficiently accurate determination of the f number can be made with the aid of a curve such as is shown in Fig. 1. To produce this curve, the values of the quantity, f number, D/A, are plotted as a function of D/A. Hence, for a given value of D/A, the increment that must be added thereto to yield the f number can be read easily from the graph. For values of D/A greater than 15, the values of D/A and f number are equal for all practical purposes since their difference is less than 0.1 per cent.

III. Results of Measurement

When the values of the scale deflections of the light meter are plotted against the f numbers of the standard diaphragms on logarithmic

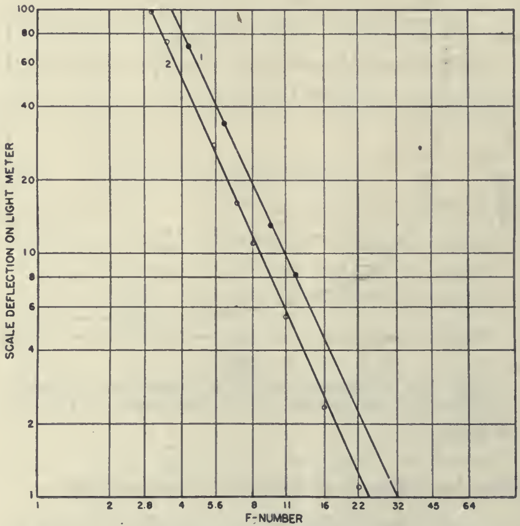

Fig. 2—Scale deflection on light meter versus f number. Curve No. 1 is for the standard diaphragms. Curve No. 2 is for the lens under test.

paper, the resulting curve is a straight line with a slope nearly equal to 2. The fact that the slope is not exactly 2 may be attributed to a slight departure from linearity of the response of the light meter to varying amounts of light indicated on the receiver. This curve, shown as curve 1 in Fig. 2, shows the relation between the scale deflections of the light meter and the f numbers of an ideal lens.

In a like manner, the values of the scale deflection of the light meter are plotted against the f numbers of the actual lens on the same curve sheet. The resulting curve, designated curve 2 in Fig. 2, is a straight line parallel to curve 1 but displaced laterally therefrom. This displacement shows in a striking manner the effect of light losses in the actual lens. A fairly close approximation of the relative light transmission of the actual lens at a given *f* number can be made at once, as it is simply the ratio of the ordinates of curve 1 and curve 2 for the given *f* number.

It must be mentioned that while curve 1 is always a straight line, this is a consequence of its accurately determined *f* numbers. On the other hand, the *f* numbers for curve 2 are read directly from the lens markings and are subject to a variety of errors that will be discussed later in the paper. As a result of these random and systematic errors the points for curve 2 sometimes do not fall as close to the straight line drawn as could be desired. This is especially noticeable at the small apertures associated with the large *f* numbers. However, these variations in no way interfere with validity of the final results but are in fact helpful in tracking down errors in the *f* numbers.

The values of the calibrated *f* numbers for the actual lens may be obtained readily from these curves. The calibrated *f* number is a term used to designate the *f* number of an ideal lens (i.e., a lens having 100 per cent transmittance) transmitting the same amount of light that is transmitted by the actual lens at a given marked *f* number. The terms *T*-aperture ratio or *T* stop [3, 6, 7] and equivalent-aperture ratio [1] are other designations of this same quantity. To determine the calibrated *f* number, the value of the scale deflection for a given marked *f* number of the actual lens is noted and the value of the *f* number of the ideal lens for which the same scale deflection is obtained is read from curve 1. This has been done for twenty lenses covering a wide range of focal lengths and *f* numbers. The results are listed in Table I.

The unusual values of marked *f* numbers which are listed in the first column result from assigning a calibrated *f* number to the maximum stop opening for each lens. The maximum stop opening of a lens quite frequently does not fall in the commonly accepted series of marked *f* numbers although the remaining marked *f* numbers of the lens usually do. The calibrated *f* numbers, in most instances, are larger than the marked *f* numbers. This is as expected because it is known that some of the light incident on the front surface of a lens is lost as a result of reflection back in the object space or by absorption in the glass. The considerable differences in the calibrated *f* numbers for a given marked *f* number indicate appreciable differences in the light-transmitting qualities of the various lenses. This is illustrated in Fig. 3 where the calibrated *f* numbers are plotted on semilogarithmic paper for ten lenses. The values are given for the marked *f* numbers, 4, 8, and 16. Departures as great as $^1/_3$ stop opening are indicated in many instances. Since the departures may be in either direction from the marked stop opening, it is possible to select two lenses such that, on using each for the same scene at the same marked stop opening, the effective difference in exposure is equal to that produced by a change in excess of one full-stop opening. The fact that some lenses have calibrated *f* numbers less than the marked stop opening may seem anomalous in that it indicates a transmittance greater than unity. This is, however, for the most part, an indication of errors in the marked stop opening and will be discussed in more detail in a later section.

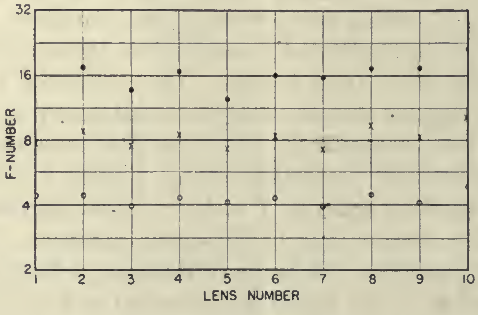

Fig. 3—Departure of the calibrated *f* number from the marked *f* number at *f*/4, *f*/8, and *f*/16 for 10 lenses. The line separations shown are equal to one stop opening.

Lens No. 7 is of especial interest in that the indicated stop openings are marked in *T* stops, consequently the values of the calibrated *f* numbers are quite close to the marked *f* numbers. Lenses Nos. 2, 3, 7, 9, 11, and 20 have coated surfaces to reduce reflection losses. The gain in transmittance is definitely present but is somewhat obscured in Table I because the marked aperture ratios frequently differ from the true geometric-aperture ratio.

The fact that the calibrated *f* number varies so much from lens to lens for the same nominal *f* number gives support to the proposition

MEASURED VALUE OF THE CALIBLENGTHS THAT RANGE FROM

Marked f Number	1	2	3		17	18	19	20
	0.5	0.5	1.0		19.0	24.0	30.0	47.5
1.9	2.40		2.09					
2.2								
2.3								
2.5		2.82						
2.7								
2.8	3.25	3.13	2.86					
3.0								
3.5								
4.0	4.42	4.45	3.92					
4.5								
5.6	5.32	6.32	5.52					
6.8								
7.5								
8.0	7.80	8.78	7.50					
9.5				3				
11.0	11.0	11.8	9.94	4	13.6	14.3		
12.5							15.6	
15.0								16.0
16.0	15.4	17.2	13.6	5	19.2	19.8	19.3	17.3
22.0	21.3			8	25.8	28.2	26.7	23.3
32				0	37.6	40.9	39.2	34.7
45				8	50.8	59.9	53.4	48.6
64				8	69.6	86.8	79.0	71.1
90				0	98.0	117.0	99.0	97.6
128								143.0

SETTINGS OF THE STOP OPENINGS IN T0 PER CENT TRANSMITTANCE FOR

Calibrated f number	1	2	3	16	17	18	19	20
	0.5	0.5	1.0	6.5	19.0	24.0	30.0	47.5
2.8	2.33	2.48	2.74					
4.0	3.58	3.60	4.08					
5.7	5.92	5.10	5.80					
8.0	8.10	7.24	8.57					
11.3	11.3	10.5	12.7	3.60				
16	16.4	14.9	19.1	3.1	13.2	12.4	12.8	14.6
22.6	23.2			3.6	19.2	18.2	18.8	20.6
32				6.9	27.4	25.2	26.2	29.0
45				3.2	39.3	35.1	37.3	41.0
64				6.3	58.6	47.8	53.0	58.2

that all lenses should be so marked that differences in light-transmitting properties are negligible for a given *f* number. This can be done from the curves shown in Fig. 2, by reversing the procedure used in deriving the information reported in Table I. The deflection of the light meter for a given *f* number of the ideal lens is noted on curve 1 and the *f* number of the actual lens which will yield the same deflection is read from curve 2. This can also be done by plotting the calibrated *f* number for a lens listed in Table I against the marked *f* number on logarithmic paper. The marked *f* number for a given calibrated *f* number can then be read directly from the graph. This has been done for the same 20 lenses and the results are listed in Table II. This table shows the proper settings in terms of the marked *f* number so that each of these lenses will yield uniform performance for each of a series of calibrated *f* numbers.

IV. SOURCES OF ERROR IN THE NOMINAL *f* NUMBER

In addition to the light losses in the lens arising from absorption and reflection, there are several sources of error that affect the reproducibility in the amount of light reaching the focal plane at a given stop opening. The first of these is backlash in the iris-diaphragm stop and results in differences in light transmission dependent upon the manner in which the diaphragm is set at a given stop opening. The second error is an actual error in the markings themselves and may arise from errors in aperture, errors in equivalent focal length, or errors in both at the same time. The backlash error varies for each lens while the error in *f* markings contributes to variations in performance when several different lenses are in use for the same type of work.

1. *Error in Setting the Lens at a Given f Number*

When the diaphragm is set at a given *f* number, there is an appreciable difference in the amount of light passed by the lens dependent upon the direction of movement of the diaphragm control. The error arising from this source has been investigated and the results are listed in Table III for several lenses. This backlash error is determined by two methods. In the first method, the lens is mounted on a stand and the edges of the diaphragm are illuminated from the rear of the lens by a fixed source. Photographs of the stop opening are made with an auxiliary camera placed in front of the lens. Each stop opening is photographed for the condition of the setting being made with the diaphragm closing and with the diaphragm opening. Prints are made of these negatives and the area of each image is measured with a planimeter. Let the area of the image, taken for the condition when the setting is made by closing the diaphragm, be *Ac;* and the area of

TABLE III

RATIOS OF RELATIVE ILLUMINATION IN THE AXIAL REGION OF THE FOCAL PLANE FOR LENSES USED UNDER IDENTICAL LIGHTING CONDITIONS, SETTINGS BEING MADE WITH THE DIAPHRAGM CONTROL MOVING TO CLOSE AND WITH THE DIAPHRAGM CONTROL MOVING TO OPEN THE LENS

Nominal Focal Length, Inches	Nominal *f* Number	Ratio of Light Transmissions Diaphragm Closing to Diaphragm Opening		
		Planimeter, *Ac/Ao*	Light Meter, *Lc/Lo*	Weighted Average
16.5	9.5	1.01	1.04	1.03
	11	1.01	1.02	1.02
	16	1.02	1.04	1.03
	22	1.02	1.07	1.06
	32	1.05	1.11	1.10
	45	1.13	1.08	1.09
	64	1.11	1.08	1.09
19.0	11	1.00	1.00	1.00
	16	1.06	1.02	1.03
	22	1.05	1.04	1.04
	32	1.07	1.06	1.06
	45	1.10	1.09	1.10
	64	1.24	1.26	1.26
24	11	1.00	1.00	1.00
	16	1.00	1.03	1.02
	22	1.05	1.05	1.05
	32	1.02	1.11	1.09
	45	1.09	1.14	1.13
	64	1.06	1.18	1.16
30	12.5	0.99	1.01	1.00
	16	1.04	1.03	1.03
	22	1.02	1.02	1.02
	32	1.04	1.06	1.05
	45	1.08	1.02	1.03
	64	1.08	1.07	1.07

the image for the same stop opening, taken for the condition when the setting is made by opening the diaphragm, be *Ao*. Then the ratio *Ac/Ao* is accepted as the ratio of the relative illuminations in the axial region of the focal plane when the lens is used under identical lighting conditions for these two processes of setting the lens at a given *f* number.

In the second method, the data taken in Section II are treated in such manner as to separate the light-meter readings *Lc*, taken for the condition of the setting being made with the diaphragm closing, and the light-meter readings for the same stop opening *Lo*, taken for the condition of the setting being made with the diaphragm opening. Then the rate *Lc/Lo* is accepted as the ratio of the amounts of light

TABLE IV

COMPARISON OF NOMINAL AND MEASURED VALUES OF EQUIVALENT OF FOCAL LENGTH AND EFFECTIVE APERTURE FOR A REPRESENTATIVE GROUP OF LENSES

Lens No.	Equivalent Focal Length		Difference in Equivalent Focal Length, Per Cent	Effective Aperture		Difference in Aperture, Per Cent
	Nominal, Mm	Measured, Mm		Nominal, Mm	Measured, Mm	
1	12.5	12.35	−1.2	6.58	7.07	+7.4
2	12.5	12.99	+3.5	5.00	5.07	+1.4
3	25.4	25.56	+1.0	13.37	13.65	+2.1
4	35.0	37.50	+7.1	12.96	14.06	+8.5
5	40.0	42.08	+5.2	14.81	14.94	+0.9
6	50.0	51.39	+2.8	18.52	19.62	+5.9
7	50.8	50.62	−0.4	25.40	24.40	−3.9
8	75.0	75.31	+0.4	26.78	27.36	+2.2
9	75.0	75.02	0.0	32.61	32.58	−0.1
10	76.2	74.71	−2.0	25.40	24.60	−3.2
11	101.6	99.42	−2.1	39.53	40.64	+2.8
12	177.8	180.81	+1.8	26.15	26.15	0.0
13	190.5	190.53	0.0	42.34	40.17	−5.1
14	279.4	284.85	+2.0	34.92	35.74	+2.3
15	342.9	351.60	+2.5	45.72	42.21	−7.7
16	419.1	418.14	−0.2	44.12	41.30	−6.4
17	482.6	481.97	−0.1	43.87	43.29	−1.3
18	609.6	605.55	−0.7	55.42	51.40	−7.2
19	762.0	756.54	−0.7	60.96	59.14	−3.0
20	1206.5	1207.60	+0.1	...	...	...

passing through the lens for these two conditions and is comparable to *Ac/Ao* obtained by the first method.

The values of these ratios are tabulated in Table III for a series of stop openings for four lenses. The differences by the two methods result mainly from the fact that a greater number of sets of data is used in the determination of *Lc/Lo*. The third column gives the weighted average with a weight of 4 given to Lc/Lo and a weight of 1 given to Ac/Ao. It is noteworthy that this error arising from backlash varies from 1 to 2 per cent at the larger stop openings to as high as 10 to 26 per cent for the smaller stop openings. It is clear that error from this cause can be avoided by always making the diaphragm setting in the same manner, and preferably in the direction of closing the diaphragm.

TABLE V

NOMINAL AND MEASURED VALUES OF THE *f* NUMBER FOR A REPRESENTATIVE GROUP OF LENSES

Lens Number	Nominal Focal Length, Mm	*f* Number		Error in *f* Number, Per Cent	Relative Transmittance
		Nominal	Measured		
1	12.5	1.9	1.77	−6.8	1.15
2	12.5	2.5	2.62	4.8	0.91
3	25.4	1.9	1.87	−1.6	1.03
4	35.0	2.7	2.67	−1.1	1.02
5	40.0	2.7	2.82	4.4	0.92
6	50.0	2.7	2.62	−3.0	1.06
7	50.8	2.2	2.07	−5.9	1.13
8	75.0	2.8	2.75	−1.8	1.04
9	75.0	2.3	2.30	0.0	1.00
10	76.2	3.0	3.04	1.3	0.97
11	101.6	2.5	2.51	0.4	0.99
12	177.8	6.8	6.91	1.6	0.97
13	190.5	4.5	4.74	5.3	0.90
14	279.4	8.0	7.97	−0.4	1.01
15	342.9	7.5	8.33	11.1	0.81
16	419.1	9.5	10.12	6.5	0.88
17	482.6	11.0	11.13	1.2	0.98
18	609.6	11.0	11.78	7.1	0.87
19	762.0	12.5	12.79	2.3	0.96

There still remains the random error of making the setting, even if care is taken to move the control always in the same direction. This error is, however, small in comparison to backlash error, and it is believed that it should be negligible for the careful worker at the larger stop openings and perhaps rising to approximately one fourth of the backlash error for the smaller stop openings.

2. Errors in the Existing Geometrical f Number

(*a*) *At full aperture*—The true geometrical *f* number is obtained by dividing the equivalent focal length of the lens by the diameter of the effective aperture. It is therefore obvious that errors in the value of the equivalent focal length and the effective aperture will be reflected by errors in the *f* number. Table IV lists the nominal and

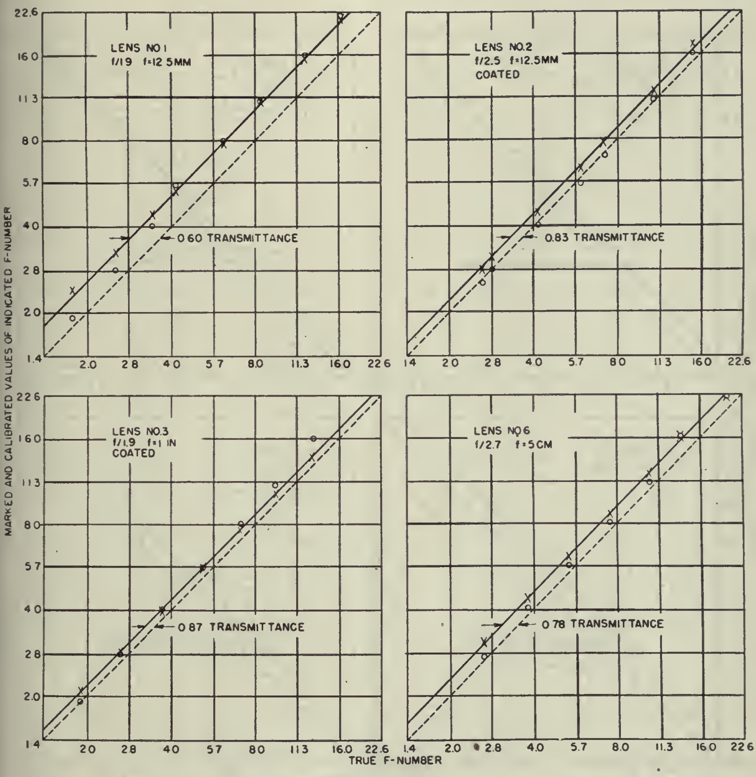

Fig. 4—Marked and calibrated values of *f* number versus true geometric *f* number. The circles indicate the marked *f* numbers and the crosses indicate the calibrated *f* numbers. The circles would fall upon the dotted diagonal line if marked and true *f* numbers were equal. The crosses would fall upon the dotted line if the transmittance were 100 per cent. The separation of the dotted and solid-line curve gives a measure of the transmittance of the lens. The steps in the net equal one stop opening for ready appraisal of differences in fractions of a stop opening.

measured values of equivalent focal length and effective aperture. In those instances, where the nominal focal length was given in inches, conversion has been made to millimeters. The nominal values of effective aperture are computed from the values of nominal focal length and nominal f number. Examination of this table shows that the measured value of the equivalent focal length is within ± 2 per cent of the nominal focal length for 15 of the 20 lenses. The average departure for the entire 20 lenses is ± 1.7 per cent. The errors in

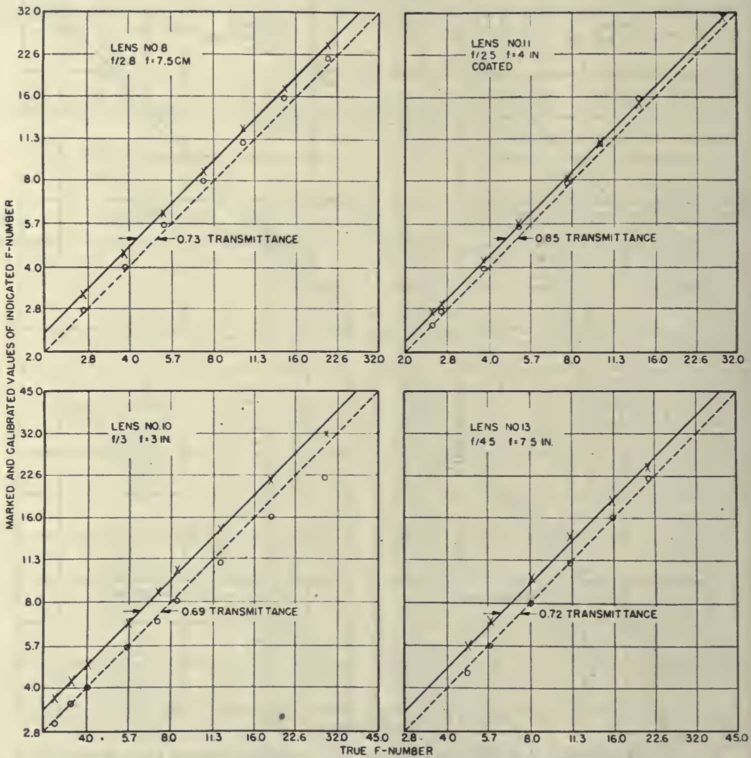

Fig. 5—Marked and calibrated values of f number versus true geometric f number. The circles indicate the marked f numbers. The circles would fall upon the dotted diagonal line if marked and true f numbers were equal. The crosses would fall upon the dotted line if the transmittance were 100 per cent. The separation of the dotted and solid-line curve gives a measure of the transmittance of the lens. The steps in the net equal one stop opening for ready appraisal of differences in fractions of a stop opening.

effective aperture are as high as ± 8 per cent with an average for 19 lenses of ± 4 per cent. Nine of the nineteen lenses show errors in effective aperture in excess of ± 3 per cent. It is doubtful if the errors in focal length can be brought below ± 2 per cént during the process of manufacture but it does seem that the error in aperture at the maximum aperture could also be reduced to ±2 per cent.

As a result of these departures of the measured values of the equivalent focal length and effective aperture from their nominal

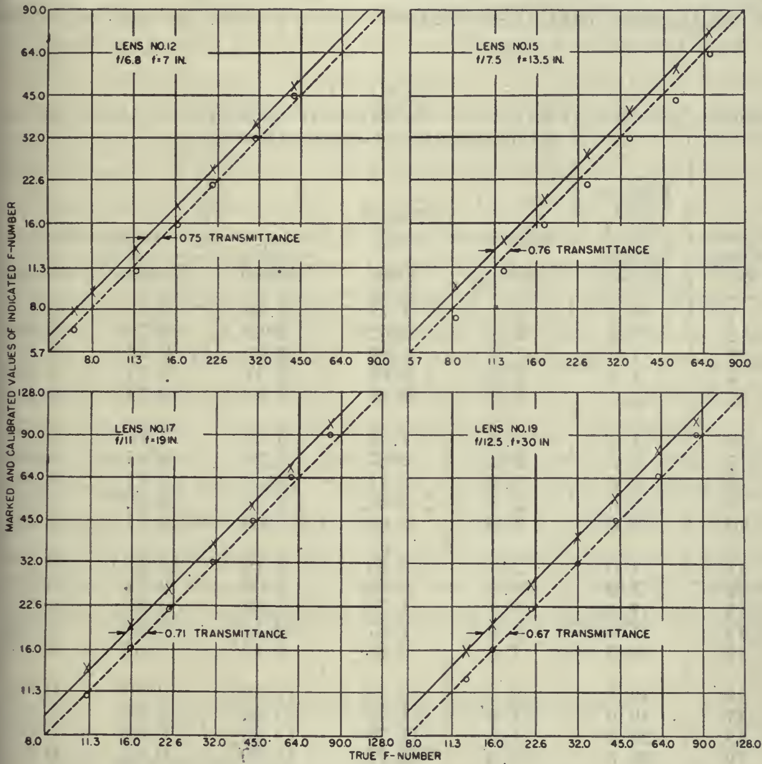

Fig. 6.—Marked and calibrated values of *f* number versus true geometric *f* number. The circles indicate the marked *f* numbers and the crosses indicate the calibrated *f* numbers. The circles would fall upon the dotted diagonal line if marked and true *f* numbers were equal. The crosses would fall upon the dotted line if the transmittance were 100 per cent. The separation of the dotted and solid-line curve gives a measure of the transmittance of the lens. The steps in the net equal one stop opening for ready appraisal of differences in fractions of a stop opening.

values, appreciable errors in the *f* number are produced. This is shown in Table V, which lists the nominal and measured *f* numbers for the same group of lenses. The errors in the *f* numbers range from −6.8 to +11.1 per cent. The effect of these errors in terms of relative transmittance is shown in the last column. These values of relative transmittance show that, neglecting losses in the lens, the difference between nominal *f* number and true geometric *f* number may alone produce deviations of as much as 19 per cent between the expected and actual values of the amount of light passed by the lens. It must be emphasized that these differences are present at maximum stop

TABLE VI
NOMINAL AND ACTUAL VALUES OF THE TRANSMITTANCE AT FULL APERTURE FOR A REPRESENTATIVE GROUP OF LENSES

Lens Number	Equivalent Focal Length, Inches	*f* Number			Transmittance	
		Marked	True	Calibrated	Nominal	Actual
1	0.5	1.9	1.77	2.40	0.63	0.54
2	0.5	2.5	2.62	2.82	0.79	0.86
3	1.0	1.9	1.87	2.09	0.83	0.80
4	1.4	2.7	2.67	3.14	0.74	0.72
5	1.6	2.7	2.82	3.14	0.74	0.81
6	2.0	2.7	2.62	3.09	0.76	0.72
7	2.0	2.2	2.07	2.23	0.97	0.86
8	3.0	2.8	2.75	3.20	0.77	0.74
9	3.0	2.3	2.30	2.45	0.88	0.88
10	3.0	3.0	3.04	3.68	0.67	0.68
11	4.0	2.5	2.51	2.79	0.80	0.81
12	7.0	6.8	6.91	8.00	0.72	0.75
13	7.5	4.5	4.74	5.60	0.65	0.72
14	11.0	8.0	7.97	10.1	0.63	0.62
15	13.5	7.5	8.33	9.72	0.59	0.73
16	16.5	9.5	10.12	12.30	0.60	0.68
17	19.0	11.0	11.13	13.60	0.65	0.67
18	24.0	11.0	11.78	14.30	0.59	0.68
19	30.0	12.5	12.79	15.60	0.64	0.67

opening where the effective aperture is that of a true circular opening and not that of a many-sided opening which is operative when the aperture is determined by the iris diaphragm. In 6 out of 19 cases, the relative transmittance deviates from unity by 10 per cent or more, which may produce significant differences in exposure time in some instances of use.

(*b*) *Errors in the marked f numbers at reduced apertures*—It is clear that errors of the type described in the preceding section are also present for all of the marked *f* numbers. Because the aperture formed by the usual many-leaved iris diaphragm is a polygon, the accuracy of determining the diameter of the effective aperture is somewhat less than that for the full aperture where the limiting opening is circular. Where the number of leaves is greater than six, two diameters at right angles to one another are measured and the average is considered to be the diameter of a circular opening of the same area. For those diaphragms having four to six leaves, the area is computed from two or three diameters, and the diameter of the equivalent circle is used in computing the *f* number. It is believed that the *f* number obtained in this manner is correct within ±2 per cent for the small *f* numbers and rising to ±5 per cent on the average for *f* numbers greater than 22.

The errors in the *f*-number markings for twelve lenses are shown graphically in Figs. 4, 5, and 6, where the marked *f* numbers are plotted as ordinates and the true (measured) *f* numbers are plotted as abscissas. The dotted line with slope of unity passing through the origin is the line upon which the marked *f* numbers would lie if there were no error in the markings. The points are plotted on logarithmic paper so that one may see at a glance what the magnitude of the error is in terms of fractions of a stop opening. For example, in the case of lens No. 3, Fig. 4, the true *f* number corresponding to the *f* number marked 16 is 12.9. This error of marking is clearly shown on the graph to exceed one-half stop. For lens No. 10, Fig. 5, at *f*/16, the true *f* number is 18.4, or more than one-half stop in the opposite direction. For lens No. 12, Fig. 6, the values of marked and true *f* number are very close together throughout the range of the markings.

V. MEASUREMENT OF TRANSMITTANCE

1. *Transmittance at Full Aperture*

It is possible on the basis of the information obtained in the course of this experiment to determine the light transmittance of the lens itself. It must be emphasized, however, that the transmittance so determined is the ratio of the amount of light passing through the lens to amount of light incident on the front surface of the lens, and does not differentiate between image-forming and nonimage-forming light. There are two ways of making this determination. The first method yields the nominal transmittance, and is simply the square of the ratio of the nominal *f* number and the ideal *f* number that gives the same deflection on the light meter. Values obtained by this method are listed in Table VI, under the heading of nominal transmittance. Since no cognizance is taken of the errors in the nominal *f* number, the nominal transmittance is affected by the error in *f* number as well as by reflection and absorption losses in the lens.

The second method yields the actual transmittance, and is the square of the ratio of the measured and calibrated *f* numbers. Since this method rules out the error in *f* number, the actual transmittance is affected only by reflection and absorption losses in the lens.

It is interesting to consider lenses Nos. 16, 17, 18, and 19. These are all of the same type, having 8 glass-air surfaces but ranging in focal length from 16.5 to 30 inches. The nominal transmittance for these four lenses varies from 0.59 to 0.65, while the actual transmittance is almost invariant, changing from 0.67 to 0.68.

The effect of antireflecting coatings on the lens surfaces can be seen in this table. Lenses Nos. 2, 3, 7, 9, and 11 are coated and all have transmittances which exceed 80 per cent. Only one, No. 5, of the uncoated lenses has a transmittance above 80 per cent and the remaining 13 lenses have transmittances ranging from 62 to 75 per cent with one lens (No. 1) falling as low as 54 per cent. The antireflecting coatings increase the transmittance by 25 per cent or more. Even so, consideration of the actual values of the transmittance shows that 10 per cent or more of the incident light is still lost by the coated lens. This is not surprising when it is remembered that antireflecting films usually yield close to 100 per cent transmittance for only one wavelength of light. Accordingly, when a broad region of the spectrum is covered, as is the case for white light, the transmittance measured is the average for the whole region.

The fact that the values of transmittance obtained by this procedure are affected in some small amount by the presence of nonimage-forming or scattered light cannot be considered as important. It is improbable that markedly different values would be obtained by the use of collimated light incident on the front surface of the lens during the experiment. In any comparison between the broad source method of measuring transmittance or calibrating a lens and the collimated light method, it is unlikely that light scattered by the lens will produce appreciable difference in the end result. The broad source fills the lens with light giving rise to a greater amount of scattered light. However, the diaphragm in the focal plane rigidly restricts the measured scattered light to that falling within a small area. The collimator system, at least for the larger aperture, illuminates the inner surface of the barrel with light at small angles of incidence favorable for reflection. All the light that is scattered and emerges from the lens is evaluated by the detector. A priori it is difficult to say which will give the most weight to scattered light. Certainly for a well-constructed lens the differences in results obtained by the two methods will be small. For a lens purposely made to reflect the light from the mount, the result is open to question. However such lenses do not constitute a threat, because they would not make satisfactory photographs. The extended source does give a measure of the light (some of which is scattered) which will be incident on a central area of the film when a subject is photographed with a reasonably average illumination over the entire field. The collimator method gives a measure of the light available over a central area of the film, plus all scattered light, when a relatively small bright source is photographed on a dark ground.

2. *Average Transmittance for all Apertures*

The value of transmittance obtained in the preceding section is a reliable one for full aperture, but since a lens is frequently used at a reduced stop opening it is advantageous to consider a method of determining average transmittance throughout the entire range of stops. This is done by plotting the calibrated *f* number against the true *f* numbers as has been done for 12 lenses in Figs. 4, 5, and 6. The crosses show the relation thus obtained. It is clear that these crosses lie on a straight line, shown as a solid line, parallel to the dotted diagonal line. If the crosses should fall on the dotted line it would indicate a transmittance of 100 per cent. As it is, the displacement of the solid line from the dotted line gives at once a measure of the average transmittance for all apertures. This has been computed from the curves and the value of the average transmittance for all apertures is shown for each of the 12 lenses in the proper figure.

It is worthy of mention that this method of plotting the results of measurement serves the dual purpose of showing the consistency of the method of calibration and reliability of the measured values of the true *f* number. Errors in either operation would cause the crosses to fall away from the solid-line curve. The fact that these deviations are small indicates that both calibrated and true *f* numbers have been quite accurately assigned.

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Projection Equipment for Screening Rooms*

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Summary—Motion picture screening rooms have many and varied uses such as for motion picture studios, film laboratories, recording studios, film exchanges, and many other applications. The material to be presented here, however, will be concerned with screening rooms which are used in motion picture studios, and those in film laboratories. In many respects, considerably more is required of the projection equipment used in such screening rooms than is required when used in other types of screening rooms, or in regular theaters.

Until recently, standard motion picture equipment has been supplied for most types of screening rooms. A study of the conditions encountered, together with the experience gleaned from the many installations of projection equipment made in screening rooms during the past few years, has taught us that some modifications of standard equipment are desirable in order to obtain best results. It is important that the projection equipment used in these types of screening rooms perform so as not to cause any undesirable screen effects, which could be mistaken for errors made by the cameraman, or poor work on the part of the laboratory.

Before discussing projection equipment for screening rooms, we should first consider the purpose of these screening rooms so that it will be easier to understand the reasons for some of the requirements demanded of the equipment, and why it is desirable to modify slightly some of the components used.

The main functions of a screening room in a motion picture studio or a film laboratory are to check the action, direction, artist make-up, sequence of scenes for editing purposes, set lighting, photography, sound, and the laboratory processing of the film. In order to determine how a motion picture will appear on the screen of the average theater, it is important that some of the conditions in the screening room approach closely those which are encountered in a regular theater. These conditions are such things as the intensity of light on the screen, ratio of viewing distance to picture size, and amount of

* Presented October 16, 1945, at the SMPE Convention in New York.

ambient light. Otherwise, a picture that looks well in the screening room may look bad in a theater, and the opposite also can be true. Consideration must be given, moreover, to the difference in the magnification of the picture to determine its quality when projected on very large screens such as that used at Radio City Music Hall, and those used at drive-in theaters.

Checking Photography

In checking the cameraman's photography, a close examination must be made of the objects in the picture for steadiness and focus. It is important, therefore, that the projection equipment be free from vibration, be adjusted to prevent any lateral or vertical film weave, and that the projection lens be held firmly in focus. Whenever an out-of-focus condition is noticed on the screen, the projectionist usually is requested to check the adjustment of the projection lens. In order to check the focus of the lens quickly, the adjusting knob should be located where it is accessible readily from either side of the projector mechanism. (Fig. 1)

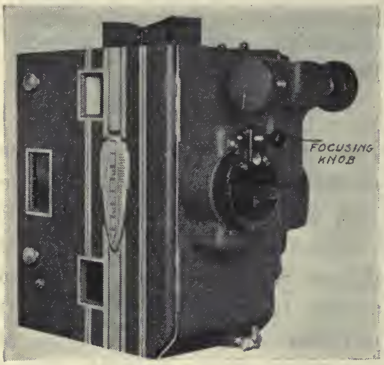

Fig. 1—Brenkert BX-80 projector mechanism showing accessibility of projection-lens processing knob and framing knob from both sides of projector.

Checking Laboratory Work

The projector must be in correct adjustment when checking the work done by the laboratory, because improper adjustment of the film guides, gate, and intermittent movement may easily result in a poor picture motion on the screen, which may be taken for improper printer registration or motion. These adjustments are important because a lateral movement of two thousandths of an inch of the film in the film trap will result in a picture movement of approximately three eights of an inch on a twelve-foot screen. Unless the film gate and guides are known to be correctly adjusted, it will be difficult to determine whether poor picture motion is due to the projector or to laboratory work.

The main causes for flicker inherent in the film have been explained by Grignon,[1] as being due to one or more of three things: the original photography, printing, or to background projection. To determine if flicker is present in the picture it is important that the flicker from the projection equipment be negligible. Power for the arc lamp should have a very low ripple content, and the intensity of light on the screen should be kept within the limits recommended, as flicker due to the projector shutters becomes more objectionable as the light intensity is increased.

Checking Special Effects and Relative Density

The intensity, and the quality of the light on the screen in the screening room plays an important part when checking night scenes, subdued lighting scenes, special effects, background photography, the lighting of the set where the picture was photographed, the artists' make-up, and when judging by visual observation the optimum relative density of each scene on the film. To check these effects correctly, the lighting conditions on the screen should coincide with those on the screen in the average theater; the intensity of light should be kept within the limits[2] of 9 to 14 foot-lamberts, and it should be of daylight quality, such as is obtained from a high-intensity arc lamp.

CONDITIONS ENCOUNTERED IN SCREENING ROOMS

Green Film and Film Splices

Much of the film projected in screening rooms at film studios and laboratories is "green." Oftentimes difficulty is experienced when this film is being projected unless several precautions are taken to prevent the deposit of emulsion in the film trap. When emulsion does collect in the film trap, it usually results in difficulty in keeping the picture in focus, lateral and vertical picture motion on the screen, and, because of the increased friction of the film in the gate, torn sprocket holes. In order to avoid these difficulties, projectionists have used many expedients such as decreasing the tension on the film pads in the film gate, and dropping oil on the film as it passes into the film trap. In some cases, the emulsion deposit has been so thick and caused so much trouble that it has been necessary to stop the projector before running all of the film and clean the emulsion from the film trap.

In many cases the film which is projected in these screening rooms consists of short sequences spliced together. No modifications need be made to a well-designed projector mechanism in order to run a film with a large number of patches. It is important, however, that the gate be adjusted properly in order to minimize the picture jump when a patch goes through the film trap.

Size of Screening Rooms

Many of the screening rooms in use are very small in size, necessitating the use of a small screen and a short "throw." Although a definite relationship should be maintained between screen width and viewing distance, it has been found difficult to maintain such a relationship in many screening rooms.

In the past, low-intensity arc lamps were used almost exclusively for screening-room projection. Because of the small screen used in most cases, sufficient light could be obtained from this type of arc lamp to meet the ASA recommendation of the American Standards Association of 9 to 14 foot-lamberts. Today, however, a large percentage of pictures made are in color and the color quality of the light is equal in importance to the quantity of light. As a result, most of the screening rooms use high-intensity arc lamps and copper-coated Suprex carbons which produce light that has a snow-white color characteristic. The current range of Suprex carbons is 40 to 50 amperes for the 7-mm positive and 6-mm negative, and 60 to 70 amperes for the 8-mm positive and 7-mm negative. The arc lamps must be operated within the above ranges in order to obtain good operating stability. The quantity of light, however, even when the carbons are operated at the low end of the range, is usually more than is required for the small screens used at these screening rooms. Therefore, in order that the intensity of the light on the screen will fall within the recommended limits of 9 to 14 foot-lamberts, it is sometimes necessary to reduce the amount of light transmitted to the screen.

Equipment for Screening Rooms

Projectors

The double-shutter type of projector has been found preferable in most of these types of screening rooms. However, in some cases a few minor modifications are desirable. The problem of emulsion collecting on the film shoes has been alleviated in some cases by replacing in the film trap the steel film shoes with highly polished chrome-plated shoes. Although the steel shoes ordinarily supplied are highly polished and work satisfactorily with film which has been properly waxed, in some cases emulsion from "green" film adheres more readily to polished steel shoes than to chrome-plated shoes.

Fig. 2 shows the location of the film shoes on the film trap used on the Brenkert BX-80 projector. Also shown are the adjustable Hollywood film guides. Accurate adjustment of these guides allows correct passage of the film through the film trap with negligible lateral motion of the film. These guides may be easily and accurately aligned by means of a gauge which may be purchased from the manufacturer.

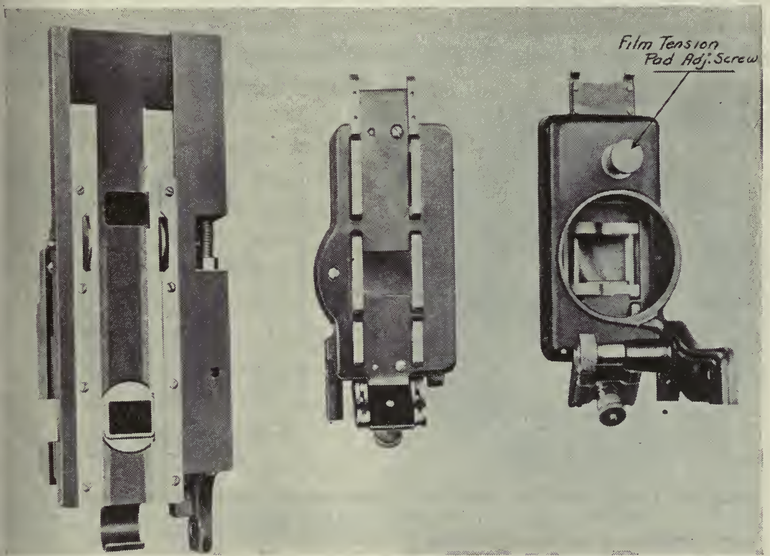

Fig. 2—Film trap and gate used with Brenkert BX-80 projector. All three sets of film-tension pads are adjusted easily and simultaneously by one adjusting knob.

It can be noted in Fig. 2 that the film gate has been designed for three sets of film-tension pads. An equal amount of tension is applied to each of the two upper sets of pads, but the tension applied to the lower set of pads is somewhat greater, caused by the use of a heavier spring on the lower set of pads. The design and construction of this film gate aids greatly in holding the film steady in the film trap during the time the picture is being projected. This is especially true when a patch is being fed through the trap. One adjusting screw controls the pressure of all pads at the correct ratio.

It was stated earlier that the use of high-intensity lamps for some of the small screening rooms results in excessive screen brightness. One way to reduce light on the screen, and at the same time increase the threshold of flicker is to use three-bladed shutters on the projector mechanisms. Fig. 3, which is reproduced from a paper by Engstrom,[3] shows the relationship between screen brightness and flicker rate when the screen is viewed at a distance of four and one half times its width. It also shows that flicker decreases with an increase in the percentage of time the image is illuminated during one frame cycle, and decreases with an increase in the light impulse-frequency. Inasmuch as a three-bladed shutter increases the light impulse-frequency to 72 cycles, the threshold of flicker is increased considerably and the amount of flicker seen on a screen with a brightness of from 9 to 14 foot-lamberts is negligible.

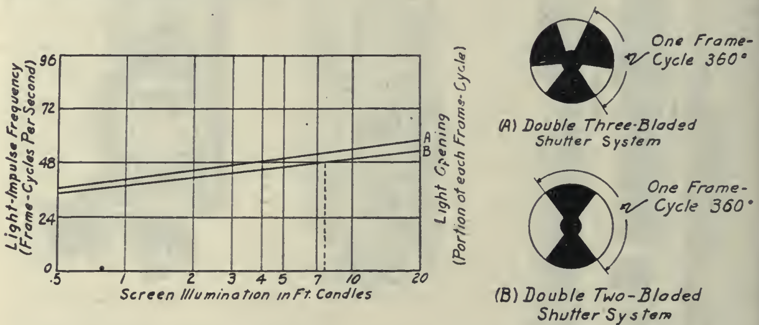

Fig. 3—Chart showing effect of light-impulse frequency on threshold of flicker. Screen viewed from a distance equal to six times screen width; vision concentrated at center of screen. Data taken from: *Proc. I.R.E.*, April, 1935 (E. W. Engstrom); *Soc. Mot. Pict. Eng.*, October, 1942 (E. W. Kellogg).

Arc Lamps

Where the screens are exceptionally small, the screen brightness will be excessive even though three-bladed shutters are used. In such cases, additional steps must be taken to reduce the transmission of light to the screen.

One of the best methods of obtaining an additional reduction in light intensity is to step down the speed of the optical system in the arc lamp by reducing the effective area of the reflector through the use of a dull-black metal shield. Fig. 4 shows such a shield installed on a reflector from a modern arc lamp. The size of the shield depends on the screen brightness required. This method of reducing the amount of transmitted light has the advantages of protecting the mirror, reducing the radiant energy on the film aperture, and improving the depth of focus.

Power Source

A motor generator is preferred as a power source because of its low-voltage ripple content, and because it is not critical to sudden voltage changes. The capacity and regulation of the generator should be such that no change in the light intensity will be noticed on the screen when the second arc lamp is struck. Full-wave three-phase rectifiers are satisfactory, however, when used in conjunction with a projector employing either the two- or three-bladed shutters. Four-tube rectifiers, designed for operation from a three-phase power source, usually employ a Scott-connected transformer which actually results in a full-wave, two-phase rectifier. This type of rectifier has been found to give satisfactory results when two-bladed shutters are used on the projectors, but annoying flicker may develop when used in conjunction with a projector employing three-bladed shutters. The reason for this is that a two-phase, full-wave rectifier has a voltage-ripple frequency of 240 cycles, which is an exact multiple of 48 cycles but not of 72 cycles. The intensity of the ripple voltage from a two-phase, full-wave rectifier is also greater than that of the three-phase, full-wave rectifier. When using any kind of a rectifier it is important that the alternating voltage across each phase be substantially the same.

Fig. 4—The effective area of the arc-lamp reflector can be reduced by a metal shield whenever a reduction of light on the screen is required.

Screen

In all cases a seamless white screen is recommended. Such a screen is obtainable in the sizes most frequently used.

Although most screens have black borders, it has been found that light-colored borders are much more pleasing and comfortable for the eyes. It has been pointed out by Luckiesh and Moss,[4] that the screen border should not be extremely dark because of bad physiological effects such as eye fatigue. They have proved that certain eye muscles suffer more fatigue under conditions of dark surroundings than when some general lighting is available.

The surrounding border should not be brighter than a dark area on the screen. This would tend to make the observer more aware of the screen border than of the screen. Various shades of gray border have been found to be desirable. It has been recommended that the border should be at least one thousandth to one five hundredth as bright as the screen high lights.[5] The contrast of a black-velvet border against the screen is estimated to be from one to ten thousandths as bright as the screen high lights.[6]

Conclusions

Care should be given to the selection of projection equipment for screening rooms in film studios and film laboratories.

Because of the many tests made in these screening rooms, the equipment must be kept in good adjustment at all times.

It may be necessary to reduce the amount of light transmitted to the screen when small screens and high-intensity arc lamps are used.

Screen brightness should be checked carefully so as to determine the approximate results which may be expected in the average theater.

The motor generator is the preferred power source for both two- and three-bladed shutters. However, the full-wave, three-phase rectifier was satisfactory when used with either two- or three-bladed shutters.

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The Gaumont-Kalee Model 21 Projector*

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Summary—The main features of the design of this 35-mm model are a completely enclosed projector, for silence, safety, and cleanliness. The mechanism operates in a totally enclosed oil bath, and the equipment has built-in accessories such as automatic change-over and fire-quenching devices.

Introduction

The purpose of this paper is to indicate the tendency in design of 35-mm sound-film projectors in Europe, and so that members of the Society could study the projector in detail, and compare it with current practice in the United States, the Gaumont-Kalee Company of Toronto brought a model to the Convention Exhibition.

When, nearly twenty years ago, the talking film passed from the experimental to the commercial stage, sound-film equipment was naturally designed for use with existing picture-projection equipment. Sound was only an addition to the basic thing, the picture. For a long time after the arrival of sound films there was a clear-cut line dividing the sound equipment from the picture equipment. The complete picture and sound equipment was a mating dictated by expediency of the products of a number of different manufacturers.

More than one designer, in Europe and America, made a logical bid to end piecemeal design by producing a combined picture and soundhead, but although technically such a concept was attractive, commercially it did not secure acceptance. The user's preference was for a more flexible design that permitted the retention of existing projector mechanisms, or of existing soundheads.

The design of complete equipment which is to satisfy expressed preferences both in Europe and America must take into account

* Presented October 22, 1947, by A. G. D. West, at the SMPE Convention in New York.

established differences between equipments originating in the two hemispheres. Thus, in Europe, for the past fifteen years, projector mechanisms in the medium- and high-price groups have had oil sumps and automatic-pump lubrication. On the other hand, enclosure of the operating side has been the exception. There has, in fact, been a preference for the open machine which leaves the film path exposed. In the event of a film fire, the burning film can more easily be removed. The addition of automatically operated fire extinguishers of the carbon-dioxide type, which quench a fire and simultaneously cut the motor and the arc lamp, has been common, and in some districts compulsory.

In England particularly, owing to population density, really large cinema theaters and large screens are relatively more frequent than in most parts of the world, and as smoking is universally permitted, illumination requirements are high.

In the realm of vacuum tubes, there has been a tendency for each European country to develop types dissimilar to those of its neighbor, and dissimilar to North American types. Only the octal-base type has secured any measure of international acceptance.

The Gaumont-Kalee 21 equipment was designed for the world market, as a complete picture and sound reproducer. Its designers set up the following table of requirements:

1. Picture and sound performance to satisfy recommendations of internationally accepted authorities.

2. Over-all reliability to be greatest that straightforward design and high-grade components could attain.

3. Accessibility, including replacement of worn or defective mechanical or electrical components, to be such that unskilled personnel could undertake necessary maintenance work in remote locations.

4. Complete sound channels to be built up from a minimum number of basic panel units, and component layout to be such as to facilitate comprehension of circuit function.

5. Mechanical assembly of stand, projector, soundhead, and arc lamp to be conceived as a whole, and to incorporate such ancillaries as carbon-dioxide fire-quenching equipment, picture change-over control, and arc switches and meters, but major units, projector, soundhead, and arc lamp, to be capable of use with other equipment.

6. Projection lenses, coated, to have $f/1.9$ aperture over complete range of focal lengths up to 7 inches, and design of arc lamp and projector to permit full use of this aperture.

7. Projector mechanism to have oil-bath lubrication, high-efficiency flicker shutter, and enclosure of operating side.

8. Projector drive from soundhead to conform with American practice.

PROJECTOR STAND

As the base upon which the mechanical assemblies are erected, the description of the equipment commences with the stand (Fig. 1).

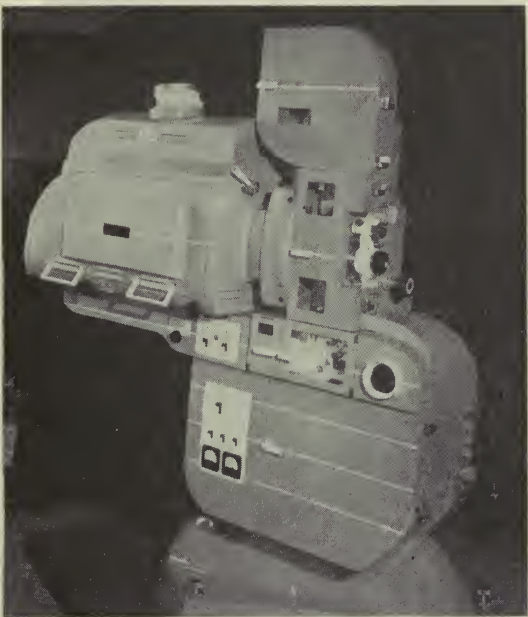

Fig. 1—Operating side of assembly, all covers closed for operation.

This incorporates platforms for soundhead and arc lamp, and the bottom spool box is an integral part. Switches for motor, exciter lamp, and picture change-over are grouped on a panel. A second panel carries arc-control switches and meters, but these may be omitted if not required. A door at the rear (Fig. 2) corresponding to the spool box door in front, gives access to the chain-driven take-up, and to the motor and arc switches controlled by the fire-extinguisher equipment. Provision is made on the front end of the stand for all cable entries, the internal wiring being run in the factory and terminated at a distribution board at the cable-entry point. Wiring arrangements are, however, sufficiently flexible to suit other installation requirements which may arise in practice. The stand is adjustable for height in 3-inch steps by insertion of distance pieces, and has a tilt adjustment by a concealed jackscrew, accessible through the door on the nonoperating side. The possible tilt varies from 10 degrees upwards and from 20 to 30 degrees downwards, depending upon the

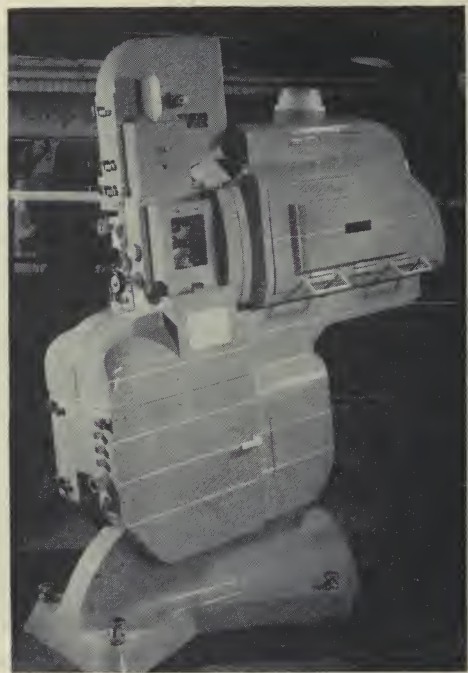

Fig. 2—Rear view of assembly of stand, projector, soundhead, and arc lamp.

height of the stand. The fixed foot of the stand is a heavy iron casting; the tilting parts, including the spool box and doors, are all substantial aluminum castings.

The Soundhead

The soundhead bolts directly upon the horizontal upper surface of the stand, which also supports the driving motor, thus making a very rigid construction (Fig. 3). The soundhead is also arranged for the more usual type of mounting on the back of a pedestal stand, when the motor is then supported by the soundhead.

The aim motivating the soundhead design has been to secure a high-grade performance that will remain stable over long periods of time, and long life because of robust construction of all wearing parts. From the maintenance point of view the soundhead is one that can be kept in service for twenty years without being sent back to the factory. Accurate jigging and dimensional uniformity of component

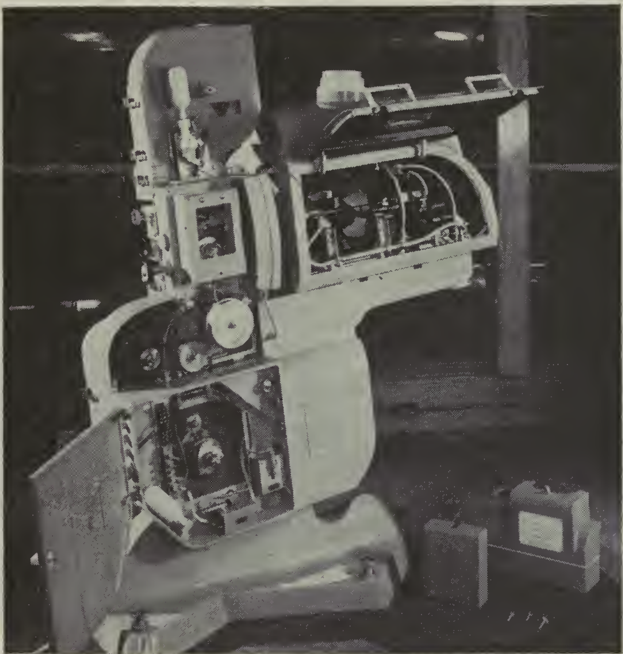

Fig. 3—Rear view of assembly of stand, projector, soundhead, and arc lamp. Doors open and covers removed.

parts ensures that replacements will fit without requiring any tools other than a screwdriver and spanner.

The soundtrack is scanned on the periphery of a rotary drum, and stabilization of film speed past the scanning point is maintained by a fluid flywheel mounted on the drum shaft (Fig. 4). The flywheel itself is a light aluminum shell containing a heavy viscous fluid, a design which eliminates the necessity for internal bearings to locate an inner member in respect to the outer shell.

The optical system is of the back-scanning or visible-image type. Immediately in front of the exciter lamp is a large condenser which projects the light horizontally forward to a prism mounted partly within the scanning drum. The prism reverses the light path and directs it back through the sound track, through the objective lens, and on to a window carrying a mechanical slit. The window is in a housing containing a prism, which directs the received light vertically downward on to the cathode of the phototube. As the optical magnification is six times, an enlarged image, six times that of the

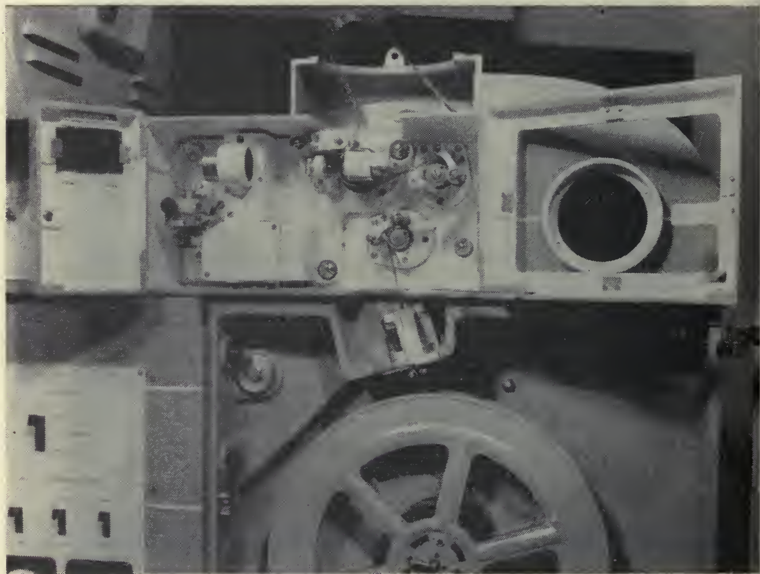

Fig. 4—Operating side of soundhead.

actual soundtrack, is impressed on the window. With the film stationary it is possible to check whether the focus is approximately correct, and with the film running it is evident if either sprocket holes or the edge of the picture is being projected on to the slit. The window has fixed masks to accept the internationally accepted scanned width of soundtrack of 0.084 inch. The adjustable tracking of the lay-on roller, centers the scanned soundtrack on the window. The slit is correctly adjusted for azimuth at the factory and locked.

Various types of slits can be used with the 83 soundhead, depending upon the purpose for which the head is used. For re-recording, a very fine slit is used so that a straight-line frequency response may be obtained from the phototube. For all normal reproduction purposes a comparatively wide slit is used, because the over-all frequency-response curve recommended by the Academy of Motion Picture Arts and Sciences entails curtailment above 2000 cycles. The standard reproducing slit is 0.0108 inch wide, and taking into account the six-times magnification of the optical system, corresponds to a slit dimension at film of 0.0018 inch. This dimension results in an increased amount of light being passed to the phototube, with a gain in output and an in-

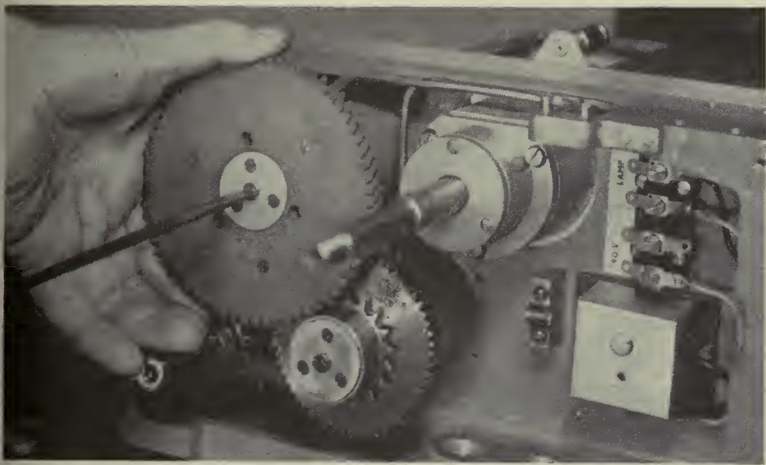

Fig. 5—Rear view of soundhead; flywheel, and driving pulley removed.

creased signal voltage on the grid of the first tube. Its effect on the frequency-response curve is progressively to attenuate the response above 2000 cycles, giving a loss of −12 decibels at 8000 cycles.

The efficiency of the optical system is high by reason of the large effective aperture of all optical components. All lenses and prisms are hard-coated.

All the components of the scanning system, exciter lamp, optical system, scanning drum, and phototube, are carried on a plate which is resiliently mounted within the soundhead body proper.

There are three rotating shafts in the soundhead, the one carrying the fluid flywheel and scanning drum, and two which carry a film sprocket at one end and a gear wheel on the other (Fig. 5). These three shafts are not carried in bearings located in the soundhead casting, but each shaft, with its bearings, is contained in a long, flanged housing of circular cross section which in turn fits a machined bore in the soundhead casting. The flywheel shaft runs on precision ball bearings as it must impose a minimum load on the film. The two sprocket shafts run on oilite bearings as they are driven by the motor. When, after long service, it is necessary to renew a shaft and its bearings, the complete housing can be withdrawn by taking out three screws, and a new shaft and bearings, complete in a housing, replaces the worn components. The two assemblies of sprocket shaft, bearings, and housing are identical and interchangeable.

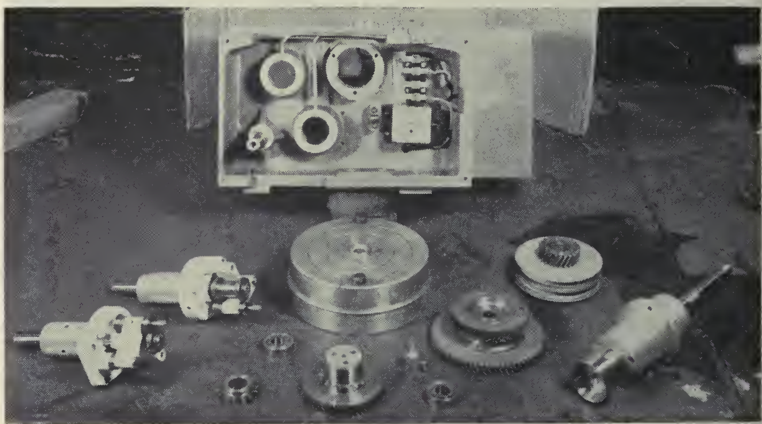

Fig. 6—Soundhead dismantled.

The whole gear train of the soundhead is carried on the two sprocket shafts plus one stationary layshaft. This layshaft is hardened and ground, and held in a machined bore in the soundhead casting. All the gearing is accessible when the soundhead cover is removed, and the complete train can be taken down in a few minutes (Fig. 6). Gears which rotate with their shafts are held thereto by key washers and end screws.

Every component part of the soundhead, electrical, optical, and mechanical, down to such items as small thrust washers, carries its part number engraved on it.

The complete soundhead is rustproof. The soundhead body, the scanning plate, and the doors are light alloy castings. The bearing housings, the mounts for exciter lamp, condenser and prisms, the phototube housing, the slit unit plate, the brackets for lay-on and pad rollers, and the strippers are light alloy die castings. Small rollers and retaining screws are either stainless steel or chrome-plated.

The resiliently mounted motor is carried in front of the soundhead with its shaft horizontal, and parallel with the sprocket shafts of the soundhead. The drive from motor to soundhead is by twin short canvas and rubber vee belts. The motor and the belt drive are protected by a quickly detachable louvered cover, through which an inching handle projects on the operating side. Motors are available for 25-, 30-, 40-, 50-, and 60-cycle supplies.

For studio requirements, a three-phase synchronous or an interlock motor is used, and as truly synchronous speed must be maintained on the film sprockets, gear drive takes the place of belt drive.

THE PROJECTOR

The projector is not bolted directly to the top of the soundhead, but is mounted on a detachable base which in turn attaches to the soundhead; this gives flexibility to suit other soundheads and avoids the inconvenience which sometimes would arise, were it always necessary to attach the projector by bolts from beneath the soundhead into tapped holes in the projector base.

American practice employs a small 17-tooth pinion which meshes with the projector gear train. This is an inconveniently small size, which, used with an oil-bath mechanism, involves an external gear train in order to keep the projector drive shaft at sufficient height above the oil level to avoid danger of oil leakage, or the employment of a stuffing box or equivalent expedient. This difficulty has been avoided by substituting for the 17-tooth pinion one of 34 teeth, running at the same speed and at the same relative center distance, thus maintaining interchangeability of soundhead drives. This 34-toothed pinion meshes directly with a drive gear mounted on the bottom sprocket shaft which is carried through the frame on both sides. This is the lowest bearing of the machine and is thus the limit to the amount of oil which the mechanism can contain without overflow.

The projector body is a substantial box casting, the bottom of which is the oil sump. The mechanism gear train runs in an oil bath, with oil circulated by a gear pump and distributed after passing through a filter, readily detachable for cleaning. The rear cover of the machine has a large clear window for viewing the mechanism and the working of the oil distribution; a "sight" window is provided at the operating side to show the correct oil level. This is marked with a series of lines to indicate the correct level corresponding to different angles of tilt. Optional positions are provided for an oil-drain plug in the front end, and on the nonoperating side of the mechanism, to suit different soundheads. The floor of the box casting is sloped internally so that the oil can be drained from the front, even in the case of a positive rake.

The projector gear train comprises throughout, cast-iron pinions and fiber gears in pairs. All have helical teeth for quiet running and their ratios have been worked out to secure a "hunting-tooth" condition in each pair, conducive to quiet running. The drive to the shutter shaft, which is at right angles to the main train, is by 45-degree spiral gears. Racking or framing is effected by rotation of the intermittent unit about the sprocket axis, timing compensation being obtained by sliding in synchronization the spiral-driven gear on the shutter shaft.

The intermittent unit has a large-size cross and cam of 2-inch nominal diameter. All working parts are of heat-treated-steel precision-ground. The roller is rigidly supported on a fixed pin carried between cheeks on both sides. The flywheel is mounted directly upon the cam shaft, there being no gearing inside the unit. The mechanism operates inside an oil box which is constantly flooded in all working positions. Adequate oil-return arrangements prevent leakage of oil. The unit is rigidly supported in the projector in a long fixed quill in which it rotates for masking adjustment. The intermittent sprocket, as all the projector sprockets, is hardened and ground.

The top and bottom sprocket assemblies are constructed as units which can be detached without dismantling. The intermittent unit and also the pump are similarly removable as units. The shutter shaft which is supported in bearings in the frame can also be withdrawn without dismantling. The rest of the gear train, including the housing which receives the intermittent unit, is removable in the form of two complete subassemblies.

Much attention has been given to the achievement of maximum shutter efficiency. The light must be cut off from the screen while the film is moving from frame to frame, and again for an equal balancing period in order to obtain a sufficiently high frequency of obturation to avoid an objectionable flicker effect; hence the maximum efficiency consistent with avoidance of "travel ghost" and marked flicker is about 50 per cent.

In practice, efficiency can be increased to some extent by encroaching into the period of film movement, which also enables a corresponding reduction in the balancing cover period. This is possible by talking advantage of the fact that there is a small but appreciable period at both the beginning and end of the film movement when its displacement is relatively small. The amount of encroachment tolerable can only be determined by trial, since it is to some extent dependent upon the intensity of illumination and also upon the rate of increase in illumination which depends upon the characteristics of the shutter.

Offsetting this the shutter does not cut a single ray of light, but a beam of sensible diameter, hence its operation cannot be instantaneous and the corresponding intervening twilight periods between full illumination and full cutoff involve some loss of potentially useful light, and the only effective way of increasing shutter efficiency lies in shortening this period.

One method of attack, adopted in several projectors of recent design has been the employment of twin shutter blades rotating in opposite directions, thus making a scissors-type shutter which, by cutting the beam simultaneously from opposite sides, cuts it in one half the time required by the conventional single shutter. Experiments made with this type of shutter showed a gain in average illumination of about 15 per cent. The current 21 projector employs a single-bladed shutter running at twice the normal speed. This achieves the same efficiency as the double shutter since it, too, cuts the light beam in one half the time of that taken by a normal single shutter.

The principle has been employed in 16-mm projectors and was in fact used in the first Kalee projector made 37 years ago. As applied to the 21 projector it affords a very straightforward construction with avoidance of external gears and oiling points. The high shutter speed, 2880 revolutions per minute, demands adequate lubrication to ensure quiet, troublefree running. A pipe furnishes a constant supply of oil from the pump, and the shutter shaft has a spiral oil groove which pumps oil continuously through the bearing, after which it is again returned to the sump by a return passage, a "flinger" assuring that no oil escapes into the shutter casing. Since the shutter runs at twice normal speed it requires a single blade of approximately 180 degrees cover instead of the usual pair of 90-degree blades. The blade is counterbalanced by steel plates riveted to the blade, which is of light-gauge aluminum. This makes a very stiff construction in perfect balance. The shutter casing houses the transformer for the threading lamps and the magnet of the change-over unit, with associated wiring and fuses.

An advantage of the open-sided mechanism is the freedom from restrictions imposed upon the lens holder by enclosure, which makes it easy to use large-diameter, big-aperture lenses. It has, however,

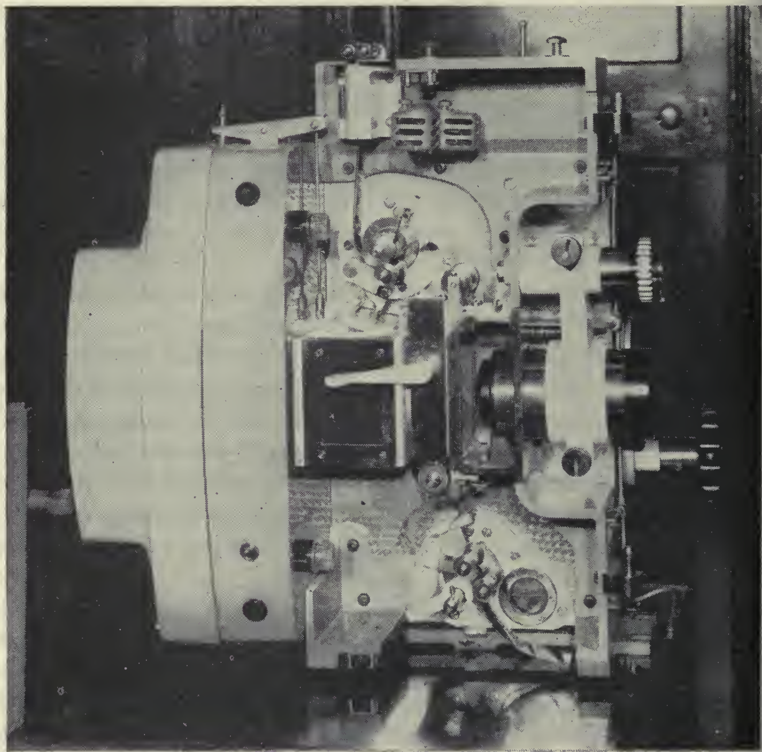

Fig. 7—Operating side of projector.

been possible to retain much of this advantage by arranging the lens holder outside the enclosure (Fig. 7). The bore of the holder is standard 2.781-inch diameter and it is furnished with a removable liner to take 2.062-inch diameter. The gripping length, while adequate, is kept short and close to the film plane, and permits the use of large-diameter lenses with still larger stepped-front elements. It is thus possible to use $f/1.9$ lenses throughout the whole range of focal lengths up to 7 inches.

The gate opens with a parallel action, is self-sustaining when open, and operated by a conveniently located handle. The front part of the gate assembly, which carries the spring-loaded film-guide rollers and pressure pads, is carried in a box-shaped casting which also receives the rear end of the projection lens. The gate simply hooks into a location in the face of this box. This construction gives utmost rigidity combined with accessibility as the gate assembly is instantly removable for cleaning.

The gate has twin apertures; the lower one is the projection aperture, and the upper one is for verification that the film is in frame. When the gate is closed the stray end of a broken film cannot intrude into the light path.

The whole gate assembly is detachable as a unit. A polished reflector is provided just behind the aperture to reject the heat of overspill illumination and this, together with massive construction and ample radiating surface, assures cool operation. The mask plate is of hardened steel and retained in slots in the gate bracket from which it is quickly detachable.

The framing aperture and the working side of the projector are illuminated by a pair of small low-voltage lamps. The lamps are fed from a transformer tapped to suit both 100/115- and 200/240-volt supplies.

The safety shutter is housed in the rear of the gate unit, and is actuated by a centrifugal governor on the shutter shaft of the projector.

PICTURE CHANGE-OVER

The electrically operated picture-change-over device operates on the safety shutter, but in such a way that no derangement of the change-over system can prevent the shutter falling when the force exerted by the centrifugal governor fails when the machine slows down or stops.

The safety shutter is raised by a floating lever acted upon independently by both the governor and a change-over magnet. Neither acting alone can open the shutter, which can only open and remain open so long as both exert a pull. The change-over operating mechanism proper is very simple, consisting merely of a tractive magnet arranged to pull down an armature connected to the floating lever operating the shutter. Magnet core and armature are laminated and fitted with slug rings, and wound for operating on alternating or direct current supply at mains' voltage. The magnet is in circuit the whole time that the picture is on the screen; change-over is effected by a throw-over switch which breaks the magnet circuit of the outgoing machine, closing the shutter, and simultaneously energizes the magnet of the incoming machine, the shutter of which opens because its actuating lever is being pulled both by centrifugal and magnetic force.

A two-station switch circuit is employed which allows operation from either machine. This can be extended for three-machine operation. The picture change-over readily could be coupled to the sound change-over, but there is divergence of opinion among operators as to the merits of such a provision.

FIRE CONTROL

The Pyrene fire-extinguisher equipment comprises a sealed cylinder of compressed carbon-dioxide gas and a spring-loaded piercer, which punctures the seal and releases the gas. This piercer is held back by a celluloid loop. A quick-burning gun-cotton fuse instantly transmits a fire at any of several points along the film path to the loop which ignites and releases the piercer. Pipes conduct the gas to various points along the film path, effectively quenching any fire. The gas is also led into both top and bottom spool boxes and to pistons which knock off switches, cutting the power supply to both motor and lamp, thus shutting down the equipment. In practice, in the event of a fire, not more than two frames are lost.

THE LAMP

The arc lamp employs a 16-inch diameter elliptical mirror with focuses at 6 and 36 inches. This mirror works at a larger collective angle than the more usual 14-inch mirror, and hence transmits more light. Experience has also shown that important practical advantages of its larger dimensions are that arc focus is less critical and the greater crater distance results in substantial freedom from pitting and reduced risk of mirror breakage. It has been found quite safe to operate this lamp at rakes of as much as 30 degrees.

It has been possible to maintain the generally accepted optical-center height with this large-diameter mirror by keeping the positive-carbon drive to the rear of the lamphouse. This has resulted in a clear unobstructed floor in front of the mirror. The lamp mechanism is of straightforward orthodox type. The positive carbon is driven directly by a variable-speed motor connected across the arc gap. The negative carbon is driven from the same motor through a variable-ratio drive comprising a cam-operated variable-stroke roller clutch. The complete drive unit can be withdrawn through the rear of the lamp. The whole of the mechanism and the mirror holder is mounted on a stiff cast tray which forms the base of the lamp. The lamphouse itself is constructed throughout of sheet steel fabricated and welded into a stiff one-piece shell with flush fitting doors, similarly fabricated.

Knobs on the operating side of the lamp, below the door line, give independent manual control of positive and negative carbons. These have quick releases for resetting and can be clutched together by pressing in a push button on the rear control panel to focus the crater, keeping the gap constant. A periscope system contained inside the lamphouse forms an image of the crater on a screen in the top of the lamp. A push-button strike is provided.

A wedge-operated quick-release positive-carbon grip safeguards against excessive clamping force and instantly dismantles for cleaning, and a tachometer shows the actual speed of the feed motor.

Sound Amplification

The complete amplifier system for a single or dual channel is built from basic units, all of which are mounted on cadmium-plated, rust-proof panels of uniform width (Fig. 8). Panels are mounted in the vertical plane. All components, including tubes, are on the front face, with terminals projecting through to the back, on which side, in one plane, is all the wiring (Fig. 9). Every component is rated for continual tropical use, and in the design, care has been taken to operate tubes and rectifiers at less than the rating permitted by the manufacturers for continuous service. Tubes used are exclusively of the internationally accepted and available octal-base type.

The basic working panels comprise a three-stage preamplifier, a volume control, a 30-watt power amplifier, a power-supply unit, a meter panel, a dividing network, and exciter-lamp supply units. From these units a complete single-channel system can be evolved. A dual-channel equipment requires the addition of a switch-control panel, and for technical reasons, a separate unit to provide heater current for the tubes in the preamplifier. An optional unit, which can be added to either a single-or dual-channel equipment, is a panel-mounted monitor and deaf-aid amplifier.

The standard equipment is suitable for operation from 50- or 60-cycle mains of any voltage from 90 to 130 volts and from 190 to 260 volts. Alternative power-supply and exciter-supply panels are available which permit of direct operation from 25 cycles. These 25-

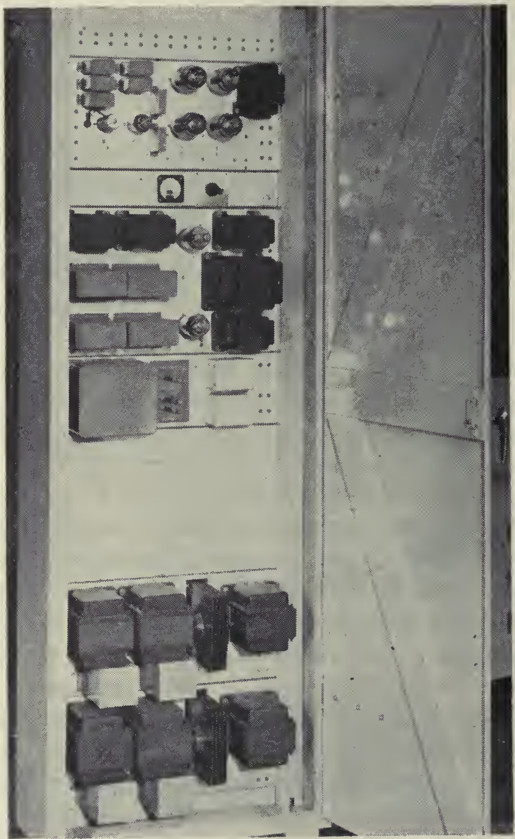

Fig. 8—Front view of cabinet rack.

cycle units will operate equally well from 30-, 40-, 50-, or 60-cycle supplies. Such small items as the monitor and deaf-aid panel, and the unit which provides heater current for the tubes in the preamplifiers, are made in one model only suitable for connection to mains of any periodicity between 25 and 60 cycles.

A complete single-channel amplifier is housed in two main units, a wall-mounting case for the preamplifier, and a cabinet-type rack for the power-amplifier—power-supply unit, dividing-network, and exciter-supply units. Two exciter-supply units are provided so that any soundhead test or adjustment requiring an input to the exciter lamp of the idle machine can be made during program hours.

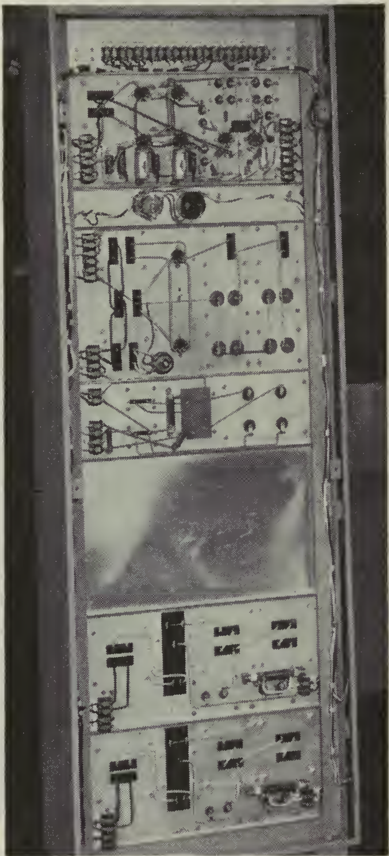

Fig. 9—Cabinet rack; rear cover removed.

Two small monitor speakers, for suspension directly over the two operating positions, are supplied. The level from the monitors is adjusted at the time of installation to suit the conditions prevailing and the operator's preference, and remains thereafter in direct relationship to the volume of sound emitted from the stage speakers. A monitor on-off switch is provided, and is fixed in a position adjacent to the telephone in the operating enclosure.

The equipment is completed by a switch-fuse distribution unit which is fixed to the wall, alongside the main switch fuse terminating the alternating current run to the operating enclosure. This distribution unit carries a voltage-adjusting transformer so that, irrespective of the incoming mains' voltage, the correct voltage may be fed to the untapped primary windings of the various mains' transformers on the working panels.

A dual-channel equipment duplicates both the preamplifier and the power amplifier. The two preamplifiers are housed in similar wall-mounting cases and two cabinet-type racks house the remaining panels. Normally each preamplifier serves one soundhead, but in emergency either amplifier can be switched to serve two soundheads.

A control panel, housed in one of the racks, selects which of the two 30-watt channels is to be used, or in a third position of the switches, links the two power amplifiers to give a total power output of 60 watts. Correct matching of the power amplifiers, both in respect of input impedance and output load is preserved irrespective of whether either channel alone or the two linked are in use. The control panel also carries a meter calibrated in decibels, and two gain-control switches, which permit the two channels to be balanced accurately for sensitivity. The meter also permits over-all frequency-response curves of the two channels to be measured.

The preamplifier has three stages, resistance-capacitance-coupled with negative feedback over the last two stages. Adjustment of frequency response is by a unit, mounted on the amplifier panel, which gives independent control of bass and treble response, permitting an over-all curve to Academy or any other recommendation to be obtained.

The main volume control is a 22-stud, click-action network with a stationary scale and a rotating pointer. Sound change-over is by instantaneous switch. Both volume and change-over can be remotely controlled from positions adjacent to the two projectors.

The power amplifier has three stages, with negative feedback over-all. The power stage comprises four 6L6G tubes in parallel push-pull, and at the rated output of 30 watts there is less than $1^1/_2$ per cent of total harmonic distortion at the frequency where distortion is at a maximum.

The power-supply unit is on a separate panel, both to reduce the weight and complexity of the power amplifier, and to permit of its ready interchange with the 25-cycle model. It utilizes two hard thermionic rectifiers of the 5U4G type.

Exciter Supply

The exciter-supply units employ selenium-type metal rectifiers, and the two-section, choke-input filter gives a smoothed output comparable to that obtained from accumulator batteries. The direct-current output of each unit is controlled by the exciter-lamp switch on the stand carrying the projector and soundhead. The alternating-current input may be left connected to an unloaded unit for an indefinite period without harm to the rectifier or any other component.

Throughout the design of the amplifier channel and associated equipment, great attention has been paid to accessibility. The pre-amplifiers are carried on hinged frames that permit immediate access to the back of the panels. The cabinet-type racks have full-length doors in front to give access to tubes and components, and quickly detachable backs to give access to the wiring. Any component on any

Fig. 10—Complete duosonic speaker assembly, small size.

panel can be removed and replaced without disturbing any other component. All high-tension smoothing capacitors are of the steel-cased paper-dielectric type.

Components which are not immediately identifiable as to type and value by manufacturers' markings are part numbered. All panels carry on their front faces a metal label giving the type number of the panel.

LOUDSPEAKERS

The loudspeaker assemblies (Fig. 10) which are of the usual two-way type, are supplied in four different sizes. High-frequency and low-frequency units have permanent magnets of Alnico 5.

The dividing network has a crossover frequency of 500 cycles, with

TABLE I

PERFORMANCE OF GAUMONT-KALEE 21 PROJECTOR IN VARIOUS THEATERS IN GREAT BRITAIN

Theater	Arc Volts	Amperes	Arc Watts	Total Lumens	Lumens per Watt	Average Foot-Candles	Lens Focus	Lens Speed	Picture Width
Astoria, London, W.	40	62	2400	7,098	2.95	26	3.25	f/2.2	18
Gaumont, Princes Park, Liverpool	38	60	2280	6,615	2.90	25	4.25	f/1.9	19
Trocadero, Elephant, and Castle, London	40	58	2320	10,887	4.69	25	5.00	f/1.9	24
Gaumont, Plymouth	39	59	2301	7,706	3.34	16	4.25	f/1.9	26
Dominion, London, W.	40	58	2320	6,425	2.64	18	5.75	f/1.9	23
Classic, Belfast	38	58	2204	6,542	3.42	17	5.00	f/1.9	23
Gaumont, Birmingham	38	60	2280	8,658	3.79	16	4.25	f/1.9	27
Gaumont, Coventry	41	58	2378	7,581	3.14	16	4.50	f/1.9	24
Picture House, Glasgow	42	61	2562	8,114	3.20	20	5.00	f/1.9	23

a 12-decibel-per-octave loss on each side of that frequency. An attenuator with five 2-decibel steps is provided to equalize the acoustic output of high- and low-frequency horns.

The high-frequency horns are of all-metal construction, with from eight to eighteen cells, according to the horizontal and vertical angles to be covered.

The low-frequency horn is of the direct-radiation pattern with no back emanation. In the larger sizes of horn, where the number of low-frequency units employed would result in a departure from optimum-load conditions, an impedance-matching transformer is used.

The design of the low-frequency horn is such that, in addition to the normal back access to the low-frequency units, side access is provided as well. This permits the loudspeaker assembly, where backstage room is limited, to be positioned close against a rear wall without impairing accessibility of the units.

THEATER PERFORMANCE

Some measurements of light efficiency, taken at various theaters in London and the provinces, are shown in Table I. These indicate an average performance as follows:

Arc watts	2400
Total lumens of light output	8000
Lumens per watt	3.3
Average illumination on a 23-foot-wide screen (projector running with no film in the gate), foot-candles	20
Average brightness on a 23-foot-wide screen, foot-lamberts	14
Screen efficiency, per cent	70

NOTE BY G. T. LORANCE

When I was informed that the Chairman of the Board of Editors had suggested that "perhaps it would be interesting to publish with the paper a short note by Mr. Lorance discussing points wherein British practice differs from that in this country," I felt quite complimented and indicated my willingness to write such a note. It was not until I received a copy of the paper by Messrs. Audigier and Robertson and began to study it that I got into trouble because it was clear that the authors have already well covered the points which I was supposed to emphasize.

At the risk of appearing to have developed a philosophical outlook, let me first say that this is one of those cases, when, in comparing the Gaumont-Kalee machine with American machines, an introvert would find many, many similarities and an extrovert would find many, many differences. To the introvert this is still a projector, a soundhead, a motor, magazines, and an arc lamp mounted on a pedestal much as they have always been designed and mounted. To the extrovert this new assembly of equipment with the design of each piece correlated to the design of its associated pieces and with certain new details and with emphasis on them, this is a new projector and sound system. Neither viewpoint, of course, is the correct one and in what follows I shall endeavor to find a reasonable middle ground.

Audigier and Robertson refer to attempts to produce a combined sound and picture head, indicating that such a concept was technically attractive but commercially unacceptable and that the user preferred a more flexible design that allowed combinations of equipment from various sources and at various times. I cannot help but agree with the authors regarding the attractiveness, from a technical standpoint, of a combined design. I think they must have had it very much in mind because the design which they describe in this paper represents to me a very determined and worth-while endeavor to have your cake and eat it too, in that they have striven for a unified and co-ordinated over-all assembly of major components but have retained much of the familiar breakdown into major components. Incidentally, it seems reasonable to state at this time that, in portable and semiportable equipment, unified designs of a combination of projector, soundhead, and arc have been commercially successful for a number of years and that the performance of some of these unified equipments compares quite favorably with the performance of equipment of the regular type as designed for permanent installation in projection rooms.

By and large this new Gaumont-Kalee equipment appears to follow pretty generally accepted American practice although it has been, of course, modernized in detail. A few points are enumerated and discussed below. An attempt has been made to restrict them to points of difference or to points of interest about which more knowledge would be of value.

SOUNDHEAD

Rear scanning, similar in principle to that employed in the Gaumont-Kalee soundhead, has been used in American equipment. It is possible, of course, to do good work with either front or rear scanning and it is necessary to know more than is disclosed in this paper before we would know if this system represents an improvement over American systems.

The use of a slit image 0.0018 inch high at the film represents a departure from American practice that may be open to question. The desire to utilize the dropping high-frequency response of such a slit image as part of the desired over-all reproducing-system response characteristic is understandable. It may, however, result in other undesirable effects, such as irregular, rather than steady reproduction of high frequencies. In my opinion, a slit image height of 0.0012 inch, as used in much American equipment, is a little larger than is desirable if quality of reproduction is to be stressed.

To the best of my knowledge, commercially available American equipment has not used a fluid flywheel as described in this paper. While realizing that the fluid flywheel eliminates the necessity for internal bearings, the quality of which is extremely critical, American designers apparently have not yet given favorable consideration to the fluid flywheel. This probably is because of a belief that to maintain or improve on performance, a much larger fluid flywheel would be needed. Quantitative information on the performance of this soundhead with this size of fluid flywheel would be of interest.

The Projector

The description of the use of a 34-tooth pinion for the 17-tooth pinion is not entirely clear to me. If, however, it provides for a higher oil level in the projector without decreasing the speed of the projection drive shaft it may well represent a new and improved solution to this general problem.

There is much more to shutter efficiency than the authors of this paper have taken time and space to present. The use of a single-bladed shutter, such as described, rotating at 2880 revolutions per minute is one method of attack which has, to the best of my knowledge, not yet appeared commercially in American machines. Factors affecting shutter efficiency involve such things as the number of blades on the shutter, whether it is double or single, speed of rotation, diameter of the shutter, and size of the light beam where the shutter cuts it. Circumstances do not permit enlargement upon this thought in this note.

While the lens holder is, dimensionally, in line with current American practice, there are indications that American designs may adopt a larger lens diameter. At least one projector has been shown with facilities for clamping a lens having a diameter of approximately 4 inches.

Picture Change-Over

From a technical standpoint it seems quite feasible to use the safety shutter as the change-over as well and such a design probably does simplify the complete system.

Fire Control

To me, the use of built-in fire extinguisher equipment is novel in so far as American equipment is concerned. The subject in general is of such a controversial nature and exact and reproducible data are so difficult to obtain that I do not feel competent to comment further on this point.

The Lamp

More information of a definite nature would be appreciated regarding the lamp. We are not informed regarding the optical speeds involved nor are we informed regarding the size of the carbons, consequently we are unable to comment accurately on the performance of the lamp.

Sound Amplification

While the available output power is stated, there does not appear to be any statement regarding the noise level.

Loudspeakers

An unusual point is noted in regard to loudspeakers in that the design of the low-frequency horn is such that access to the low-frequency units is provided through the side as well as through the back of the horn. This is a detail which should be noted by American designers.

Theater Performance

Figures are quoted regarding the amount of light put on the screen. Information regarding the distribution of light on the screen would also have been of interest. Reference should be made to the recently published results of a survey by the Screen Brightness Committee,* which gives in considerable detail the performance of a variety of equipments in some eighteen American theaters.

In conclusion, may I state the hope that the above remarks will be taken as being well intentioned. Messrs. Audigier and Robertson have developed and designed some very interesting equipment which, in my opinion, is well worthy of study by American engineers.

* *J. Soc. Mot. Pict. Eng.*, vol. 50, pp. 260–274; March, 1948.

REPLIES BY AUTHORS TO QUERIES RAISED

Arc Lamp

The optical speed is $f/1.9$, to match the aperture of the projection lens. Carbon sizes used for results given in Table I were 8-mm positive and 7-mm negative, of "POOL" high-intensity type. (In

Great Britain during the war the number of types of carbons was greatly reduced, and the product of all manufacturers pooled.)

Intermittent Sprocket

The diameter is 0.945 inch.

Sound Amplification

This paper has failed to give a clear impression of the physical layout of the complete amplifier channel. The three-stage preamplifier is a separate unit, mounted on the wall centrally between the two machines, so that the circuit from the phototubes to the input of the preamplifier is not unduly lengthy.

Low-capacity concentric cable is employed, and the ratio of phototube-lead capacitance to total amplifier input capacitance is such that a difference in length of several feet between the right-hand and left-hand cell lead will result in a negligible disparity in the over-all response curves of the two machines. The change in frequency characteristic is less than 1 decibel at 8000 cycles for a 6-foot difference in phototube-lead length.

The total amplifier noise level under normal operating conditions is between 30 and 35 decibels below 0.006 watt.

Scanning Slit

Before adopting the wide slit, experiments were conducted with slit widths of from 0.0004 to 0.0018 inch (equivalent at film), and shaping the response curve by means of a wide slit was not found to impair reproduction as compared with the alternative method of shaping the amplifier's frequency response.

The wide slit has been used consistently since 1939.

Fire Control

Accumulated practical experience of the carbon-dioxide fire control, which has been an in-built feature of Gaumont-Kalee design since 1939, shows that a film fire originating anywhere in the picture mechanism is extinguished within less than one second of its inception, with a loss not exceeding two frames of film, and that the action of the device is certain if charged and set.

Zoomar Lens for 35-Mm Film*

By F. G. BACK

Research and Development Laboratory, 381 Fourth Ave., New York 16, New York

Summary—**The 35-mm Zoomar is at present mainly used for newsreel work where it has proved itself a valuable tool especially in the field of sports shots. A studio Zoomar of more rigid construction and higher optical correction which can also be used for color work is in preparation.**

Three articles[1–3] dealing with the basic principle of the Zoomar lens have already been published in this journal, so it is hardly necessary to go into theoretical details again. The 35-mm Zoomar has already established its place as a valuable tool in newsreel photography one year after appearance of its smaller brother, the 16-mm Zoomar.

Numerous newsreel companies are using it regularly for their sport shots. Fast sports, especially, change their center of interest rapidly from one single player to a large group or even to the entire field. This demands the use of a Zoomar lens because the standard turret does not give satisfactory results. While changing lenses breaks the continuity and makes the picture jumpy and confusing, the Zoomar gives a continuous transition which makes it easier to understand the game. It is even possible to follow the players or participants over the whole field and nevertheless keep them always the same size on the screen regardless of their position. This is of great importance in certain sports such as racing, football, and baseball. This striking effect cannot be obtained by any other means.

The 35-mm Zoomar was primarily developed for use of newsreel photography with emphasis on sports, because it was almost impossible up to then to catch the high lights of a game except by accident.

It is self-evident that the 35-mm Zoomar lens for studio work has to fulfill other requirements than the newsreel Zoomar. Each one will have to be designed differently. The lens for news photography has to be comparatively light in weight. It has to be capable of rapid transition but it works only for black-and-white. The studio lens on the other hand may be much heavier but has to be more rigidly constructed because it must be suitable for taking unconscious zooms

* Presented October 21, 1947, at the SMPE Convention in New York.

which are never demanded of the newsreel Zoomar. The picture quality of the studio lens has to be superior to that of the newsreel lens, and above all the studio lens must be suitable for both black-and-white and color.

Fig. 1 shows the 35-mm newsreel lens mounted on an Akeley camera. The coupled Zoom viewfinder is of the same basic design as the one in the 16-mm sport Zoomar. The cameraman is not confined to a fixed position to view the finder image. He sees the finder frame comparatively large and free from any ground-glass diffusion.

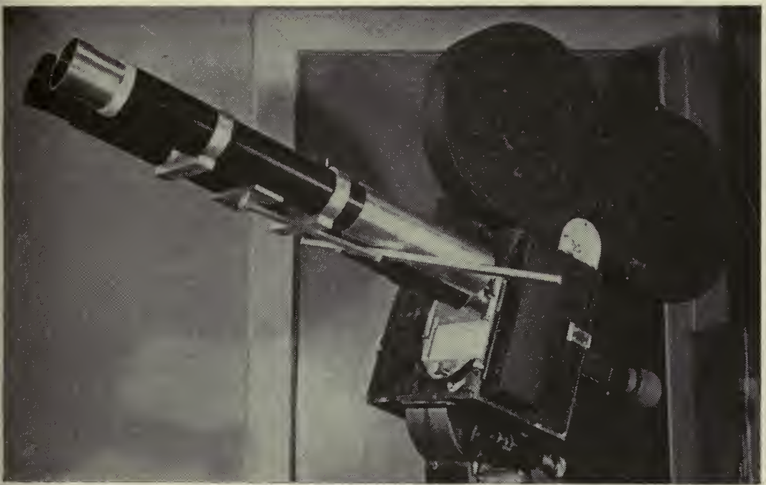

Fig. 1

A parallax adjustment of the viewfinder was not provided, for a very good reason. Practical experience has shown that better results are obtained when the cameraman is trained to make allowances for the parallax instead of operating a parallax adjustment, because the target changes its distance from the camera and therefore a parallax adjustment will have to be reset continuously throughout the take. Actually, this is never done, and therefore the framing of a viewfinder with parallax adjustment is not only inaccurate most of the time but this inaccuracy changes continuously. The Zoomar finder has a fixed parallax of five inches which is always maintained regardless of the Zoom position and of the object distance. Once the cameraman has learned to take these five inches into consideration he will never fail.

The specifications for the 35-mm newsreel Zoomar are:

Aperture range: $f/4.5$ to $f/22$
Zoom range: Interchangeable wide-angle front lens, 2 to 7 inches.
Zoom range: Interchangeable telephoto front lens, 3.5 to 13 inches.
Field coverage: Difference in field area in any one continuous shot, 15 times.
Object distance: From 12 feet to infinity.
Height: 3 inches
Length: 26 inches
Width: 8 inches, including viewfinder
Weight: 11 pounds, including viewfinder

The design for the 35-mm Zoomar for studio work has not yet been completed. There is also a special Zoomar for animation work in preparation.

Without doubt the 16- and 35-mm Zoomar lens have proved their merits and have stimulated enthusiastic cameramen to develop many new ideas for their uses in a variety of fields. These pioneers will eventually develop a new technique which will prove a valuable contribution to the art of motion picture production.

REFERENCES

(1) Frank G. Back, "A positive vari-focal viewfinder for motion picture cameras," *J. Soc. Mot. Pict. Eng.*, vol. 45, pp. 466–472; December, 1945.

(2) Frank G. Back, "Zoom lens for motion picture cameras with single-barrel linear movement," *J. Soc. Mot. Pict. Eng.*, vol. 47, pp. 464–469; December, 1946.

(3) Frank G. Back, "The physical properties and the practical application of the Zoomar lens," *J. Soc. Mot. Pict. Eng.*, vol. 49, pp. 57–64; July, 1947.

DISCUSSION

DR. K. PESTRECOV: What is the speed of the lens?

DR. FRANK G. BACK: The geometrical speed of the lens is $f/4.5$.

DR. PESTRECOV: Does the speed change while zooming?

DR. BACK: No. The speed is independent of the zoom. If you set your lens for a certain speed this speed remains constant over the entire zoom.

MR. R. E. LEWIS: What is the resolving power of the lens in lines per millimeter?

DR. BACK: The 35-mm lens has a resolution of approximately forty lines in the center and a little less toward the edges. We are working now on increasing this resolution.

CHAIRMAN WILLIAM H. RIVERS: What approximately is the weight of the 35-mm lens and is there any additional support needed for field use of this lens?

DR. BACK: The weight of this lens is not more than the weight of one of the large telephoto lenses. For instance, if you take a 25-inch telephoto lens it is heavier than this one. Just as it is, it weighs approximately 11 pounds, and we have found that for general use it is not absolutely necessary to put any support underneath. Of course, a support can be used with the lens very easily.

DR. PESTRECOV: What is the range of focal length covered?

DR. BACK: The range of this particular lens with the telephoto front lens is from three and a half inches up to thirteen inches. We are working now on increasing the range as well as the focal length. If we use the wide-angle front lens by exchanging the front lenses the range goes from approximately two inches up to seven inches.

MR. WILLARD W. JONES: What is the depth of field?

DR. BACK: The depth of field is exactly the same as on any other lens of comparative focal length. For instance, if you take the lens in the telephoto position the depth of field becomes rather shallow as it would be, for instance, on a thirteen-inch lens at *f*/4.5. If the zoom lever is in the wide-angle position the depth of field increases accordingly. In this case you would have the same depth of field as a lens of three and a half inches focal length at *f*/4.5.

This is the reason why it is not necessary to refocus on those follow shots where the subject moves toward or away from the camera and still remains the same size on the screen. These follow shots have been focused in the telephoto position where the subject is at the greatest distance from the camera because in this position the depth of field is very small. If everything is sharp in this position even when the subject comes closer and we go into our wide-angle position by moving the zoom lever everything still remains in focus, due to the greater depth of field in this position.

FORTY YEARS AGO

Moving Pictures from a Balloon

Berlin, April 25.—Photographs for the cinematograph have just been taken from a balloon successfully by Herr Ernemann, a Dresden engineer. As the exciting aerial voyage was ending he passed over the Sensteberg coal mine. Here, too, Ernemann succeeded in taking fine photographs. But just then the balloon shot down so suddenly that even the cinematograph apparatus had to be thrown from the basket. Luckily the pictures were afterward found intact.—*New York World.*

—*The Moving Picture World, May 2, 1908*

Parabolic Sound Concentrators

By R. C. COILE

Washington, D. C.

Summary—**Parabolic sound concentrators have long been investigated for application to military antiaircraft location, radio broadcasting, and motion picture recording. Olson and Wolff, of the Radio Corporation of America, developed a combination horn-reflector concentrator in 1929. Obata and Yosida, of Tokyo University, published measurements of amplification in 1930. Hanson, of the National Broadcasting Company, described the use of parabolic reflectors in broadcasting in 1931. Dreher reported in 1931 on the use of microphone concentrators in motion picture production. Sato and Sasao published the results of tests on the sound fields of deep parabolic reflectors in 1932.**

Rocard published an analysis of the theory of the amplification of the reflector-type parabola in 1932. Schneider of the Moscow Radio Center made amplification and directivity measurements in 1935 while studying the application of parabolic concentrators to Russian broadcasting and checked his amplification data with Rocard's theory. Gutin, in Leningrad, independently derived the theory of amplification and went on to analyze directivity in 1935.

This paper presents the pertinent historical background and reports on an experimental verification of the theoretical acoustical directivity of parabolic concentrators as well as further checks of the amplification theory. The sound fields inside parabolic reflectors have also been investigated experimentally with an agreement found with theoretical fields calculated by principles of geometrical optics.

Historical Background

The idea of using a parabolic mirror as a concentrator of sound by placing one's ear or a microphone at the focus was a subject of research in World War I. Waetzmann[1] has described German parabolas and Tucker[2] has reported on English and French development of plaster and concrete parabolic reflectors. The only quantitative data given in these reports is an estimate by Waetzmann that for a parabola having an opening diameter of 3.2 meters and a depth of 0.8 meter the magnification was about five times compared with unaided ears for whispers and less for lower notes.

The first quantitative work published on sound concentrators was a report by Olson and Wolff[3] in 1929 of their development of a combination horn and reflector. The theory behind this was that the amplification of a reflector-type sound concentrator depends on the wavelength of the impinging sound being less than the dimensions of the reflector. Hence the low frequencies whose wavelengths are larger than the dimensions are amplified very little. But by building a horn on the parabolic reflector, the amplification of the horn raised the low-frequency response. This design worked fairly well and microphone concentrators of this type have been used in Hollywood for recording motion pictures.

Obata and Yosida,[4] engineers of the Tokyo Imperial University's Aeronautical Research Institute, made a study of acoustical properties of some sound collectors for the aircraft sound locator in 1930. They made measurements of the amplification and directivity of two different horns and two 200-centimeter diameter open-bowl parabolic reflectors of different focal distance.

Dreher[5] reported on the use of microphone concentrators in motion picture production in this JOURNAL in 1931. Military searchlights with a microphone at the focus were used in outdoor recording, and other types of parabolic bowls were also used.

The developments of the National Broadcasting Company were announced in 1931 by Hanson,[6] chief engineer. Measurements of the amplification, directivity, and effect of microphone position on the axis were reported on a design of an open-bowl parabolic reflector built by NBC engineers.

Engineers of the Aeronautical Research Institute, Sato, Sasao, Kubo, and Nisiyama published several papers[7, 8] on the sound fields of parabolas in 1932. Their measurements were performed on deep parabolic reflectors and hence the results are rather complicated looking. The measurements were taken in the region beyond the focus, for the most part. These writers did not explain these results but merely said, "The experiment was very laborious and troublesome and therefore was carried out with only two pitches of sound, C_2 and C_4. . . . For C_4, the sound field becomes very complex and many maxima and minima due to interference fill up the space in front of the mirror."

In 1932, the first theoretical treatment was published in Rocard's paper[9] on "Les Paraboloides Acoustique" in the *Revue d'Acoustique*, where Rocard derived an expression for the amplification of a parabolic reflector.

In 1935, Rocard's theoretical predictions were experimentally verified by Schneider,[10] an engineer of the Moscow Radio Center. Schneider's paper in the *Zhurnal Teknicheskoi Fiziki* examined all previously published work and reported on measurements of amplification which checked Rocard's predictions.

Neither Rocard nor Schneider had been able to cope with the theory of the directivity of a parabolic reflector. In 1935, Gutin,[11] a physicist in Leningrad, knowing nothing of the work of either Rocard or Schneider, derived independently the expression for amplification and went on to work out the theory of directivity which he published in the *Izvestia Elektropromishlennosti Slabova Toka.*

Experimental Study of Parabolic Concentrators

An experimental study has been made of the following characteristics of the parabolic reflector: (1) frequency response, (2) amplification, (3) directivity, and (4) sound fields. The published experimental work on reflector-type concentrators has been very meager as outlined above. Most of the published papers show the results of experiments completed prior to 1932. The microphones used were not always of the highest quality or of small size—a desirable feature of a sound-field measuring device. Some of the work by Obata and Yosida,[4] for example, was done using a large homemade condenser microphone with most of the experimental work performed indoors with the sound source rather close to the parabola. What work had been done outside is open to considerable question because of ground effects, as the parabola was simply placed upright about a foot off the ground.

Other experimenters have used parabolas with opening diameters ranging from 40 to 300 centimeters. A 130-centimeter copper parabolic reflector was used in this experimental setup to simplify measurement of the sound fields inside the reflector for we might expect acoustical reflection similar to optical reflection when the sound wavelengths are small compared to the dimensions of the parabola and diffraction effects when the wavelengths are comparable to the dimensions. The large size of the parabola indicated outdoor measurements to avoid errors from reflected sound although outdoor measurements present difficulties of wind and extraneous noises.

Kellogg[12] described five methods for minimizing echo errors in a paper in the *Journal of the Acoustical Society* some years ago. Fig. 1 depicts these schemes. In *A* both the loudspeaker and the microphone are well above the ground. If the distance is large compared with the wavelength of the lowest frequency employed the image sources are negligible. In B image sources are taken into consideration by placing both the loudspeaker and the microphone on the ground so that the difference between path length r from loudspeaker to microphone and the path length r' from image to microphone is less than a quarter wavelength of the sound. In C the speaker is supported in the air with the microphone on the ground. The sound reflected from the ground, if the ground is not a good absorbent, is sometimes strong enough to cause some back pressure on the loudspeaker. This can be fixed by putting the microphone on a slope as shown in D, so that the sound is reflected off at such an angle that it has little effect on the loudspeaker. One more method is to get the microphone out on a boom as far from any building as possible and to have the sound source at the corner of the building as illustrated in E.

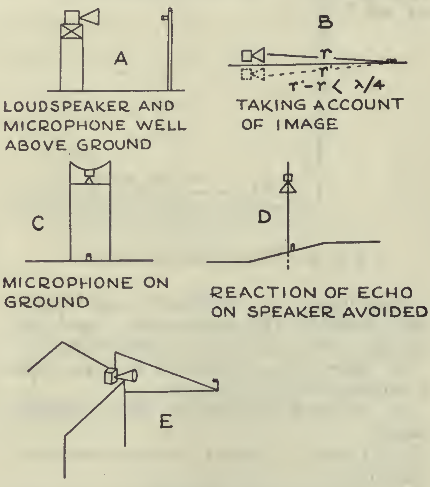

Fig. 1—Arrangements for minimizing echo errors.

The most convenient method for this particular experimental setup was a variation of D as illustrated in Fig. 2. The sound source was a General Radio beat-frequency oscillator which excited a Western Electric loudspeaker unit in a 6-foot exponential horn suspended out of a window of one of the sound laboratories at the Massachusetts Institute of Technology. The parabolic reflector was placed about 100 feet from the side of the building and was pointed toward the sound source. A Western Electric Type 630-A moving-coil microphone, step-up transformer, General Radio amplifiers, and General Radio output meter were used in the frequency response–amplification measurements, and a General Radio sound-level meter with a Brush sound-cell crystal microphone for sound-field measurements.

FREQUENCY RESPONSE–AMPLIFICATION

An expression for the theoretical frequency response and amplification of parabolic reflectors was derived independently by Rocard and Gutin. This expression is as follows:

$$\left|\frac{P_\beta}{P_\alpha}\right| \cong 4\pi \frac{a}{\lambda} ln \left(1 + \frac{l}{a}\right) = 4\pi \frac{a}{\lambda} ln \left(1 + \frac{R^2}{4a^2}\right)$$

where

P_β = pressure with concentrator
P_α = pressure without concentrator
a = focal distance
l = depth of parabola
R = radius of opening

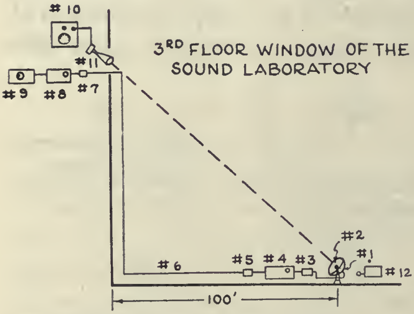

Fig. 2—Experimental setup.

Equipment: 1. Parabolic bowl reflector: diameter, 130 centimeters; depth, 35 centimeters; focal distance, 30 centimeters.
2. Microphone, Western Electric 630-A moving-coil microphone.
3. Step-up transformer, 30 to 100,000 ohms.
4. General Radio battery-operated amplifier.
5. Step-down transformer.
6. Transmission line.
7. Step-up transformer, 30 to 100,000 ohms.
8. General Radio battery-operated amplifier.
9. General Radio output-level meter.
10. General Radio beat-frequency oscillator, 20 to 20,000 cycles per second.
11. Six-foot exponential horn with Western Electric 555 unit.
12. General Radio sound-level meter with Brush crystal microphone.

For the parabola under test, R the radius of opening was 65 centimeters; a the focal distance was 30 centimeters; and l the depth was 35 centimeters. The expression for the amplification of this parabola reduces to

$$\left|\frac{P_\beta}{P_\alpha}\right| = 4\pi \frac{30}{\lambda} \ln (2.16) = \frac{291}{\lambda}.$$

This theoretical amplification at the focus is an inverse function of the wavelength and is plotted as the straight line in Fig. 3.

The frequency response and amplification of the parabolic concentrator were determined first by measuring the response of the microphone alone in free space, and then measuring the response of the microphone in the concentrator. The microphone was placed at the focus of the paraboloid. The measured frequency response and amplification characteristic are shown in Fig. 3. This agreement between measured gain of the concentrator and the computed values of amplification is as good as that reported by Gutin,[11] for the work of Obata and Yosida,[4] and the comparisons reported by Schneider.[10] The measured amplification differs from the computed amplification by about 10 decibels at the higher frequencies (7000 cycles) for the parabola investigated. Obata and Yosida's[4] measurements for frequencies from 475 to 188 cycles show the same trend, a divergence between theory and measurement for the higher frequencies. At their highest frequency of 475 cycles, the difference between theoretical and measured amplification was on the order of 20 per cent for one parabola 200 centimeters in diameter and 72.5 centimeters in focal length; and about 80 per cent difference for another parabola of the same diameter with a 54.5

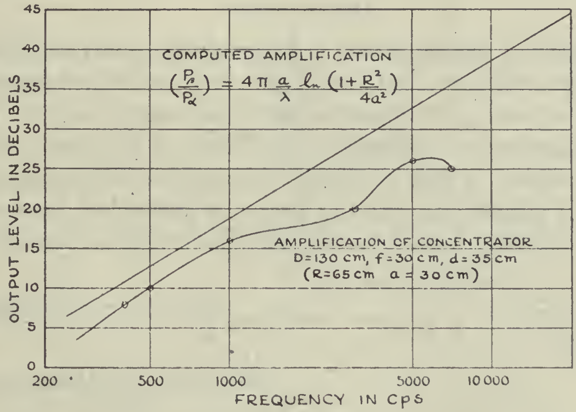

Fig. 3—Frequency-response amplification of the parabolic sound concentrator.

centimeter focal length. The curves of Schneider show this same trend. Schneider does not draw theoretical curves for frequencies higher than 4000 cycles because the disagreement is so large.

The size of the probe microphone used in the measurements affects the accuracy of the results. Schneider used three microphones in his tests, a large Reisz (carbon) with a diaphragm area of 70 square centimeters, a small Reisz with a diaphragm area of 40 square centimeters, and a condenser microphone with an area of 20 square centimeters. Examination of his data shows that the smaller the diaphragm area, the better the agreement between theoretical and measured results. Schneider did not attempt to explain this phenomenon. It may possibly be attributed to phase-cancellation effects, the diaphragm being so large that the higher-frequency sounds which behave more or less as geometrical optics predict, arriving in pencils of rays, hit the diaphragm in different phase thus reducing the output. Instead of having an infinitely small collector of the sound arriving at the focus in phase, we have a large sound-receiving surface that can pick up sound of different phase which will tend to reduce the output. The Western Electric Type 630-A microphone used in the frequency response–amplification tests has a diaphragm area estimated at 10 square centimeters, and the Brush sound-cell crystal used as a probe microphone in tracing out the sound fields has an area estimated at 2.5 square centimeters.

Directivity

The directivity characteristic is important in many applications of the parabolic reflector. Sato and Sasao have published experimental directivity curves and Schneider published some curves. The first published paper on an analysis of the theory of the directivity of the parabolic reflector is that of Gutin, who derived an expression for the coefficient of amplification at the focus of a paraboloid for an arriving sound wave whose normal made an angle α with the axis as follows

$$\frac{P}{P_1} = \frac{i\omega\rho(\varphi_1 + \varphi_2)}{i\omega\rho\varphi_1} = 1 + i4ak\epsilon^{-ika(1+\cos\alpha)}\left[\cos\alpha\int_0^{\frac{R}{2a}}\frac{\epsilon^{-i2akt^2\sin^2\alpha/2}I_0(2akt\sin\alpha)}{1+t^2}t\,dt - i\sin\alpha\int_0^{\frac{R}{2a}}\frac{\epsilon^{-i2akt^2\sin^2\alpha/2}I_1(2akt\sin\alpha)}{1+t^2}t^2\,dt\right].$$

Gutin derived a simpler expression using the theorem of reciprocity that is essentially the same at higher frequencies. This expression for the coefficient of amplification at the focus is

$$\frac{P}{P_1} = 1 + i4ka\epsilon^{-ika(1+\cos\alpha)}\,\epsilon^{-i2akl\sin^2\alpha/2}\int_0^{\frac{R}{2a}}\frac{I_0(2akt\sin\alpha)}{1+t^2}t\,dt.$$

Neglecting the incoming wave with respect to the reflected wave, the directivity characteristic expressed as a fraction of the maximum amplification (i.e., $\alpha = 0$) is

$$2\int_0^{\frac{R}{2a}}\frac{I_0(2akt\sin\alpha)}{(1+t^2)\ln(1+(R^2/4a^2))}t\,dt.$$

Gutin has given a table showing the position of the first minimum of the directivity for values of $R/2a$.

The measured directivity characteristic is shown in Fig. 4. The directivity was determined first by lining up the axis of the parabola

TABLE I
FIRST MINIMUM OF DIRECTIVITY

$R/2a$	$\sin \alpha$
1.0	$0.683\ \lambda/R$
0.7	$0.66\ \lambda/R$
0.6	$0.64\ \lambda/R$
0.4	$0.62\ \lambda/R$
0	$0.61\ \lambda/R$

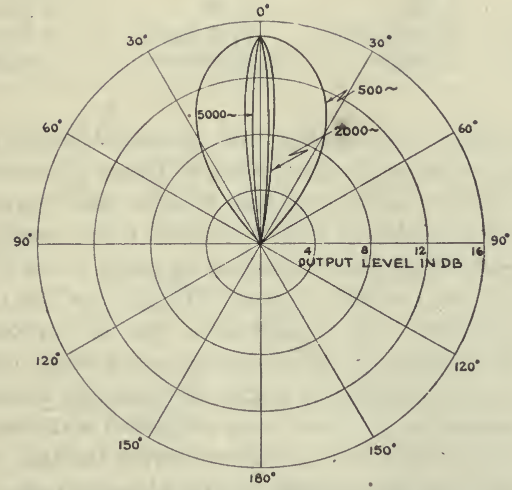

Fig. 4—Directivity characteristics: Massachusetts Institute of Technology parabolic concentrator.

with the axis of the 6-foot exponential-horn sound source, and then tilting the parabola and measuring the response at different angles. The lobes other than the fundamental were negligible and could not be distinguished from background noise. The main features of interest are the angles at which the response falls to its first minimum. These angles can be calculated by the method developed by Gutin. The procedure is as follows: The angle at which the directional characteristic goes through its first minimum is given by the expression

$$\alpha = \sin^{-1} K\, \lambda/R$$

where

λ = wavelength of sound being received
R = radius of opening of parabola
K = constant depending on $R/2a$ (see Table I).

The constant K is determined by calculation of $R/2a$ and then use of Table I. For the parabola investigated $R = 65$ centimeters; $a = 30$ centimeters; $R/2a = 1.08$; $K = 0.69$. Hence we can compute the angle of the first minimum.

TABLE II

CHECK OF THEORY AND MEASUREMENTS OF DIRECTIVITY

f	500 cycles	2000 cycles	5000 cycles
λ	69 centimeters	17.2 centimeters	6.9 centimeters
λ/R	1.06	0.264	0.106
$0.69\,\lambda/R$	0.725	0.180	0.0725
α (computed)	46.5 degrees	10.2 degrees	4.2 degrees
α (measured)	45 degrees	15 degrees	5 degrees

This agreement of theoretical and measured angles for the first minimum was a reasonably good check of Gutin's directivity theory. It is of interest to note that the *Izvestia Elektropromishlennosti Slabovo Toka* is available at so few libraries in the world that even Schneider, another Russian, publishing his paper in the *Zhurnal Teknicheskoi Fiziki*, also in 1935, stated "The story of the concentrator is very complicated. The amplification has an approximate solution.... The directivity characteristics are without theory...."

The experimental directivity curves of Schneider measured with a condenser microphone have also been compared with theoretical predictions. The calculations have been carried through in a manner similar to those for the parabola at the Massachusetts Institute of Technology: $R = 47$ centimeters; $a = 27.4$ centimeters; $R/2a = 0.86$; $K = 0.675$.

TABLE III

DIRECTIVITY CHECK OF SCHNEIDER'S DATA

f	700 cycles	1600 cycles	3000 cycles	5500 cycles
λ	49.2 centimeters	21.5 centimeters	11.4 centimeters	6.25 centimeters
λ/R	1.04	0.456	0.242	0.133
$0.675\,\lambda/R$	0.705	0.308	0.163	0.0896
α(computed)	45 degrees	18 degrees	9.4 degrees	5.2 degrees
α(measured)	50 degrees	42 degrees	11 degrees	5 degrees

The results check reasonably well with the exception of the 1600-cycle data. However, Schneider's measurements were made indoors so that there is a greater possiblity for a freak measurement than if the measurements had been made outside with less chance of reflections introducing errors.

SOUND FIELDS

There has been very little published on the sound fields of parabolic reflectors. Sato and Sasao[8] have reported measurements on fields in a deep parabola. These previous experiments studied complex sound fields in regions beyond the focus. It was thought of interest to examine the region between the focus and the vertex.

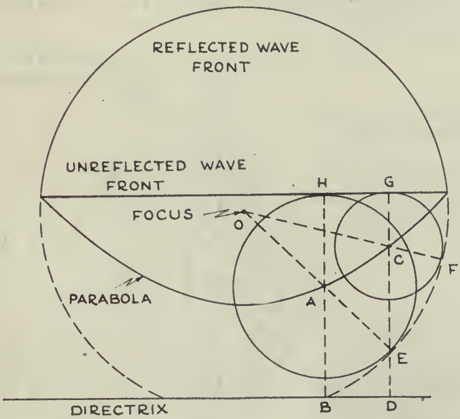

Fig. 5—Reflection from a parabolic mirror.*

* Wood, R. W.: "Physical Optics," Macmillan Company, New York, N. Y., 1934, p. 47.

According to the principles of geometrical optics a source placed at the focus emitting spherical waves will have them reflected at the walls of the parabola and sent out as plane wave fronts. And, conversely, plane waves arriving at the parabola will be reflected as spherical waves converging on the focus. When the incident and reflected waves meet there can be either constructive or destructive interference. If the difference in path length is $m\lambda$, where $m = 0, 1, 2, 3, 4, \ldots$ there will be constructive interference. If the difference in path length is $(2m + 1)(\lambda/2)$ where $m = 0, 1, 2, 3, 4, \ldots$ there will be destructive interference.

Hence, in attacking this portion of the problem, the contours of constructive and destructive interference were first determined by geometrical optical construction and then measured by the acoustical setup described.

The construction of the reflected wave fronts is a simple matter. The fundamental definition of a parabola is that it is the locus of points equidistant from a fixed line called the directrix and a point called the focus. Reflected wave fronts may be constructed in a graphical manner similar to that outlined by Wood.[13]

In Fig. 5 let O be the focus of the parabola and line BD the directrix. Let the unreflected wave front be represented by line HG.

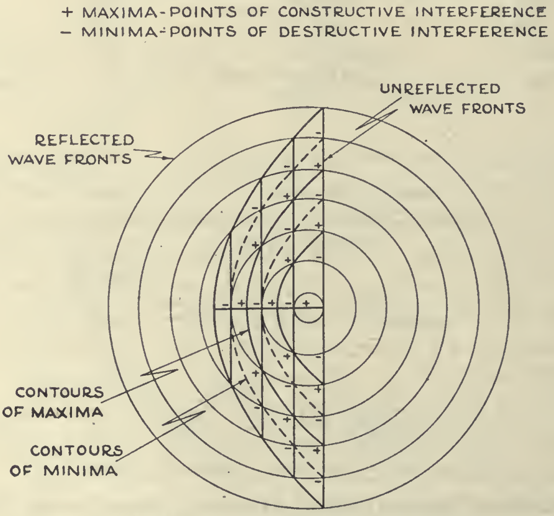

Fig. 6—Calculation of sound-field contours by geometric optical interference phenomena.
f = 1720 cycles per second
λ = 20 centimeters

Through any two points on the parabola A and C draw lines from O, the focus. Construct circles about points A and C of radius equal to the distance from these points on the parabola to the unreflected wave front. A circle drawn about O with radius OE will pass through point F and will be the reflected wave front. This may be proved as follows: every point on the parabola is equidistant from focus and directrix, $OA = AB$ and $OC = CD$; the small circles constructed about A and C had radii of $AE = AH$ and $CG = CF$; but now $OE = BH$ and $OF = DG$ adding the two parts of each line. But since $DG = BH$, for the unreflected wave front is parallel to the directrix, hence $OE =$

OF and a circle of the reflected wave front has been determined. Now we can see that as the unreflected wave front moves into the parabola, the reflected wave fronts become smaller and smaller circles converging on the focus.

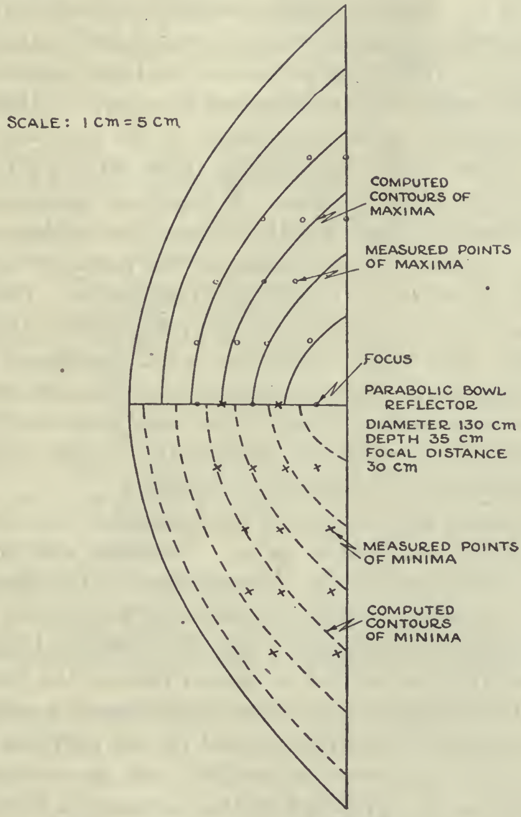

Fig. 7—Sound-field contours of constructive and destructive interference.
f = 3440 cycles per second
λ = 10 centimeters
Brush sound-cell microphone; Federal Radio sound-level meter.

A useful short cut in drawing these wave fronts is apparent on examination. The reflected wave fronts, circles about the focus, intersect the parabola at the same points as the unreflected plane wave front. Therefore, it is an easy matter to draw a circle with center at the focus and radius equal to the distance from the focus to the points of intersection of the parabola and the plane wave front.

Using this simple method of constructing reflected wave fronts, the contours of points of constructive interference (maxima) and points of destructive interference (minima) may be traced out after finding these points by checking path lengths. This construction is illustrated in Fig. 6. A series of plane unreflected wave fronts approaching the parabola has been drawn spaced a half wavelength apart. The frequency of 1720 cycles per second has been chosen to give a convenient wavelength of 20 centimeters ($\lambda = c/f = 34400/1720$). A series of concentric circles converging on the focus has been drawn corresponding to the c/f approaching plane wave fronts. There are numerous points of intersection. For each of these points we trace out the difference in path length between the incident and reflected wave. For example, at the surface of the parabola the path-length difference is zero, hence constructive interference; but moving out from the parabola along any circle of a reflected wave front there are points whose path-length difference is $\lambda/2$ designated by a minus sign; λ designated as plus, $3\lambda/2$ minus, etc. The points of constructive interference marked "plus" have been joined and in a similar fashion lines have been drawn through the "minus" points. These lines are the contours of maxima and minima.

These contours were traced out by a crystal probe microphone and a General Radio sound-level meter. Predicted and measured data have been plotted in Fig. 7. Examination of the figure shows the theoretical contours of constructive interference plotted as solid lines in the upper half of the parabola and the theoretical contours of destructive interference plotted as dotted lines in the lower half. Of course, both contours occur in three dimensions as a series of confocal shells of paraboloids of revolution, but for our purposes the contours are cross-section pictures of the parabola with the contours of minima made invisible in the upper half and the contours of maxima made invisible in the lower half.

The experimental points have been plotted as little circles for maxima and X's for minima. There are two places where the points do not check so well, points a great distance from the axis, and points on the axis. The explanation for the discrepancy of the points quite distant from the axis may be attributed to two things: distortion of the sound field by ground effects, and/or lack of rigidity of the microphone probe equipment. Measurements could not be made with sufficient precision to determine quantitatively the magnitude of the ground effect. For the purpose of checking the theoretical contours of constructive and destructive interference the experimental points nearer the axis must suffice and it is felt that, on the whole, a reasonable agreement is found within the magnitude of the errors of measurement.

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To make recommendations and prepare specifications on those film dimensions which affect performance and interchangeability, and to investigate new methods of cutting and perforating motion picture film in addition to the study of its physical properties.

(Under Organization)

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To make recommendations and prepare specifications for the operation, maintenance, and servicing of motion picture projection equipment, projection rooms, film-storage facilities, stage arrangement, screen dimensions and placement, and maintenance of loudspeakers to improve the quality of reproduced sound and the quality of the projected picture in the theater.

(Under Organization)

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To collect facts and assemble data relating to the historical development of the motion picture industry to encourage pioneers to place their work on record in the form of papers for publication in the JOURNAL, and to place in suitable depositories equipment pertaining to the industry.

(Under Organization)

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To make recommendations and prepare specifications on motion picture optical printers, process projectors (background process), matte processes, special process lighting technique, special processing machines, miniature-set requirements, special-effects devices, and the like, that will lead to improvement in this phase of the production art.

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The Hotel Statler, Washington, D. C., will be the Convention Headquarters. Room-reservation cards were mailed to the membership in August. These should be checked to indicate the accommodations desired for the 64th Semiannual Convention and returned to the hotel promptly, so that the hotel can book and confirm room reservations.

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Parlor suites, with connecting bedroom, \$17.50 to \$26.50

Rail, Pullman, and Plane Travel

The Convention Committee suggests arranging travel accommodations at least a month prior to the Convention, since travel conditions still remain acute, especially into Washington, D. C.

Convention Registration and Papers Program

The Papers Committee can only function successfully in the early assembly, scheduling, and release of the tentative and final Convention programs by receiving the title of paper to be presented, name of the author, and a complete manuscript mailed to one of the following vice-chairmen of this committee:

J. E. AIKEN
225 Orange St., S. E.
Washington 20, D. C.

N. L. SIMMONS
6706 Santa Monica Blvd.
Hollywood 38, Calif.

E. S. SEELEY
250 W. 57th St.
New York 19, N. Y.

H. L. WALKER
P. O. Drawer 279
Montreal 3, Que., Canada

R. T. VAN NIMAN
4431 W. Lake St.
Chicago 24, Ill.

The Convention business and technical sessions will be held in the Presidential Ballroom of the hotel. Registration and Information Headquarters will be set up in the Capitol Terrace, adjacent to the Presidential Ballroom. All persons attending the Convention should register and receive their Convention badges, also identification cards, which will admit them to all sessions held at, and away from, the hotel. These cards also will be honored at the de luxe motion picture theaters in Washington. Only through your registration can the Society derive the revenue needed to defray the Convention expenses. Please co-operate. Convention Press Headquarters and headquarters of Harold Desfor, SMPE Publicity Committee Chairman, will be located in the Continental Room.

Special Meeting

It is expected that the Thursday evening meeting will be held at a naval station. Tickets will be required for admission to this meeting, which can be obtained at the time of registration. Noncitizens will be required to register on Monday if they wish to attend this meeting. Busses will be available for transportation and, due to naval security regulations, all those attending will be required to go on such busses for which there will be a small charge.

Convention Get-Together Luncheon

The 64th Semiannual Convention Get-Together Luncheon will be held in the hotel's Congressional Room at 12:30 P.M. on Monday, October 25. Although there will be no technical session scheduled for that morning, Registration Headquarters will be open from 9:30 A.M. to noon in the hotel's Capitol Terrace, so that you may register and purchase Luncheon and Banquet tickets.

Seating at the luncheon will be assured only if tickets have been purchased from W. C. Kunzmann, who will be at the hotel several days before the Convention, or at the Registration Headquarters prior to noon on October 25. Only through your co-operation can the committee and hotel provide satisfactory accommodations for this function. Checks or money orders made payable to W. C. Kunzmann, Convention Vice-President, may be mailed to W. C. Kunzmann, c/o Hotel Statler, Washington, D. C., from October 18–25 for Luncheon and Banquet tickets. Advance reservations should be picked up at Registration Headquarters. Tickets for the Luncheon must be purchased in advance and there will be no refund for tickets not used.

Luncheon and Banquet fees will be announced in the Convention bulletin, published in the October Journal.

Convention Social Cocktail Hour

The Convention Cocktail Hour for holders of Banquet tickets will be held in the Hotel Statler on October 27 in the Congressional room.

Informal Banquet

The Convention informal banquet (dress optional) will be held in the Presidential Ballroom on the evening of October 27. At this time the annual Awards will be presented, and there will be dancing and entertainment.

Table reservations should be made at the Registration Headquarters. No tables for the Banquet will be reserved except for holders of tickets that have been purchased before noon of October 27, and there will be no refunds for tickets not used.

Ladies' Headquarters and Registration

The Ladies' Reception and Registration Headquarters will be located in the Potomac Room in the hotel, and open daily during the Convention dates, from 10:00 A.M. to 5:00 P.M. Mrs. Nathan D. Golden will serve the Convention as Hostess to the visiting and local ladies attending the 64th Semiannual Convention. The ladies' entertainment program will be announced in later released convention bulletins.

Motion Pictures and Recreation

The identification cards issued to registered members and guests will be honored at the following motion picture theaters in downtown Washington: Loew's Capitol, Loew's Palace, Metropolitan, RKO Keith, and Warner.

Literature and information will be available at the Registration Headquarters on the many places of historic interest in Washington and vicinity. The Convention recreational features will be released later by the local arrangements committee.

TENTATIVE PROGRAM

Monday, October 25, 1948

9:30 A.M.	Registration, Capitol Terrace Room. Advance Sale of Luncheon and Banquet Tickets
12:30 P.M.	Get-Together Luncheon, Congressional Room
3:00 P.M.	Technical Session, Presidential Ballroom
8:00 P.M.	Technical Session, Presidential Ballroom

Tuesday, October 26, 1948

9:30 A.M.	Registration, Capitol Terrace Room. Advance Sale of Banquet Tickets
10:00 A.M.	Technical Session, Presidential Ballroom
2:00 P.M.	Technical Session, Presidential Ballroom
3:00 P.M.	Business Session of the Society, Presidential Ballroom
3:30 P.M.	Resumption of Technical Session, Presidential Ballroom
	Open Evening

Wednesday, October 27, 1948

9:30 A.M.	Registration, Capitol Terrace Room
10:00 A.M.	Advance Sale of Banquet tickets
10:00 A.M.	Technical Session, Presidential Ballroom
	Open Afternoon
6:45 P.M.	Cocktail Hour, Congressional Room
8:00 P.M.	64th Semiannual Banquet, Presidential Ballroom

Thursday, October 28, 1948

	Open Morning
2:00 P.M.	Technical Session, Presidential Ballroom
8:00 P.M.	Technical Session, location to be announced later

Friday, October 29, 1948

10:00 A.M.	Technical Session, Congressional Ballroom
2:00 P.M.	Technical Session, Congressional Ballroom
5:00 P.M.	Adjournment of the 64th Semiannual Convention

Section Meeting

Cleveland Meeting

The June 18, 1948, meeting of the Midwest Section was held in Cleveland, Ohio, at the General Electric Lighting Institute at Nela Park. Seventy-five guests and members attended this all-day affair and about twenty-five ladies attended the dinner and a special evening program.

The doors were open at 9:30 A.M. and coffee was served during the registration period.

At 10:00 A.M. the group was divided into smaller sections to visit the Sundeck Gallery, Horizon House, store, office, and school. Expertly handled demonstrations illustrated the methods used in creating lighting combinations which were truly dramatic and functional as well.

At 11:30 A.M., R. T. Van Niman, chairman, called the meeting to order in the Auditorium. F. T. Bowditch gave a résumé of the Report of the Standards committee as presented in Santa Monica. Frank Carlson was called upon as the representative of our host, the General Electric Lighting Institute, and welcomed all to Nela Park.

Gordon Chambers reported on the Santa Monica convention. He began with a series of Kodachrome slides which were projected on a large screen showing the Del Mar Beach Club, the surrounding territory, and some prominent members of the Society of Motion Picture Engineers. Mr. Chambers then summarized a few of the papers presented at the 63rd Semiannual Convention. Also he reported the high spots in the group of color papers which were presented on the coast.

"The Engineering Aspects of Drive-In Theaters," by George M. Peterson, Cleveland, Ohio, was next presented by the author. It was revealed in this paper that there are approximately 800 drive-in theaters in this country with average capacity for 500 cars each. Mr. Peterson stated that many operators "build their theaters without any engineering assistance," a fact which he greatly deplored. Subjects covered in this paper were: traffic problems, grading, ramps, sound circuits, surfacing, and screen building.

At 1:00 o'clock one half of the group visited the Automotive Lighting Laboratory, and the other half visited the Optical and Photographic Laboratories. After luncheon, which was served in the Cafeteria, the groups were reversed for visits to the Optical and Photographic Laboratories and the Automotive Lighting Laboratory.

The meeting was resumed in the Auditorium, with R. T. Van Niman presiding, at 3:15 P.M.

"Practical Applications of New Photographic Techniques," by John Campbell, vice-president, Jam Handy Organization, was supplemented by an 800-foot reel of 16-mm pictures showing samples of the various techniques described in the paper. "Light Sources for Television Studio Lighting," was given by Richard Blount of the General Electric Company. M. D. Temple of the Brush Development Company presented his talk, "Some Applications of Magnetic Recording in the Motion Picture Field," from a reel of tape which was recorded a few days previously in his living room and edited to match the series of slides which were simultaneously projected. Boyce Nemec, executive secretary of the SMPE, gave

R. T. Van Niman, chief sound engineer for Motiograph, chairman of the Midwest Section, and in charge of the program, and Frank E. Carlson, General Electric Lamp Department illuminating engineer and host to the group.

Typical scenes at the General Electric Lighting Institute, Nela Park, where the Midwest Section of the Society of Motion Picture Engineers held its June meeting at Cleveland. Nearly seventy members were in attendance for the day portion of the program.

Frank E. Carlson lights a tiny grain-of-wheat lamp with a huge 50-kilowatt lamp for R. T. Van Niman and G. W. Colburn, president of the G. W. Colburn Laboratories and secretary-treasurer of the Midwest Section.

a rather complete report on "Flicker in Motion Pictures; Further Studies," by L. D. Grignon, Twentieth Century-Fox Film Corporation. This paper was presented at Santa Monica in May and was considered an important contribution to the art for design of future equipment.

At 5:15 P.M. the meeting adjourned for refreshments at the Coffee Bar for members, guests, and their ladies. This was followed by dinner, which was served in the Managers' dining room. The only speech was by Mr. Van Niman leading a rising vote of thanks to our hosts, the General Electric Lighting Institute.

At 7:00 P.M. a popular lecture by Alston Rodgers of the General Electric Company called, "New Horizons in Lamp Research," was given. This was a combination magic and vaudeville show with amazing stage props which was highly entertaining and enlightening to engineer and layman alike.

"A Gearless, Sprocketless 8-Mm Projector," by Otto R. Nemeth, included a demonstration of this new 8-mm projector following a discussion of engineering features. This projector without gears or sprockets is driven directly from motor to shutter and cam shaft with a belt. The lamp is 750 watts, lens $f/1.6$, one inch, coated, and the mechanism is built into a self-contained carrying case with total weight $12^1/_2$ pounds.

Mr. Nemeth then gave a brief description of "A Professional Wire Recorder for Studio Use." The complete paper was presented at the Santa Monica Convention. This machine features a magazine for handling the wire and automatic threading.

"The Optimum Performance of High-Brightness Carbon Arcs," was next presented by F. T. Bowditch and M. T. Jones of the National Carbon Company. The arc trim described is applicable to studio lighting. The 16-mm positive and 11-mm negative carbon holders are water-cooled jaws. Current at the crater is about 450 amperes. The light output is in excess of 40,000 lumens.

"Tungsten-Filament Sources for Picture Projection," by D. A. Pritchard, of the General Electric Company, dealt with photometric measurements of various places in the optical system of a group of competitive projectors. The measured results indicate output performance as a percentage of light output. The report clearly indicated that peak performance may be obtained from standard equipment if there is proper alignment of the tungsten filament.

"A Photometric Analysis of Picture-Projection Systems," by Edward E. Bickel of the Simpson Optical Manufacturing Company, was comprised of a mathematical and geometrical analysis of factors limiting the light output of motion picture projection systems. Based on mathematical values, performance results were computed that compared with actual laboratory test results. The formulas given establish limits beyond which it is physically impossible to go.

While the foregoing papers were presented, the ladies attended special demonstrations at "Horizon House" by Aileen Page and "Color and Indoor Sunshine" by Alston Rodgers.

Book Review

The Preparation and Use of Visual Aids, by Kenneth B. Haas and Harry G. Packer

Published (1946) by Prentice-Hall, Inc., 70 Fifth Avenue, New York 11, N. Y. 218 pages + XII pages + 6-page index. 167 illustrations. $6^1/_4 \times 9^1/_4$ inches. Price, $4.00.

Unique in a long procession of recent publications in the field of the preparation and use of audio-visual materials, this book provides a truly how-to-do-it approach. Tempered with enough of the philosophical to point out clearly the strengths and advantages, in terms of the learning process inherent to the use of the several mechanical divisions within the broad medium of audio-visual presentation, detailed explanation continues to show how in the local training situation the preparation of valuable teaching materials may be undertaken.

Designed primarily for use in personnel training, sales demonstrations, adult-education programs, and advertising, the book should find a use or place in the school professional library as well.

Stress is continually made that visual materials are to be regarded as necessary supplementing experiences to good training programs. Too often the impression is given that here is a "new broom." Rather, this book stresses the idea that *visual materials are not intended to displace but rather to improve and to supplement.*

The authors, Packer and Haas, have very methodically organized the discussion of the several audio-visual materials: motion pictures, filmstrips, slides, opaque projection, flash cards, maps, charts, posters, manuals, photographs, the blackboard, the bulletin board, the field trip, objects and specimens, and television. In each case they have ended the chapter considering the several materials with a detailed "how to arrange it," "how to do it," set of instructions regarding projection equipment and the production of the materials to be projected.

The book is well illustrated and includes numerous sketches and photographic examples to help the interested person to follow out the thinking and helpful ideas stressed in the book—indeed a valuable addition to the growing literature in this field.

W. A. Wittich
Bureau of Visual Instruction
University of Wisconsin
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FORTY YEARS AGO

Moving Pictures for Medical Students

In one of the New York hospitals moving pictures have been made of epileptic patients, as well as of persons affected with locomotor ataxia. This is following the example set in Vienna, where moving pictures have been made of celebrated surgeons performing critical operations. The purpose in both cases is, of course, to enable students and practitioners to study the peculiarities of diseases and the methods of distinguished operators.

—*The Moving Picture World, April 18, 1908*

Journal of the Society of Motion Picture Engineers

VOLUME 51 OCTOBER 1948 NUMBER 4

Subscription to nonmembers, $10.00 per annum; to members, $6.25 per annum, included in their annual membership dues; single copies, $1.25. Order from the Society's general office. A discount of ten per cent is allowed to accredited agencies on orders for subscriptions and single copies. Published monthly at Easton, Pa., by the Society of Motion Picture Engineers, Inc. Publication Office, 20th & Northampton Sts., Easton, Pa. General and Editorial Office, 342 Madison Ave., New York 17, N. Y. Entered as second-class matter January 15, 1930, at the Post Office at Easton, Pa., under the Act of March 3, 1879.

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Improved Safety Motion Picture Film Support*

By CHARLES R. FORDYCE

Eastman Kodak Company, Rochester, New York

Summary—Extensive experimental work on safety cine film support has resulted in an improved product which offers possibilities for professional motion picture use.

This product is a highly acetylated cellulose acetate with physical properties which are considerably different from those of ordinary commercial cellulose acetate previously used. Certain improved physical characteristics and improved aging properties of this base material are described in detail.

As a cine positive film support the high-acetyl cellulose acetate is shown to give satisfactory behavior in printing, processing, and projection operations and compares favorably with present standard release positive film.

Experimental studies on the use of the high-acetyl base for 35-mm negative film are described showing that this base will lend itself to use for negative materials. Particularly important is the fact that this base offers a very low degree of shrinkage on long time keeping.

The motion picture industry has for many years employed two types of film stock; one on cellulose nitrate base for professional use, and the other on cellulose acetate base mostly in widths of less than 35 mm. The requirement of safety for amateur film has made the use of acetate necessary in this field, regardless of its comparative qualities in other respects. An improved safety-base stock, made of a cellulose acetate propionate was adopted by the Eastman Kodak Company in 1937, and afforded physical properties midway between those of cellulose nitrate and the former acetate. The characteristics of these films were discussed in detail by Calhoun[1] in 1944.

The cellulose acetate propionate base was an improvement over cellulose acetate in many respects. It was less subject to brittleness at low humidities, and more resistant to dimensional change by moisture under varying conditions. During the war years of 1941 to 1945 this safety film gave very satisfactory service for many purposes, including theater use for short subjects. For rigorous professional motion picture use, however, this product fell somewhat short of requirements. Its comparatively low strength provided insufficient

* Presented May 17, 1948, at the SMPE Convention in Santa Monica.

wearing qualities and it lacked necessary rigidity for screen steadiness in projection with high-intensity lamps. For these reasons still further improvements, particularly in strength and rigidity of the base, were desirable.

In continued experimental work toward further improvements in safety base it has been found that of all plastic materials which have offered potential possibilities of better quality film support, the product most promising was a cellulose acetate selected in the range of higher degrees of acetylation than the product commonly used.

In the manufacture of cellulose acetate a hydrolysis step is usually employed to remove part of the acetyl groups and provide a material soluble in acetone. To gain this advantage in solubility the product is transformed from a strong, more rigid, very heat-resistant acetate to one more plastic. This is adverse to the basic requirements of good film support.

Cellulose triacetate, the product of complete acetylation of cellulose is soluble in only a limited number of organic solvents, and would be of doubtful success for motion picture film base because of the difficulty of splicing. Furthermore, casting procedures are difficult with this material, tending to give brittle film. By selecting an intermediate chemical composition, within the range of 42.5 to 44.0 per cent acetyl content, it has been found possible to retain the advantages of high physical strength and at the same time eliminate the problem of proper manufacturing quality and splicing behavior.

The chemical nature of these safety base materials is shown graphically in Fig. 1. The trilinear chart is used to show the relative chemical compositions of cellulose acetates and cellulose acetate propionates.[2] Cellulose acetates of different acetyl contents lie along the left boundary line of the triangle. Cellulose propionates are identified along the right boundary line. Within the area of the triangle are mixed esters of acetic and propionic acid. Cellulose triacetate (44.8 per cent acetyl) and cellulose tripropionate (51.8 per cent propionyl) are identified at points which mark complete esterification of the cellulose. Point *A* identifies the commercial acetone-soluble cellulose acetate used in safety base before 1937. The range *B* designates the material used in the present new safety-base development. Within the area of the triangle the point *C* identifies the cellulose acetate propionate used as Eastman Safety Base since 1937.

The new safety base has proved to be a useful improvement for both 35-mm and narrow-width motion picture films and is being used at the present time for some Eastman films. These include safety release positive film, in both 16-mm and 35-mm widths, as well as the 32-mm width film, later to be converted to 16-mm product; fine-grain duplicating positive film, type 5365, in both 35-mm and 16-mm widths; sound-recording film, type 5373, in both 35-mm and 16-mm widths; and high-contrast positive film, type 5363, in 16-mm width. In addition, the new base is being used for certain professional 35-mm duplitized-color positive films.

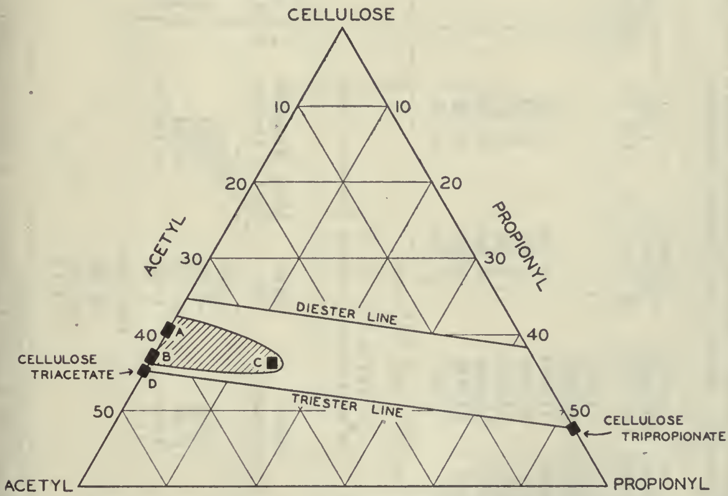

Fig. 1—Chemical composition of cellulose esters used in safety film base. *A*, acetone-soluble cellulose acetate; *B*, high-acetyl cellulose acetate; *C*, cellulose acetate propionate.

Careful evaluation of this base for 35-mm film indicates it should be suitable for professional motion picture positive and negative stock, for which cellulose nitrate base is now employed. The results of these tests are summarized in the following experimental sections.

PROPERTIES OF FILM BASE

Consideration of the physical properties of the film base will serve as a comparison of the high-acetyl cellulose acetate support with nitrate and safety products which have been in standard use (Table I). In these measurements both lengthwise and widthwise directions of the support have been included because of the slight difference in these two directions. In certain cases such differences may be of importance.

TABLE I

MECHANICAL PROPERTIES OF EASTMAN MOTION PICTURE POSITIVE FILM BASE
70 Degrees Fahrenheit, 50 Per Cent Relative Humidity

Material	Machine Direction	Tensile Strength, lbs/sq in.	Young's Modulus 10^5 lbs/sq in.	Cold Flow,* %	Flexibility (Schopper) Folds	Tear Strength (Thwing), gms
Acetate safety base before 1937	Length	11,000	...	...	7	42
	Width	11,000	...	...	7	46
Acetate propionate safety base after 1937	Length	11,900	4.42	0.62	15	50
	Width	10,400	4.02	0.83	16	57
High-acetyl safety base	Length	14,500	5.54	0.51	14	43
	Width	13,000	5.00	0.63	15	46
Nitrate base	Length	15,800	6.99	0.42	15	59
	Width	13,400	6.05	0.58	16	66

* Load = 3000 lbs/sq in.; time loaded, 7 days; recovery time, 24 hours.

TABLE II

PROCESSING OF 35-MM MOTION PICTURE POSITIVE FILM

	Before Processing	After Development	After Fix	Max. Negative Curl in Drying	Curl Change in Minutes	Curl Leaving Dryer	At Rewind
Curl, Inches	Inches		Inches	Inches		Inches	Inches
High-acetyl safety	0.00	0.00	+0.03	−0.04	2.8	+0.16	+0.03
Acetate propionate safety	0.00	0.00	+0.03	−0.04	1.8	+0.11	+0.08
Nitrate	0.00	0.00	0.00	−0.02	2.9	+0.12	+0.04
Shrinkage, Per Cent			Per Cent				Per Cent
High-acetyl safety	0.00	...	+0.28	...	..	...	−0.02
Acetate propionate safety	0.00	...	+0.42	...	..	...	+0.02
Nitrate	0.00	...	+0.14	...	..	...	−0.06

Processing Conditions

Speed, 60 feet per minute: Drying air temperature, 81 degrees Fahrenheit: Relative humidity, 35 per cent: Velocity, 950 feet per minute: Flow, 44 cubic feet per minute.

The tensile strength of the high-acetyl base is considerably improved over the former safety base and approaches that of the nitrate, indicating a corresponding increase in the mechanical wearing quality of the material. Flexibility is of importance in general handling behavior, and is in the same range for all three products. Tear values of the high-acetyl base are somewhat below those of cellulose nitrate and acetate propionate, and may be the cause of some concern if this property should prove to be critical. Young's modulus is a measure of the stiffness and rigidity of the support and is

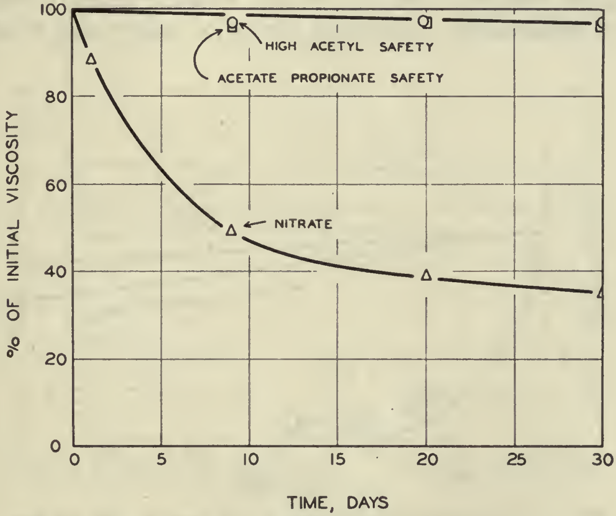

Fig. 2—Viscosity retention of film base at 100 degrees centigrade.

of importance in resisting temporary or permanent deformation. The high-acetyl base here shows appreciable improvement over the former safety base, and is somewhat inferior to the nitrate. Cold flow characteristics represent the tendency of the material to undergo permanent deformation under stress. Here again, the high-acetyl base lies midway between the other two products.

A further evaluation of the film base may be made by testing its permanence under accelerated aging. These tests involve heating samples for periods of time at temperatures above those which ordinarily would be met in standard use with the assumption that this severe condition will predict their behavior for much longer periods of time in normal use. No quantitative relation between accelerated and normal keeping times can be given. It may be pointed out, however, that a National Bureau of Standards test for Archive films[3] employs an incubation time of three days at a temperature of 100 degrees centigrade.

The chemical stability of cellulose derivatives is best measured by their resistance to viscosity degradation. Samples of film support may be incubated at elevated temperatures for periods of time after which they may be dissolved in suitable solvents and the viscosities compared with those of the same material before heating. Chemical deterioration results in loss of viscosity which is proportional to the degree of degradation. Viscosity curves of safety and nitrate film

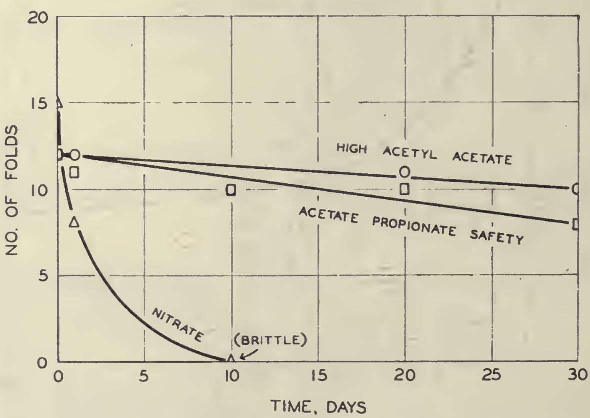

Fig. 3—Retention of flexibility of film base at 100 degrees centigrade.

support upon heating at 100 degrees centigrade for increasing periods of time are given in Fig. 2. It will be noted that the safety bases undergo this treatment with no appreciable chemical degradation, while cellulose nitrate rapidly and progressively decreases in viscosity. This comparative behavior is well known, and illustrates the possibilities of distinctly superior keeping qualities of cellulose acetate safety base.

Flexibility retention in accelerated aging tests at 100 degrees centigrade is shown in Fig. 3. Very little loss in flexibility up to 30 days at this temperature has resulted in either safety base, from which it may be predicted that very long times, under standard storage conditions, should be possible without difficulty. Cellulose nitrate support dropped rapidly in flexibility at this temperature, and became completely brittle within ten days.

As an indication of the retention of tear strength the curves of Fig. 4 give measurements of tear values of the three film bases after increasing periods of incubation. Although the high-acetyl safety base has somewhat lower initial tear values than the other products, the fact that there is little or no loss in tear strength under this very severe incubation indicates probable satisfactory behavior in film use. Cellulose nitrate support again deteriorates rapidly under this treatment.

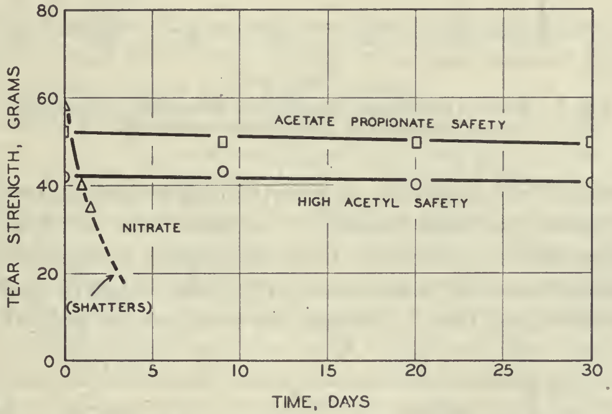

Fig. 4—Retention of tear strength of film base at 100 degrees centigrade.

An important property of motion picture film is its permanence of dimension upon aging. Results of accelerated shrinkage tests on the base at 100 degrees centigrade are shown in the curves of Fig. 5. It will be noted that the high-acetyl base here exhibits a lower order of shrinkage than either the safety or nitrate standard materials. Because of the severe temperature used in this test, a second series of shrinkage measurements were carried out at 71 degrees centigrade (160 degrees Fahrenheit) to confirm this shrinkage behavior (Fig. 6). Here again, the high-acetyl base exhibited a very low order of shrinkage as compared with the other materials. From these characteristics it may be predicted that the experimental base should give film of excellent aging shrinkage properties.

To summarize the physical properties of the base materials, the high-acetyl cellulose acetate is an improvement over former safety

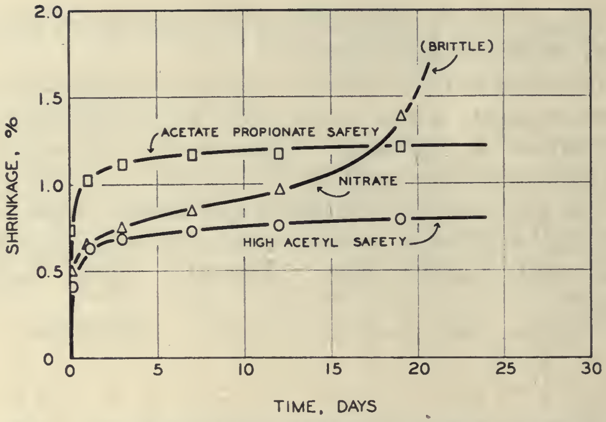

Fig. 5—Rate of shrinkage (lengthwise) of motion picture positive film base at 100 degrees centigrade.

base in most of its properties, and particularly in tensile strength and rigidity, which are most needed. Compared with cellulose nitrate, most properties are somewhat lower in original measurements, but permanence tests show that there is very little change in quality even under severe aging tests. Perhaps the most unique property of the

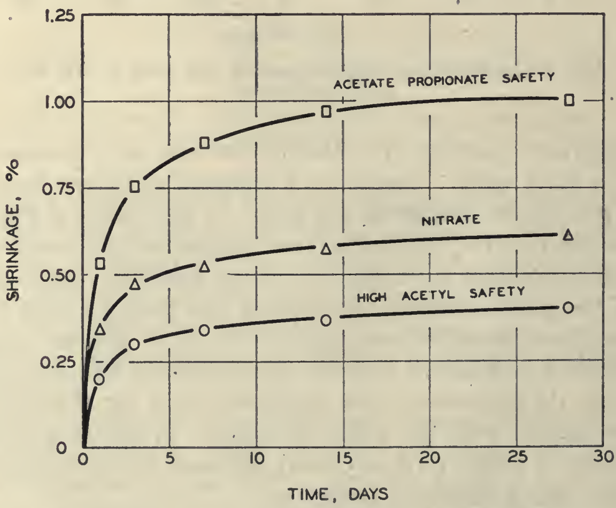

Fig. 6—Rate of shrinkage (lengthwise) of motion picture positive film base at 71 degrees centigrade (160 degrees Fahrenheit).

high-acetyl acetate is its exceptionally low shrinkage as compared with materials previously in use.

PROPERTIES OF CINE FILM

Proper evaluation of the experimental film base for cine products requires consideration of its use as both positive and negative stock. In the case of positive films, processing, printing, and projection behavior should be considered in detail. Negative products introduce the factors of camera behavior and proper shrinkage characteristics as additional important qualities.

Positive 35-Mm Film

Testing of positive 35-mm films was done by comparison with standard safety release print stock (5302) on cellulose acetate propionate base and nitrate release print stock (1302).

Processing Tests—An important factor in processing motion picture film is the degree of swelling which takes place in the developing step. If the longitudinal swell is too rapid or too great some processing machines encounter trouble from excessive slackness which allows the film to become displaced on the bottom rollers. Likewise, excessive swelling during development may result in correspondingly excessive shrinkage at the beginning of the drying operation. This has been a difficulty with previous safety films, not only because of the magnitude of swelling, but also because of the very rapid rate of shrinkage of the safety film upon drying, causing rapid building up of tension in a critical area. Of importance also is any tendency which the film may have to curl too highly negative (away from the emulsion) at the beginning of drying, or too highly positive (toward the emulsion) when completely dry.

Results of preliminary processing tests are summarized in Table II. The curl characteristics of the high-acetyl film will be seen to be of the same order as the standard check materials. A slight positive curl takes place after fixing which changes to a slight negative curl at the beginning of the drying operation. This changes again to a positive curl when leaving the drying cabinet, which returns to a very slight positive curl at the time of rewinding. The development shrinkage is also of small magnitude, and characteristic of present product. The lengthwise swelling of the experimental film during processing is 0.28 per cent. This is slightly greater than the type 1302 nitrate film, but less than the acetate propionate safety 5302 material.

The swelling and shrinkage behavior of these films may be seen in more detail in Fig. 7. Upon immersion in water the lengthwise swelling takes place quite rapidly for about 30 minutes then approaches a maximum value. The rates of shrinkage upon drying after 30 minutes' swelling are shown by descending curves. It will be seen that during the first ten minutes of drying the high-acetyl film shrinks 0.14 per cent, the nitrate 0.07 per cent and the acetate propionate safety 0.31 per cent. Thus, while the high-acetyl film exhibits an appreciable amount of swelling its comparatively slow

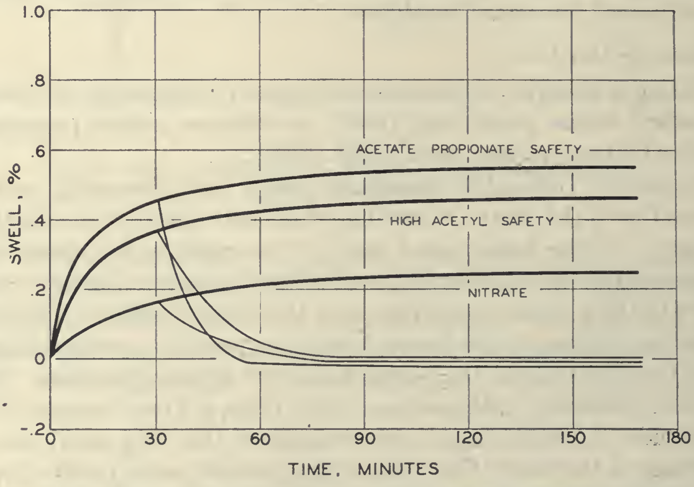

Fig. 7—Rates of swell in water at 68 degrees Fahrenheit (heavy curves) and rates of shrinkage upon drying at 70 degrees Fahrenheit, 50 per cent relative humidity (light curves) for positive films.

rate of shrinkage upon drying tends to reduce the possibility of excessive operating tensions.

Following these preliminary measurements extensive processing tests were carried out in two commercial East Coast Laboratories each test involving several thousand feet of film, to insure in so far as possible that the test represented stable continuous processing behavior. In these tests the experimental product proved to be satisfactory, giving no indication on any of the machines of greater tension than normal (Table III). Likewise, in none of the tests did the swelling during development cause difficulty from slackness.

Projection Tests—Evaluation of the projection quality of 35-mm positive film is probably the most important factor in the testing program. Many characteristics must be considered, and can only be

TABLE III

PROCESSING OF HIGH-ACETYL 5302 (35-MM) FILM

Tests in Commercial Laboratories

Laboratory	Machine Threading Length, Feet	Drying Conditions	Approximate Feet of Test	Film Curl at Rewind, Inch	Difficulties
A	1750	77°F.—42% R.H.	21,000	+0.09	None
B	2120	63°F.—60% R.H.	12,000	+0.14	None

determined by experimental projection under conditions of actual use. Preliminary tests of a laboratory nature were made in this investigation, and were followed by trade tests involving prints of several commercial feature pictures issued through selected film exchanges in different parts of this country.

Preliminary laboratory tests for physical behavior of the film involved continuous projection of short lengths of film for increasing lengths of time, followed by examination of the film for perforation damage and general appearance. A summary of the results is given in Table IV. It will be noted that slight perforation damage began to take place after about 200 projections for both the high-acetyl and the nitrate films, as compared with 100 projections for the acetate-propionate safety film. This became progressively more severe on all products until failure by complete perforation breakdown at 520 runs for the high-acetyl film as compared with 380 runs for the acetate-propionate safety and 644 for the nitrate. It should be emphasized that the numerical values of runs before failure are of significance only for comparative purposes, and do not necessarily indicate the number of runs to be expected in trade use.

Another type of laboratory test involved projection of rolls of the three types of film on a Simplex E-7 projector, with a projection throw of 157 feet to a screen 30 feet by 40 feet. Initial tests with non-rotating positive high-intensity arcs up to 65 amperes in mirror optical system lamps resulted in entirely satisfactory performance of all three types of film. A more severe test was then undertaken, using a rotating positive high-intensity arc (13.6-mm positive carbon) at 175 amperes in a condenser optical system lamp and employing an Aklo No. 3966 heat-absorbing glass filter. Certain characteristic differences in the films became evident in this test, as recorded in Table V. The acetate propionate safety 5302 film here showed

TABLE IV

WEARING QUALITY OF MOTION PICTURE POSITIVE FILM

Times Projected	High-Acetyl Acetate 5302	Acetate Propionate 5302	Nitrate 1302
100	A	B	A
200	B	C	B
300	C	D	B
400	D	Failure (380)	C
500	D	..	D
600	Failure (520)	..	D
700	..	..	Failure (644)

Condition of Film

A—No perforation damage
B—Damage in one perforation in a frame
C—Damage in two perforations in a frame
D—Damage in three perforations in a frame

considerable unsteadiness in focus,[4] and rather severe embossing after projection. The high-acetyl safety film and the nitrate 1302 were satisfactory and nearly identical in behavior. Upon examination after projection the high-acetyl film showed somewhat less embossing effect than the nitrate.

On the basis of the above background, indicating satisfactory behavior of the high-acetyl film for commercial use in regard to both

TABLE V

LABORATORY PROJECTION QUALITY OF CINE POSITIVE FILM

Arc Intensity: 175 Amperes

	High-Acetyl 5302	Acetate Propionate 5302	Nitrate 1302
Screen Quality			
Original sharpness and definition	O.K.	O.K.	O.K.
Focus drift	Normal	Excessive	Normal
Tendency to image flutter	Slight	Slight	Slight
Tendency to in-and-out of focus	Slight	Excessive	Slight
Film Appearance			
Frame embossing	Very slight	Appreciable	Slight
Image embossing	Very slight	Appreciable	Very slight

processing and projection behavior, it was decided to undertake trade tests with prints released in the regular manner for theater use. In these tests, which included four different features and a total of 22 experimental prints, each print was assembled with approximately half of the reels on the experimental stock and half on standard nitrate. The first two reels in each case were of one type of stock and the next two of the other, and so forth, to insure that each material would be used on both projectors in any theater.

Throughout these tests no difference was noted between any of the experimental and standard reels as regards condition of focus, steadiness on the screen, or general quality of either picture or sound. Likewise no detectable difference was noted in the tendency toward scratching. The conditions of the prints after completion of their trade use are summarized in Table VI. All films were comparable throughout in curl and in brittleness at low humidity. Shrinkage of the experimental film was consistently less than that of the nitrate stock. Likewise the tendency of the film to become embossed or buckled after long use was noted to be less in the experimental film. In perforation damage, no marked differences were evident, although the experimental films showed somewhat greater damage in areas of severe wear. This is in agreement with the preliminary projection tests, which indicated a slight advantage in mechanical wearing quality for the nitrate film, but is believed to be due in part also to the higher shrinkage characteristics of the nitrate, which give that material the advantage of more nearly fitting the projector sprockets.

The lower shrinkage values noted for the experimental film in these practical use tests are in agreement with the predicted behavior observed in the accelerated shrinkage tests (Figs. 5 and 6) and have been further confirmed by laboratory keeping tests of processed film under normal conditions (Fig. 8). Here the high-acetyl film will be noted to undergo a shrinkage of 0.20 per cent in one year as compared with 0.29 per cent for standard nitrate and a higher value of 0.46 per cent for film on cellulose-acetate propionate safety base.

It may be well to point out in connection with these trade tests that they were carried out while all theaters were using 0.935-inch-diameter intermittent sprockets. Because of the recently adopted change in standard to the 0.943-inch-diameter sprocket it may be expected that the new sprockets will soon replace the former in most theaters. This will be an advantage to films with low shrinkage characteristics, such as this experimental material, and should offer an improvement in wearing quality for high-acetyl cellulose acetate film even greater than that anticipated for film on nitrate base.

Splicing—The question of proper splicing behavior is one of importance for motion picture films. It was pointed out that the chemical composition of the cellulose acetate used in this film base is in a range of very limited solubility in organic solvents. This fact limits the formulation of effective cement mixtures to carefully chosen solvents, properly balanced to give good results with this specific product. For this reason it should not be expected that film cements designed for products previously in use should give good performance.

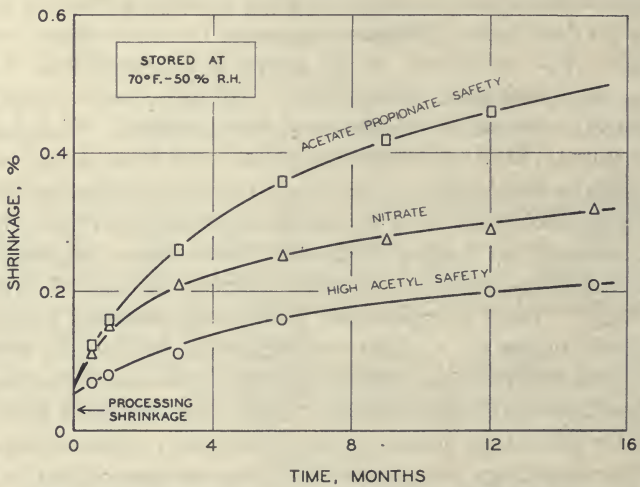

Fig. 8—Rate of shrinkage (lengthwise) of motion picture positive films. Individual developed strips were stored, freely exposed to circulating air, and shrinkage values calculated from the initial dimension of the raw stock.

It has been demonstrated, however, that properly formulated cements can be made without great difficulty, and suitable cements are now available for the purpose. With these the cementing properties of the new film are quite similar to those of other types of film with cements commonly used for them.

Proper splicing behavior must in all cases be qualified with the requirement that the emulsion be scraped properly from the film support in the area to be cemented. It is essential here to remove the bonding sublayer beneath the emulsion so that the cement solvents will have sufficient opportunity to attack the film base. This removal of sublayer is somewhat more critical on safety than on nitrate base, and

TABLE VI

THEATER TESTS OF MOTION PICTURE POSITIVE FILMS

Picture	No. of Prints	Av. Bookings	Approximate Runs		Humidity Curl, Inches — Relative Humidity 20%	50%	70%	Tear Strength 50% R.H., gms	Vise Brittleness,* 10% R.H., Inch	Av. Shrinkage, %	Perforation Condition†
A	2	34	320	Acetate	+0.08	−0.02	−0.01	44	0.033	0.11	A to B
				Nitrate	+0.08	−0.03	−0.01	55	0.030	0.32	A
B	2	35	280	Acetate	+0.07	−0.02	−0.02	44	0.034	0.11	B
				Nitrate	+0.10	−0.03	−0.02	56	0.030	0.32	A to B
C	9	22	290	Acetate	+0.03	−0.03	−0.05	44	0.026	0.18	B to C
				Nitrate	+0.08	−0.02	−0.07	53	0.028	0.36	A to B
D	9	24	280	Acetate	+0.04	−0.04	−0.06	44	0.025	0.17	B to C
				Nitrate	+0.08	0.00	−0.02	49	0.025	0.38	A to B

* Brittleness Test: Measurements indicate distance between two closing jaws at time film breaks.

† Perforation Condition: A, few light fractures; B, more numerous light and some heavy fractures; C, frequent heavy fractures.

should be understood properly by the operator. Duplitized cine films which carry emulsions on both front and back surfaces of the film, should be recognized as far more difficult to splice than single-coated films, and should receive special consideration in removal of sublayer coatings before cement is applied.

Negative 35-Mm Film

In general, mechanical properties which are necessary for positive film are also advantageous for negative. Its use on continuous printers, however, demands proper shrinkage characteristics to provide the necessary range of perforation pitch to give good printing quality. It is well understood that standard processing laboratory practice requires that negative films which are manufactured with the standard perforation pitch as raw stock undergo a shrinkage of at least 0.20 per cent for use as a negative on continuous drum printers.[5,6] A satisfactory range for good printing quality is usually considered to be a shrinkage of between 0.2 and 0.4 per cent. If shrinkage should exceed this range, however, the pitch becomes too short and again results in unsatisfactory prints.

These shrinkage characteristics of negative film have been controlled during manufacturing by allowing a small but controlled amount of solvent to remain in the support. As this escapes from the film during processing and subsequent storage of one to three months a corresponding shrinkage takes place.

A better way of meeting the requirements of negative film might be to employ a base of very low shrinkage properties and to change the standard of perforation so that the pitch will be optimum for printing throughout the life of the negative. For this to be successful the shrinkage upon aging would have to be exceptionally low, to maintain good printing quality on long keeping.

The low shrinkage characteristics of the experimental high-acetyl acetate base presented possibilities for such a product. To test this a set of experimental films was specially prepared, including both normal shrinkage and low shrinkage base, perforated to both standard and optimum pitch dimensions. These products are tabulated in Table VII. Sample *A* was made to correspond to standard nitrate negative (1231) in its shrinkage characteristics while samples *B* and *C* were made to represent low shrinkage films. This is shown by the "accelerated aging" measurements, which represent the degree of shrinkage which would normally take place over a considerable period of time. Sample *B* was perforated with a pitch of 0.1869 inch and sample *C* with a shorter pitch of 0.1866 inch to correspond to a shrinkage of 0.20 per cent.

Test rolls of each sample of negative film were exposed in a Mitchell camera and were processed by standard procedure. These were used to make prints on standard fine-grain release positive (1302) stock shortly after processing and at repeated intervals of time over a period of several months. Results of printing quality were found to be in agreement with pitch values at the time of printing. The results of shrinkage behavior are shown in Fig. 9. It will be seen that sample *A* reproduces in general the shrinkage behavior of the standard (1231) negative, sample *D*. Both of these negatives gave somewhat unsteady prints when printed soon after processing, but were satisfactory on later tests, by which time shrinkage had resulted in shorter pitch measurements. Sample *C*, on the other hand, corresponded to a shrinkage of 0.20 per cent when freshly processed because of perforation adjustment, and as a result gave immediate satisfactory printing quality. Also, because of its low shrinkage, it continued to give good printing quality after long keeping. As would be expected, the sample *B* with standard pitch perforations on low shrinkage base gave

TABLE VII

PHYSICAL CHARACTERISTICS OF EXPERIMENTAL NEGATIVE FILMS

Sample	Type	Shrinkage Level	Initial Perforation Pitch, Inch	Tray Processing Shrinkage, %		Accelerated Aging Shrinkage, %*	
				Length	Width	Length	Width
A	High-acetyl safety	Normal negative	0.1869	0.14	0.15	0.43	0.48
B	High-acetyl safey	Low	0.1869	0.06	0.05	0.16	0.18
C	High-acetyl safety	Low	0.1866	0.06	0.05	0.16	0.18
D	Nitrate 1231	Normal negative	0.1869	0.12	0.19	0.42	0.60

* Accelerated aging shrinkage: Normal development followed by incubation for seven days at 120 degrees Fahrenheit and 20 per cent relative humidity.

unsteady prints the first three months of the test period.

These results indicate the possibility of obtaining a satisfactory safety cine negative film either by standard perforation of stock duplicating present negative film in shrinkage characteristics, or by a properly adjusted perforation of stock employing low shrinkage base. The latter product may prove to be attractive to the industry because of its improved permanence characteristics and because of possible improved printing quality immediately after processing as well as after long aging.

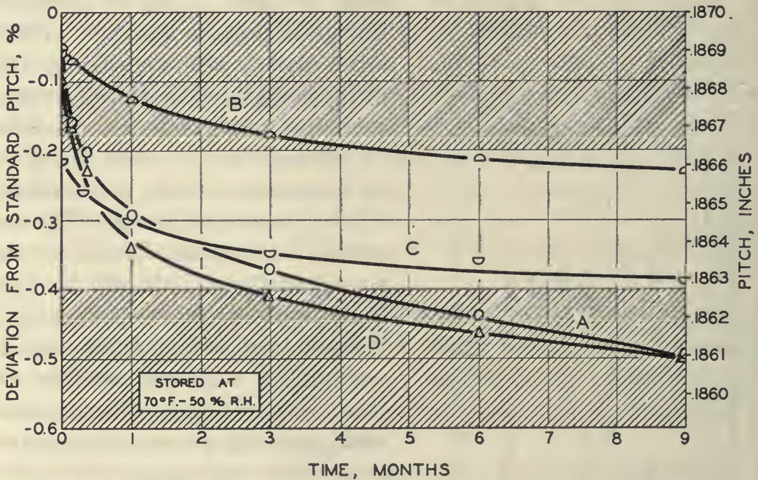

Fig. 9—Change in longitudinal pitch of developed motion picture negative films stored in rolls in untaped cans. Film rewound daily for first 30 days. *A*, high-acetyl safety base, normal negative shrinkage, initial pitch 0.1869 inch; *B*, high-acetyl safety base, low shrinkage, initial pitch 0.1869 inch; *C*, high-acetyl safety base, low shrinkage, initial pitch 0.1866 inch; *D*, nitrate base, normal negative shrinkage, initial pitch 0.1869 inch.

CONCLUSIONS

1. An evaluation of an improved safety motion picture film support, made from a high-acetyl type of cellulose acetate, has been presented.

2. The general physical characteristics of the high-acetyl acetate base are superior to those of former safety base materials, and are in the range of base from cellulose nitrate.

3. The properties of the new base have been confirmed by commercial tests of positive film in which satisfactory quality for professional motion picture use was obtained.

4. Laboratory tests on negative film have been carried out, which indicate probable satisfactory behavior. Low shrinkage characteristics of the high-acetyl acetate base offer the possibility of improved printing characteristics under proper conditions.

Acknowledgment

The author wishes to express his appreciation for the assistance and helpful suggestions received from many members of the Department of Manufacturing Experiments of the Eastman Kodak Company in the preparation of this paper.

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Discussion

Chairman W. V. Wolfe: Dr. Fordyce, I understand that your company is now putting out a universal film cement which is good for the old acetate and the new safety-base film. Is that correct, and do I also understand that you are no longer making available the old nitrate-base film cement?

Dr. Charles R. Fordyce: The first part of that statement is correct. We are putting out a film cement which we call Universal Cement for all types of film. I think I am right in stating that you are also correct in the second statement that we no longer supply the other, but I might be wrong.

Chairman Wolfe: I particularly ask that question because there has been some comment about the possibility that the Universal Cement was not so good for a nitrate-base film as the old nitrate film cement.

Dr. Fordyce: Yes, that is a question. Of course, as you know, in testing film cements, it is quite difficult to get more than two people to test them in the same way, and I do not really know what a majority opinion would be on the basis of these two cements. We like the newer cement in the tests we have run, and in our use, but maybe some of the trade would rather have the other cement.

DR. C. R. DAILY: Some years ago, we ran a series of pitch checks on release negative, starting with the first and printing from that negative, and then measuring successively 25, 50, and up to 300 prints during the release life of that negative. During that time the negative was aerated through the printer and rewound that many times, and pitch checks were made throughout the entire run to determine properties posted in the last slide that you showed, and to help determine the matter of initial pitch. Have you made live tests through a release print cycle for the aeration and pull on the negative to determine how the acetate film compares with nitrate?

DR. FORDYCE: We have given you all the shrinkage data that we have; in other words, keeping tests, but not tests made at intervals during actual use of that negative. Our data are only laboratory incubation tests. I think qualitatively that actual use data would have the same trend as our laboratory tests.

MR. K. B. LAMBERT: We have used some of this film recently, both with the long perforation and some specially perforated. We have had very successful results from the shorter perforations. With the longer perforations, we constantly encountered unsteadiness on all of the early prints. In fact, we never got away from it until we short-perforated the film.

The Research Council is at this time considering the possibility of recommending, in conjunction with Eastman, the shorter perforation of this type of film, because we are faced here with the problem of making the highest quality prints first, immediately after the negative is processed; then perhaps the negative lies idle for quite a while and some more prints are made, but if you can have a negative which can be printed over a very long period of time, and have both the first and last prints all good, it would seem to be very advantageous.

MR. G. J. BADGELY: As Eastman people are pretty well aware, we are interested in high-temperature development. What is the action of this film when it is subject to developing temperature of 125 degrees?

DR. FORDYCE: It is going to be a problem connected with the emulsion. We can say that this base is more resistant than former safety base but the degree of swelling in water is more than nitrate; if you increase the temperature, you have a higher amount of swelling. So far as I know, it is not high enough to interfere.

QUESTION: Would there be any elasticity added to the film as a result of the higher temperature? Has it a tendency to stretch under strain?

DR. FORDYCE: Yes, the higher the temperature, the softer it will be. In other words, it will be more easily distorted at the higher temperature but not so much so as prior safety films.

DR. J. G. FRAYNE: It seems a shame that we are still worrying about printing from antediluvian sprocket-type printers. Instead of spoiling a fine job, why does not the whole industry do something about the printer situation?

CHAIRMAN WOLFE: Dr. Fordyce cannot very well answer that question, nor for that matter, can anyone else answer for the industry. We agree with you, Dr. Frayne, that it would be a good idea to improve our printers as they stand today.

Color-Television Film Scanner*

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Summary—The transformation of moving color-film images into video signals is accomplished with the most faithful rendition when the pickup tube is of the continuous-cathode, or nonstorage type. This, however, imposes the limitation that the film motion, in the associated film scanner, be constant in velocity, rather than intermittent. In the color-film scanner of the Columbia Broadcasting System, the pickup tube is the Farnsworth daylight image dissector. An optical-electronic method, requiring no moving optical parts, is used to compensate for the continuous motion of the film.

The Columbia Broadcasting System postwar system of color television was put into operation in January of 1946. At first, the color-television pictures had their origin in 16-mm color film and 2-× 2-inch color slides. In the spring of the same year, the live pickup camera and equipment were completed and put into use.

Commencing with a brief review of the basic characteristics of the entire system, the remainder of this discussion will concern itself with a description of the methods involved and problems encountered in scanning the color film and slides. Particular attention will be paid to the design and function of the optical, mechanical, and electronic equipment involved in the process of transforming moving color-film images into video signals.

The fundamental property of the system is one of sequential, additive-color scanning, in which the subject matter is analyzed into three primary-color impulses of varying amplitudes following each other in sufficiently rapid succession to be integrated by the observer's eyes. Rotating color disks, one in front of the pickup device and one in front of the receiving tube, properly synchronized and phased, produce the color analysis at the transmitter and the color synthesis at the receiver. The color images are scanned horizontally in 525 lines, interlaced 2 to 1, and interlaced fields are scanned vertically at the rate of 144 per second. Each field, of $^1/_{144}$-second duration, is scanned and reproduced in succession through a different primary-color filter, so that the three color fields are presented to the viewer in $^1/_{48}$ of a second, a sufficiently short interval of time to allow the

* Presented May 10, 1946, at the SMPE Convention in New York.

eye's property of persistence of vision to give an apparent fusion of the separate colors into their resultant additive mixture.

The film pickup tube is the Farnsworth image dissector with a daylight photoelectric characteristic. Its property of nonstorage photoemissivity makes the dissector particularly suitable for color use, since there is no stored charge on the unscanned interlaced lines to be carried over from one color field to the next to produce spurious color values. Another distinct asset is its inherent freedom from shading effects. These two important characteristics of the daylight dissector account, to an enormous degree, for its fidelity of color rendition.

The light source is a Peerless Hy-Candescent high-intensity carbon arc operated at 175 amperes. This is necessitated by the low sensitivity of the dissector and by the transmission loss in the color filters. Although the daylight dissector has been especially adapted for color work by improved response in the visible spectrum, it still has appreciable sensitivity in the near infrared. Since the red, blue, and green filters transmit freely in the infrared, this unwanted radiation must be removed by suitable filters if color contamination is to be avoided. A water cell containing a disk of heat-absorbing glass of the desired characteristic is inserted in the carbon-arc beam between condenser and gate aperture and is effective in transmitting a high ratio of visible light to total radiant energy. For valid color reproduction it has been found that the proportion of infrared response must not exceed more than 5 per cent of the maximum signal in the dissector output. However, since dissector tubes vary somewhat in their spectral response, provision has been made to insert elsewhere in a cooler part of the light beam an additional heat filter, if necessary, to bring the infrared content below the permissible maximum level.

Optical System

Of greatest interest, perhaps, will be the optical system. Before describing this, it may be well to discuss first the factors instrumental in determining the choice of system to be used.

The image dissector, as has been mentioned before, is a tube with an instantaneous photoemissive, or nonstorage, type of cathode. As such it imposes one basic limitation upon the type of projection equipment to be used with it; that is, the film cannot be intermittently projected upon the cathode. This restriction is caused by the shortness of the vertical blanking interval; $^1/_{1440}$ of a second. Whereas, with a storage type of tube the film can be projected during this short interval of time and then at relative leisure be pulled down in the film-gate aperture during the remaining $^9/_{1440}$ of a second, with a dissector tube the film would have to be treated in the converse manner, i.e., projected during the $^9/_{1440}$ of a second scanning period and then pulled down during the $^1/_{1440}$ of a second blanking period. This, considering the masses and acceleration of the film and pulldown mechanism involved, is an impracticably short period of time and obviously rules out all consideration of intermittent projection.

There are several well-known methods of continuous projection some of which have undoubted merit.[1,2] All involve the use of one or more optical elements, i.e., lens, mirror, or prism, actuated or driven by cam, wheel, or drum, to compensate for the displacement of the continuously moving film. It was felt desirable to avoid the use of a number of precisely adjusted optical elements driven by precisely machined mechanical members. It was also felt that most of the optical errors inherent to these types of optical displacement compensation, or inherent to the means employed to actuate them could be avoided. A method of optical compensation was employed which had earlier been used successfully at CBS in the transmission of black-and-white film.[3] The optical elements are six in number and consist of segments of simple achromatic doublets. They are entirely stationary, easily adjusted, and remain permanently fixed in position. The only rotating component is purely mechanical in function—a rotating slotted selector disk which exposes the lens segments one at a time. Since the electronic scanning process, as will be pointed out, is also instrumental in offsetting the movement of the film, this may be termed an optical-electronic method of film-movement compensation.

Since the film is moving at the rate of 24 frames per second and must be scanned at the rate of 144 per second, it is apparent that each frame must be scanned six times. This means that each frame will be completely scanned as it moves a distance equal to one sixth of the perforation pitch. Fig. 1 is a simplification of the action that takes place.

The heavy arrows represent frame *A* occupying successive positions after each $^1/_{144}$ of a second interval as it moves down through the gate at constant linear velocity. (For the sake of clarity the arrows are shown slightly displaced to the right in each position.) At the start, frame *A* is in position *1* in the top of the gate, its lower five sixths (the heavier portion of the arrow) exposed. After $^1/_{24}$ of a second it has

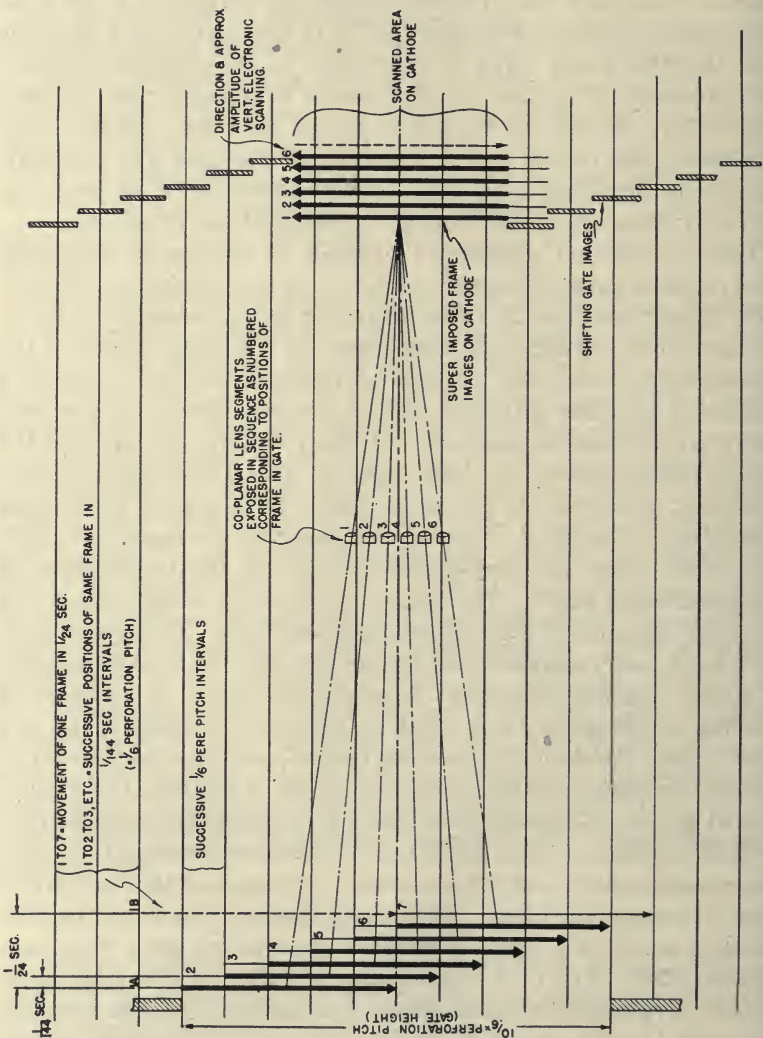

Fig. 1—Function of lens segments.

moved to position *7* in the lower part of the gate, and has been scanned six times in the interim; frame *B* now stands in position *1* ready to repeat the cycle. It will be seen from the diagram that the height of the gate aperture must be equal to $1^2/_3$ times the perforation pitch.

Corresponding to each of these six positions of the frame in the gate is one of six lens-segment projection elements. These lens segments are arranged in a common plane normal to the main optical axis, with their centers in a straight line parallel to the direction of travel of the film. Each lens is so adjusted that it lies on the straight line joining the center of the scanned area on the cathode with the center of the lower five sixths of the frame in each position in the gate. In effect then, these lens segments are projecting upon the cathode sucessive overlapping images of the gate aperture, each displaced by an amount equal to one sixth of the perforation pitch. If, now, each lens segment is exposed alone for the time during which the frame is moving across the corresponding part of the gate, it will project upon the common scanned area of the cathode an image of the frame moving upward one sixth of the perforation pitch in $^1/_{144}$ of a second. This moving optical image can then be scanned by deflecting its corresponding electronic image in an opposite direction over the physical scanning aperture at the other end of the dissector tube.

It should be borne in mind that the optical image on the cathode is not stationary, but is moving upward for one sixth of the perforation pitch, repeating this for every vertical scanning period over the identical portion of the cathode. The effectual immobilization of the image is brought about by the action of the vertical scanning in a direction opposite to the image movement, i.e., the over-all vertical scan is the resultant of one sixth upward motion of the image and five sixths (or less) downward motion of the electronic scanning. The expression "or less" is used here because it is obvious that a resultant vertical scan of one perforation pitch is a little more than is usually desired and would allow the frame line to be seen. In practice, the vertical-scanning amplitude is adjusted to a value slightly less than five sixths of the magnified perforation pitch (more exactly, five sixths of the perforation pitch less the difference between the perforation pitch and the standard projector gate aperture height) to give a scanned picture height equivalent to the standard projector gate aperture height.

Because of the geometry of the optics wherein six points spaced 0.050 inch apart (this is equal to one sixth of the perforation pitch of

0.300 inch) are focused to a common point, it is obvious that the six projection-lens elements would have to be extremely small to avoid mutual physical interference. In practice, a standard projection lens is employed to form an enlarged virtual image of the gate aperture, so that the center-to-center spacing of the projection elements now becomes of practicable dimensions. This is shown in Fig. 2, where for clarity, a simple plano-convex lens replaces the standard projection lens. In this diagram, a frame is shown in the No. 2 position in the gate with its enlarged virtual image projected through the No. 2 lens segment upon the scanned cathode area. The No. 2 lens segment is exposed through one of six slits in a rotating selector disk. These slits are concentric, adjacent arcs of 60 degrees and of differing radii, so that each slit exposes its associated lens segment at the proper time. The selector disk is driven at 24 revolutions per second by a synchronous motor, thus exposing the six lens segments in order every $^1/_{24}$ of a second. Since the selector disk must be synchronized with the film movement in order to have each lens segment exposed at the appropriate time, the motor frame is mounted so that it may be phased manually.

The size of the selector disk is determined by the ratio of blanking-to-total-vertical-scan period; in this case, 1 to 10. Therefore, if the radius of the innermost slit is made such a value as to give the slit a length equal to 10 times the lens segment effective aperture length, the optical change-over will occur wholly within the blanking period. Allowing for the radial increments of the five other slits plus a small guard rim, the selector disk is 29 inches in over-all diameter. It is completely enclosed within a housing, and driven by a $^1/_4$-horsepower, 3-phase, 1800-revolution-per-minute synchronous motor, through a 5-to-4 reduction gear box, with complete absence of vibration. This latter point is of importance where extremely fine optical registration is to be maintained.

Lens Segments

The derivation of the lens segments may be understood by reference to Fig. 3. Each segment is originally a fully formed, cemented achromatic doublet of 14-inch focus and $1^3/_4$-inch diameter. From each, the limb on each side of the optical centerline is cut or ground away until a segment of the desired thickness remains. It is evident that these lens segments of rectangular aperture will transmit more light than equivalent circular lenses of small-enough diameter to

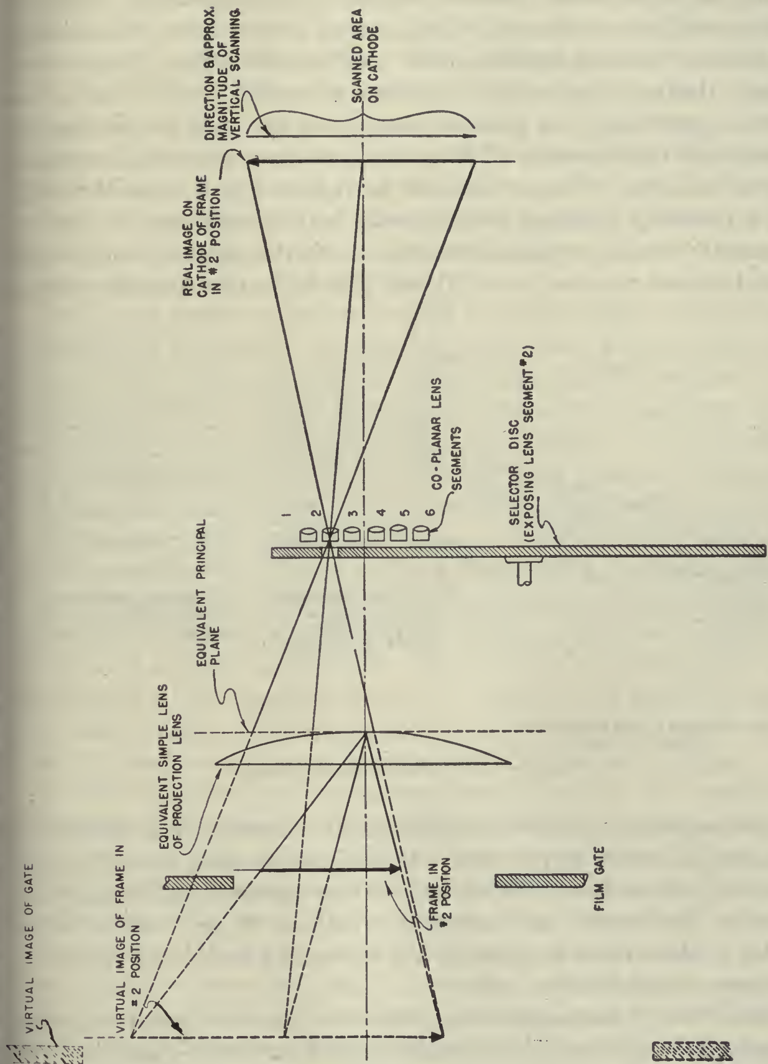

Fig. 2—Optical projection through a lens segment.

maintain the same spacing. The maximum lens segment center-to-center spacing for the optical constants involved is about 0.140 inch. Allowing 0.010 inch between segments for adjustment purposes, this would leave a narrow, fragile piece of glass only 0.130 inch thick, if the lens were cut symmetrically with respect to the optical centerline. However, by cutting the lenses unequally on each side of the optical centerline, it is possible to maintain the same center-to-center spacing of the segments while at the same time materially increasing their thickness. This is shown on the right of Fig. 3 where the degree of asymmetry increases progressively with the distance of the lens segment from the common centerline. By this means the lens thickness has been increased to 0.160 inch, thus imparting a sturdier quality

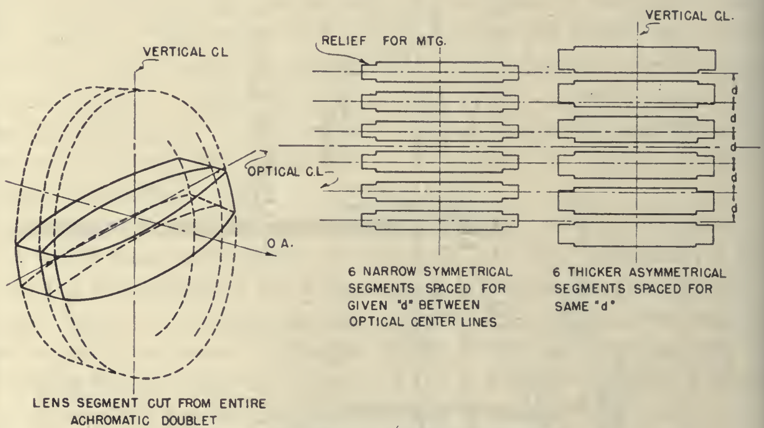

Fig. 3—Derivation of lens segments.

to the segments, and more important still, increasing their light transmission by about 20 per cent. In addition to their strongly asymmetrical cut, as shown, the top and bottom segments, not being as confined as the interior ones, actually are about 50 per cent thicker in order to allow them to transmit still more light and thus improve the average signal-to-noise ratio.

Since the six lens segments are to form six superimposed congruent images, it is necessary, for the sake of good resolution, that their real magnifications match very closely. Since the real magnification is closely dependent upon the focal length, this parameter must be controlled carefully in manufacture if satisfactory coincidence of images is to be obtained.

If it is assumed that the images are to agree in size within $\pm^1/_2$ of a picture-line pitch, and if the centers of the images are made to coincide exactly, then the greatest disagreement will be at the extreme top (or bottom) where the picture lines will fall within $\pm^1/_4$ of a picture-line pitch, which is quite satisfactory. For a 500-line picture, a tolerance of $\pm^1/_2$ of a line pitch is equivalent to a tolerance in the magnification of ± 0.1 per cent. In this instance, the focal length is 14 inches and the real magnification is 0.43 times. From the fundamental relationship among focal length, magnification, and image distance, the permissible variation in focal length turns out to be ± 0.010 inch, or a percentage variation of ± 0.08 per cent. This can be achieved in good optical practice.

Three other properties required of the lens segments for satisfactory coincidence of images are freedom from curvature of field, negligible distortion, and good color focus. Curvature of field is reduced to a negligible minimum by good design aided by the long focal length and narrow angle of projection (a maximum of 2 degrees for the top of a frame entering the gate aperture, or the bottom of an exiting one). Distortion has been found to be almost entirely a function of the projection lens forming the virtual image. A high-quality projection lens will introduce no noticeable distortion. If the projection lens is also well corrected for color and if the lens segments have been achromatized for the *C* and *F* lines, the color focus of the combination is found to be entirely satisfactory. In addition, the projection lens should have a wide aperture to avoid vignetting of the upper and lower frame images. The Bausch and Lomb $f/2$, $4^1/_2$-inch focus Super-Cinephor lens has been found satisfactory in all the above respects.

In order to realize fully the accuracy with which the lens segments are fashioned, it is necessary that they be mounted in such a manner that they may be carefully adjusted for accurate optical alignment and then rigidly and permanently fastened in place. A mounting relief, $^3/_{16}$ of an inch deep, ground into the ends of the segments, is utilized for fastening. Fig. 4A is a view of the lens-segment mount in position, with the selector disk shown behind. A sturdy brass aperture plate forms the basis of the mount and an arrangement of small metallic holding members and screws permits the individual segments to be adjusted vertically and horizontally and then clamped rigidly in place.

The actual alignment of the lens segments is accomplished in the following manner. A reel, or loop of film, of a suitable geometric resolution pattern is run through the scanner with the selector disk properly phased, and the resolution pattern is reproduced upon the picture monitor. In front of the lens segments, a slotted aperture frame (shown in Fig. 4B) receives masks containing rectangular apertures of different sizes and combinations so that the lens segments may be exposed singly or in combination. First, the No. 4 lens, lying just below the optical axis of symmetry, is exposed and the dissector electronic equipment is adjusted for normal picture-scanning amplitudes and optimum electronic focus. Then the dissector optical focus is adjusted by longitudinal racking of the dissector-tube mount until the image seen upon the picture monitor is

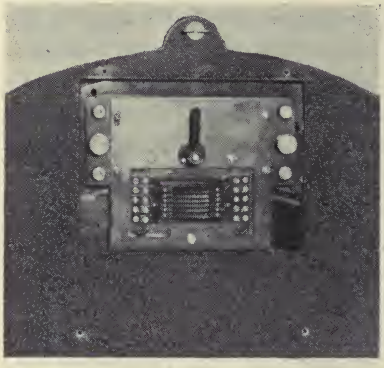

Fig. 4A—Lens segment mount in position.

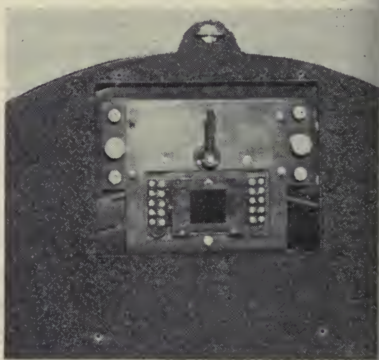

Fig. 4B—Aperture frame and fixed, segmented, tricolor filter.

in best focus. The dissector tube is left in this position during the remainder of the alignment while each lens segment is adjusted in turn with respect to the No. 4 lens segment so that the images exactly coincide. By this method, coincidence of the six images can quickly be obtained to within a fraction of a line pitch in both the horizontal and vertical directions.

The light efficiency of the optical system is unavoidably low, since the $f/2$, $4^1/_2$-inch focus projection lens is in effect stopped down by the six lens segments to an average rectangular aperture of 0.180×1.375 inches. The diameter of the equivalent circular aperture is 0.560 inch. Since the front element of the projection lens is almost completely filled with light and since the light beam has diverged only slightly when it falls upon the lens segments, the effective relative aperture of the complete system may be considered to be the ratio of 4.5 inches to 0.56 or about $f/8$.

Nevertheless, despite the light lost in heat and color filtering as well as through the restrictive lens segments, the light flux incident upon the scanned portion of the cathode, an area equal to $1^1/_2 \times {}^7/_8$ inches, is in the order of 4 lumens. This is sufficient to give a signal having an acceptable signal-to-noise ratio.

Fig. 5 is a schematic view of the entire optical system. Here are shown the carbon-arc source, condenser, water cell, and heat-absorbing filter. Following these in order are the components of the film-scanning portion—negative field lens (to be explained later) film gate, projection lens, optically polished auxiliary heat filter, selector disk, lens segments, a fixed segmented tricolor filter, and the dissector tube. It will be noted that there is no rotating color disk in this portion of the film-scanning optical system. In its place and performing the identical function of inserting sequentially in the light beam the three primary-color filters, the fixed segmented tricolor filter is used. This can be done because the lens segments are exposed sequentially and are six in number while the primary colors are three in number. Thus each lens segment is associated with a given primary color which it is called upon to transmit to the exclusion of the other two primary colors. The color order of the lens segments from top to bottom is green, red, blue, green, red, blue. The fixed tricolor filter consists of six rectangular strips of green, red, and blue Wratten gelatin filter arranged in the corresponding color order and cemented between two squares of optically polished glass. This composite filter is held in place by means of a fixed aperture plate, close to the lens segments, so that each segment transmits its own associated color. The three primary color filters are green No. 58, red No. 25, and blue No. 47. In Fig. 4B, the tricolor filter is shown in place over the lens segments, with the individual colors somewhat indistinguishable in a black-and-white photograph.

For color-slide projection a 45-degree plane, chromium-plated mirror is swung into the arc beam in front of the water cell to deflect the light through the slide-projection components. An auxiliary condenser lens, another 45-degree mirror, and a field lens serve to relay the arc beam and illuminate the aperture of the 2- × 2-inch slide carrier. From this point the light passes through another optically polished heat filter and then through the color filters of a synchronously rotating tricolor disk. The filters are six in number and arranged to

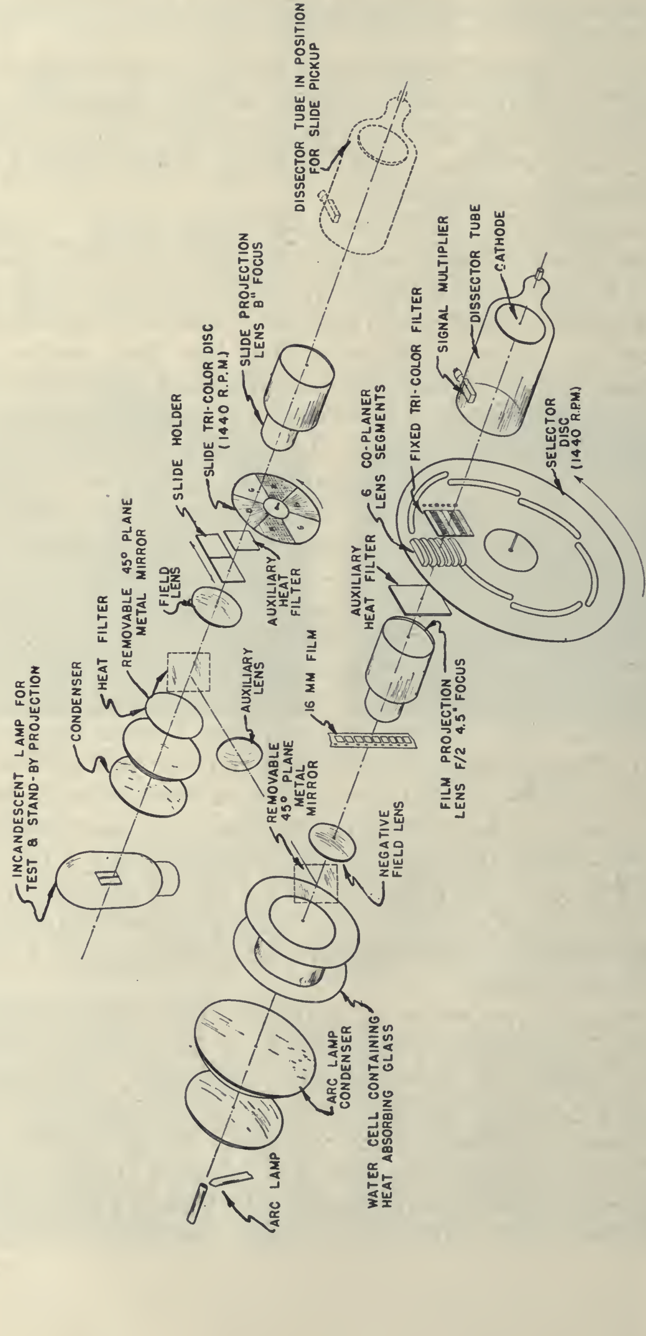

Fig. 5—Schematic of entire optical system.

give exposure in the red, blue, green order. The disk rotates at 1440 revolutions per minute so that each filter exposes the beam for $^1/_{144}$ of a second. A Kollmorgen 8-inch-focus projection lens projects the slide image onto the cathode of the dissector tube which can be moved over to line up with this new axis of projection. Whenever a black-and-white image is needed for test purposes, an auxiliary light source, using a 500-watt incandescent lamp and condenser, can be cut in by swinging out the second mirror. Since the color disk is not needed for this latter purpose, a hinged mounting on the disk-and-drive structure permits it to be swung aside out of the light path.

Film-Shrinkage Compensation

As with all types of continuously moving film projectors, some method must be employed to compensate for film shrinkage. The necessity for this is evident upon consideration that the distances between the centers of the six lens segments in the vertical direction have been permanently fixed and correspond to certain definite distances between the centers of successive frame positions in the gate. For another film, of less or greater shrinkage, these centers of successive frame positions will no longer correspond with the fixed lens segments, center-to-center distances, with the result that the superimposed images, although still remaining in sharp focus, will no longer coincide. To restore this coincidence of images, it is necessary only to refocus the *f*/2 projection lens slightly in or out, and thereby diminish or enlarge the virtual image of the frame just sufficiently to realign the successive virtual frame position centers with their corresponding lens-segment centers. This adjustment, while restoring coincidence, also alters the focus, which, however, is regained by shifting the real image plane, i.e., the dissector tube, longitudinally. The result is exactly coincident and sharply focused images for any degree of film shrinkage encountered.

Published data[4] and our own experiences have indicated that a range of 0 to 1.5 per cent shrinkage should be accommodated. The projection-lens barrel is calibrated directly in film shrinkage over this range, for both the standard and the nonstandard emulsion positions. Calibration practice consists in making the initial lens-segment-spacing adjustment, which has already been described, with a test film of measured shrinkage in the gate. This shrinkage is then marked on the lens barrel opposite a fixed reference point. Several other test films of different shrinkages are then run through the scanner, and for each the projection lens is focused and the dissector mount readjusted to give an image on the picture monitor tube having the sharpest focus and the best coincidence. Each shrinkage setting is marked on the lens barrel and the determination of four such points is sufficient to allow a smooth curve to be drawn for the interpolation of additional shrinkage settings.

In operation, the shrinkage of the film to be run is measured before

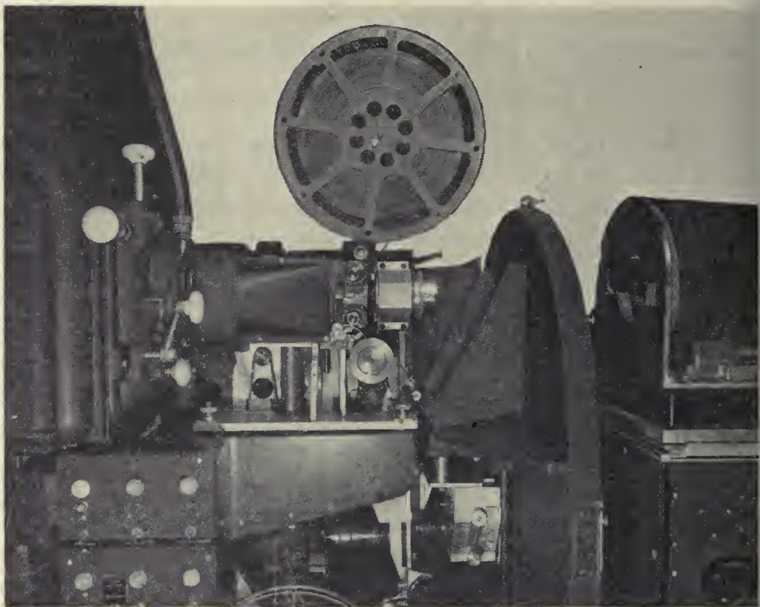

Fig. 6—Side view of film scanner.

threading and the projection-lens barrel is preset to the corresponding shrinkage. Then, while the film is being scanned, the dissector-tube mount is adjusted for best resolution of the monitor image, whereupon optimum image coincidence and focus are simultaneously achieved. Because the depth of focus of the projection lens combined with the lens segments (the real magnification is less than unity and the effective aperture is $f/8$) is large compared with the permissible shift of the projection lens as far as image coincidence is concerned, small changes of shrinkage in the body of the running film can be accommodated by a slight refocusing of the projection lens. This always brings the images back to exact coincidence leaving the focus substantially unchanged.

Film shrinkage is most easily, and with sufficient accuracy, determined by measuring the length of a given number of sprocket holes with a scale and dividing by the number of frames to obtain the average perforation pitch. It is convenient to use 39 sprocket holes and a 30-centimeter scale. This makes actual counting of the sprocket

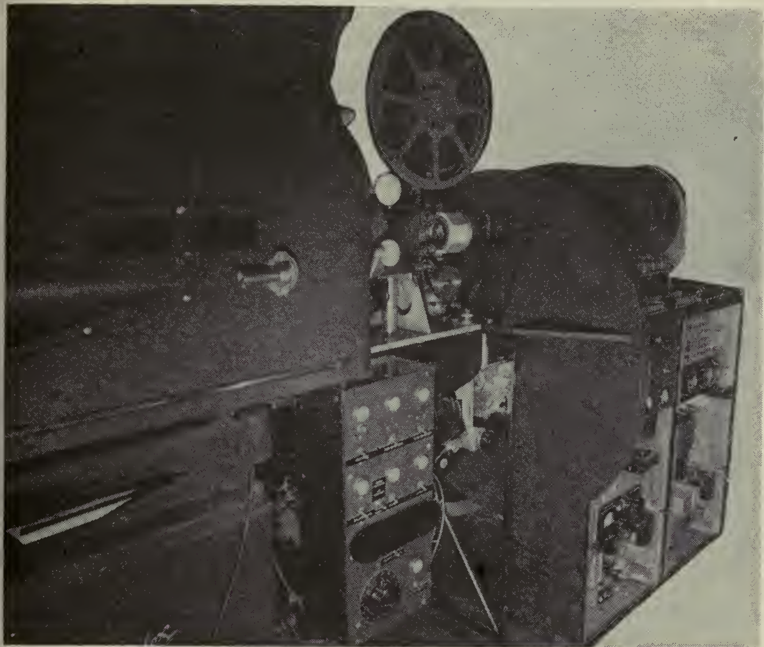

Fig. 7—Film scanner and dissector electronic scanning equipment.

holes unnecessary, since the 39th hole will always fall between 293 and 297 mm for a 0 to 1.5 per cent shrinkage range. The measurement can then be left in millimeters per 39 frames, or transformed to per cent shrinkage by subtracting from and dividing by 297 mm, the nominal length of 39 frames of unshrunk film.

FILM-DRIVE MECHANISM

Figs. 6, 7, 8, and 9 are views of the complete scanning equipment. On the left of Fig. 6 is the front of the arc lamp containing the water cell. In the center is the film-drive mechanism, and associated with it the upper and lower reel holders, projection lens, selector disk and lens-segment housing, selector-disk drive and manual phaser, and the control panel. On the right is the dissector-tube housing containing the tube and the scanning and focusing coils. The small knob beneath the dissector mount in Fig. 7 is for optical focusing and moves the tube mount longitudinally. The table-type rack beneath the dissector mount contains the electronic equipment for operating the dissector, namely, power supplies, scanning generators, and associated equipment.

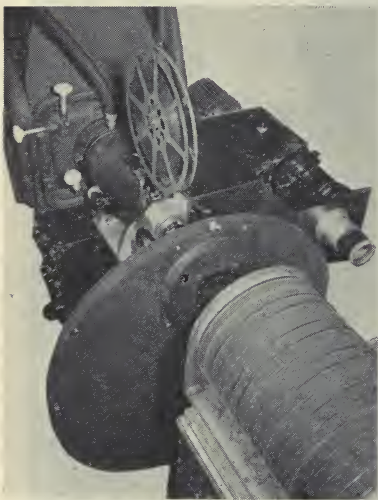

Fig. 8—Front view of film scanner.

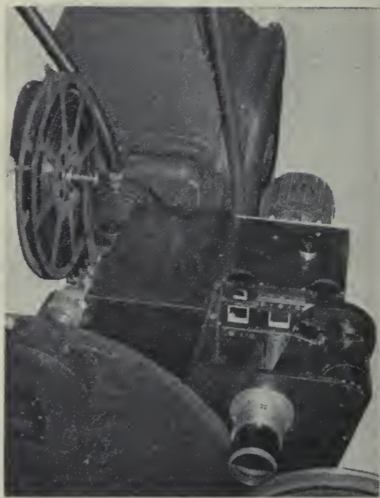

Fig. 9—Slide-scanning components.

Fig. 6 is of special interest in that it reveals the origin of the mechanism for pulling down the film at a constant rate of speed. When design of the film scanner was first begun, serious consideration was given to the possibility of adapting some existing commercially available 16-mm sound-film projector to television-film scanning. Of several models examined with this end in view, the Ampro Premier No. 10 projector was selected as being the most conveniently adaptable from the constructional standpoint. The soundhead assembly was retained in its original form while the rest of the projector was modified by removing the intermittent pull-down mechanism, the shutter drum, and the motor drive and blower. Only that portion containing the pull-down and take-up sprockets and the associated gear train was retained. Around this as a nucleus, the rest of the film drive was designed.

As shown in Fig. 6, a Maurer precision sprocket for constant-speed film drive is built in just underneath the film gate. This sprocket is driven through a mechanical filter consisting of a 10-inch flywheel, spring coupling, and suitable damping. These are shown in Fig. 10,

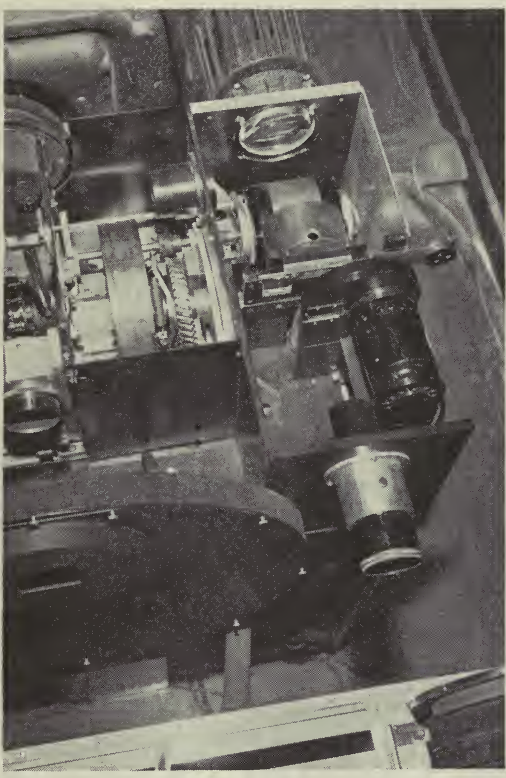

Fig. 10—Mechanical filter for constant-speed sprocket.

which is a top view of the scanner with covers removed. Although the speed of the sprocket is low, being only 3 revolutions per second, the mechanical filter is extremely efficient in smoothing out any fluctuations in the drive that might tend to be imparted to the film motion, and the images are gratifyingly steady. The inherent 24-cycle-per-second sprocket modulation normally introduced by the sprocket teeth has been minimized by suitable sprocket design, and there is no observable impairment of optical resolution from this source.

The motive power is furnished by an 1800-revolution-per-minute synchronous motor coupled to the constant-speed sprocket assembly through a 1:1 right-angled spiral gear drive and a 10:1 worm and worm gear. A motor-shaft extension engages directly with the Ampro gear train to drive the pull-down and take-up sprockets. This arrangement effectively isolates the constant-speed sprocket behind its mechanical filter and frees it from any motional irregularities introduced by the remainder of the mechanism. For picture framing, the motor shell can be rotated manually in its support by means of a long shaft and a knob located conveniently on the front of the scanner.

Also shown in Fig. 10 are some of the components of the slide projection system, the auxiliary condensers, slide holder, color disk and drive, and the stand-by incandescent-lamp source. An air blast for cooling the film and slide gates and the dissector tube is obtained from a central blower beneath the scanner and linked to those points through manifold and air-hose connections.

Flicker

The flicker to be discussed here at length is that which has its origin in the optical characteristics of the film-scanning system and not the flicker arising as a function of the field-repetition rate and the brightness level at the receiver.

Regarding the latter, however, this much will be mentioned as of general interest. The CBS prewar system of color television was based on a field repetition rate of 120 per second. This permitted a high-light brightness at the receiver of 2 foot-lamberts for just perceptible flicker. Postwar investigations indicated the desirability of a higher field-repetition rate, and when this was raised to the present 144 per second, a high-light brightness at the receiver of 9 foot-lamberts was obtained. Subsequent changes in receiver-filter characteristics have enabled the receiver-flicker threshold to be raised to a value of 20 foot-lamberts.

It might seem, from a review of the basic optical design of this type of film scanner, that flicker would be rather a vexing problem. This conclusion might, quite naturally, be drawn upon consideration of two innate characteristics of the optical system. First, successive images of a frame in successive portions of the film-gate aperture are, in effect, superimposed in projection on the photocathode. Should the gate aperture be nonuniformly illuminated, corresponding areas of the image may go through a cyclic variation in brightness and cause a 24-cycle-per-second regional flicker. Second, in performing their function of consecutively projecting a frame as it occupies different portions of the gate aperture, the lens segments must successively select different portions of the cross-sectional area of the light beam. If the light beam is nonhomogeneous, or if one of a pair of lens segments transmits light unequally, again there may be a periodic variation in the brightnesses of the superimposed cathode images, evidencing itself this time as an over-all 24-cycle-per-second flicker. (The lens segments are paired in the sense that the first and fourth are filtered to transmit only green light; the second and fifth, red light; and the third and sixth, blue light.)

It follows then, that the solution of the flicker problem depends upon two requirements. First, that of securing adequately uniform distribution of illumination in the gate aperture over its full height (equal to approximately 10/6 × perforation pitch of 16-mm film, or 0.500 inch) and second, that of obtaining equivalent transmissions of light through both lens segments in a pair.

The first requirement, that of adequate uniformity of gate-aperture illumination, is fairly easily met by the fact that the 16-mm gate-aperture dimensions (even though extended of necessity to 0.500 inch in the vertical direction) are less than those of a 35-mm film aperture, for use with which the arc-lamp condenser was designed. In addition, a negative field lens (whose function is of greater importance in enabling the second requirement to be met) behind the gate aperture permits a more enlarged crater image, so that by proper refocusing of the arc condenser a compromise between light intensity and light distribution can be effected in which the gradient of illumination from the center of the aperture upward and downward is not large enough to introduce any regional flicker as the images of a frame in the different gate positions coregister on the cathode.

The second requirement, that of obtaining equivalent transmissions of light through both lens segments in a pair, too, has not offered great difficulty. The negative field lens inserted behind the gate aperture has a focal length of 145 mm. The effective focal length of the combination of this lens with the $4^1/_2$-inch-focus projection lens is such as to project into the plane of the six lens segments a reduced image of the front surface of the forward arc-lamp condenser lens, and of a circumference closely circumscribing the total rectangular area of the six lens segments. Thus, while also insuring the maximum relaying of light through the lens segments, the homogeneity of the cross section of the light beam in this plane is considerably improved. Although this would give substantially equal transmissions of light through lens segments of equal areas, it should be recalled that the top and bottom lens segments have been intentionally designed to have appreciably greater area than the other segments. As has been pointed out earlier, the top and bottom lens segments do not have the spacing restrictions that are of necessity imposed on the interior ones. Consequently, these outer segments have been made with a 50 per cent greater area in order to increase the average light transmission and thereby improve the average signal-to-noise ratio. To exploit this situation fully, it is necessary that some means be employed to convert the repetitive light pulses of unequal level into resultant signal pulses of equal level. The mechanism to be described accomplishes this by a form of automatic gain compensation synchronized with the sequential exposure of the lens segments that permits the equalization of the magnitude of any pair of lens segments' light-to-signal conversion simply by adjusting the corresponding knobs on a control plane while the actual film-scanning process is under way.

A rotating switch arm attached to a shaft rotating at the synchronous speed of 1440 revolutions per minute sweeps over six contacts fixed at the periphery of a manually adjustable disk. Each contact is connected to its own flicker-control potentiometer and the six potentiometers are shunted across a common stage of the electron multiplier in the dissector tube. With the equipment in operation but with no film in the gate, with the selector disk running and light falling through the lens segments to focus the gate-aperture image on the cathode, the contact disk is phased by hand until the switching change-over falls wholly within a vertical blanking period (as shown upon either the wave-form or the picture monitor) and is then clamped permanently in place. It can be seen that the gain of the multiplier stage during a given color field now will depend upon the resistance of only that potentiometer which is connected across it for the duration of that color field.

If the wave-form monitor sweep frequency has been adjusted to give three color fields, it will be noted that each color field consists of two fields superimposed (two green, two red, and two blue). Since each of the six flicker-control potentiometers affects the level of its corresponding color field only, it is then a comparatively simple matter, while observing the wave-form monitor, to adjust the paired color-field amplitudes until the two components of each pair are equal and at a maximum, whereupon equal and maximum signal amplitudes for the paired lens segments of each color will have been derived. For slide transmission, the flicker-control potentiometers are switched off since they need not then, of course, be used. Once this adjustment has been made, no further flicker adjustment is thenceforth necessary, barring excessive maladjustments in the carbon-arc trim or condenser alignment.

Color mixing is accomplished in a somewhat similar manner, with the difference that the response through both of a pair of lens segments (instead of through each individual lens segment) is varied simultaneously and automatically. Color mixing means, simply, varying the ratios of red-to-blue-to-green signal levels. Although the color-filter chromaticity and transmission values have so been selected that normal color reproduction (with also the widest possible range of colors and color saturation) will be obtained when the red, blue, and green signal levels are equal, there often arises the need for altering these ratios either to achieve a more pleasing effect or to compensate for color-balance deficiencies in the film. A second rotating switch arm attached to the flicker-control switch arm shaft and space-phased to it sweeps in like manner over six contacts. These six contacts are connected diametrically in pairs and each pair is connected to its own color-level-control potentiometer.

The three color-level-control potentiometers are shunted across a second common stage of the dissector-tube electron multiplier. When proper phasing has been obtained the levels of the red, blue, and green signals can be varied independently from zero to a maximum simply by turning the corresponding knob on the color-control panel.

Other controls on the color-mixing panel include the usual brightness-level control, a master gain control which varies the red, blue, and green signal levels simultaneously without altering their ratios, and a gamma-correction control for varying the contrast distribution of the entire system.

An interesting feature of the film scanner is that it is not uniquely a color-television standards device. Provision, in fact, has been made for a quick change-over in a matter of minutes from color to the Radio Manufacturers Association standard black-and-white transmission. Should that be desired, it is only necessary to replace the six lens segments holder with one containing five lens segments adjusted for a

$^1/_5$ perforation-pitch interval of 0.060 inch of a center-to-center spacing of 0.168 inch. The six-slit selector disk is also replaced with one containing five slits arranged in a 1, 3, 5, 2, 4 order (instead of the consecutive order as in color transmission). Then with the gear-box transmission shifted to 720 revolutions per minute the selector disk rotates at the proper speed to allow a frame to be projected and scanned, as it moves $^2/_5$ of a perforation pitch, in $^1/_{60}$ of a second, giving 5 scans of 2 frames in $^1/_{12}$ of a second, or 60 fields per second.

Although the foregoing description may have created an impression of delicacy and complexity in the function of the CBS color-television film scanner, it must be emphasized, in concluding, that in two and one half years of constant use, this film scanner has given quite definite proof of the practical nature of its design. During this time it has given dependable and consistently satisfactory results as a transformer of moving color-film images into video signals, with no more than the normal amount of operating adjustment and maintenance required of any piece of studio equipment. Several similar scanners have since been built, and in every case the requisite optical, mechanical, and electronic precision and dependability have been easily reproduced.

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FORTY YEARS AGO

The Future

The future of the moving picture machine is a theatrical problem.

Some theatrical men believe that it will prove a serious competitor of the vaudeville. They suggest the time when the phonograph will work with it, and the best act of the newest New York comic opera will be flashed on the screen and sung out of the phonograph.

Others, and probably these are right, say that the picture machines have hit their highest notch.

—*The Moving Picture World, January 4, 1908*

35-Mm Process Projector*

By HAROLD MILLER and E. C. MANDERFELD

Mitchell Camera Corporation, Glendale, California

Summary—**A studio type of process projector, designed and built to meet the specifications as set forth by the Motion Picture Research Council Committee, is described. Both the single- and the triple-head projectors are discussed.**

The Mitchell background projector as supplied to most of the major studios is an outgrowth of a development originally started about 1934. Previous to this time, as well as during the period up to now, background projectors have been for the most part semi-experimental laboratory-type machines built up by studio technicians from various odds and ends available from the studio camera shop.

The present projector design is based on the recommendations as stated in the Academy specifications entitled "Recommendations on Process Projection Equipment," published in February, 1939, by the Process Projection Equipment Committee of the Research Council of the Academy of Motion Picture Arts and Sciences. The Research Council report showed the need for process projection equipment that could be used on the sound stage without the use of blimps or portable projection rooms to contain the noise of the equipment, that would be portable on a suitable dolly and movable to various stages, that could deliver the maximum light possible with a modern optical system, and that could project an absolute steady picture.

The following is a description of the various components that constitute the complete process projector which meets these requirements.

Projector Head

The projector head is composed of a vertical drive shaft and four driven cross shafts coupled by helical gears and held in accurate alignment by oilite bearings. The cross shafts drive two 32-tooth sprockets, the movement, and the 180-degree rear shutter. This mechanism is enclosed in an invar steel housing, and is lubricated by grease of 2500 to 3000 viscosity through three Zerk fittings. The unit is

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

mounted in an aluminum case which is fitted with the necessary idler rollers to guide the film to and from the sprockets and the magazines.

The Mitchell compensating link camera movement, Fig. 1, is used in the head to provide pilot registration pins necessary for "rock-steady" projection. The movement is modified for process projection by placing the claw and operating mechanism below the aperture away from the light beam and heat. The removable back plate and register plate are open between the film tracks to release condensation of moisture from the film and to eliminate the possibility of scratching. The movement is provided with an adjusting screw to adjust for shrinkage, and also to adjust for minimum film noise while running both forward and backward.

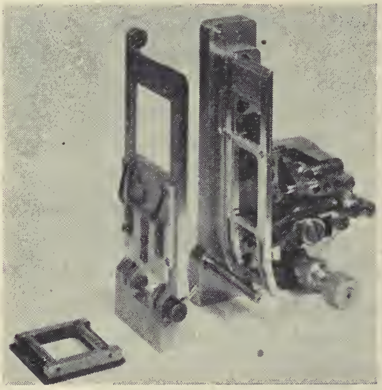

Fig. 1—Projector movement.

The movement is coupled to the head by a key coupling which can be engaged in only one position thereby insuring that the movement is in time with the shutter. The movement position is set by a dowel pin to keep the necessary alignment between aperture and optical elements, and is locked in place by thumbscrew clamps. A dummy aperture is used in place of the movement to align the optical system and check screen illumination. Both movement and dummy apertures accommodate mattes of Academy and Standard apertures.

Upper and Lower Magazines

As shown in Fig. 2, the upper magazine is mounted on top of the head and the lower magazine bolts to the back of the head. The magazines are 13 inches inside diameter, giving ample hand room when using 1000-foot reels or spools. They are lined with corduroy-velvet for protection to the film. The magazine doors are fitted with 8-inch windows, thereby providing a full view of the film passing through the head. Both magazines are equipped with adjustable overriding clutch, felt friction disk take-up drives. Also there are adjustable pull-down brakes inside of the magazines to provide the proper film tension for running forward or backward.

LENS MOUNTING

The lens mount bolts on to the front of the projector head. It has a $5^1/_2$-inch diameter opening to accommodate $f/2.0$ lenses from 4 to 8 inches focal length.

The lens mount is equipped with jackets to hold various focal-length lenses. The jackets are slipped in the lens mount and are held in place by a retaining pin. The lenses are easily changed by lifting the knob on the retaining pin, removing the jacket, and inserting another.

The lens mount has a manual focusing knob at the operating side and a Selsyn receiver motor for remote control from the camera position.

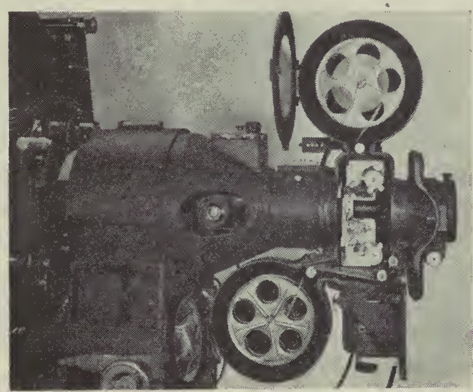

Fig. 2—Projector head and light tube.

REMOTE-FOCUSING CONTROL

The remote focusing of the objective lens on the background screen is practically standard procedure in most studios for several reasons. First, the correct focus position is that whereby the projected image looks best as viewed from the camera position. Second, while the set is being prepared for the next "take" it is quite customary for the lighting crew to set up and test the various lights. This light, when falling on the background screen, for the most part, makes it difficult and at times practically impossible to see the image on the screen from the projector position.

Several methods or means for remote focusing were considered. The method adopted was the use of Selsyn motors. Essentially it consists in interlocking two single-phase Selsyn motors, one of which is mounted as a receiver in a manner to actuate the focus of the projector objective lens, and the other one at the remote focusing point which is used as the transmitter. The latter motor shaft is provided with a small handle so it can be rotated manually in either direction and thus through the electrical interlock rotate the lens-actuating motor.

The remote-focusing motor is encased in a housing having a convenient handle for carrying the motor about on the stage. Because of its general appearance it is commonly referred to as the "beer mug." A push button is incorporated in the carrying handle which first must be pressed down in order to excite the two motors electrically. This is a safety device to prevent accidental movement of the projector lens by inadvertent movement of the "beer-mug" rotating handle.

HEAD MOUNTING

The complete projector head, magazines, and motor are coupled by means of a ring coupling to an aluminum casting, Fig. 2, commonly known as a light tube. This permits the projector to be revolved about its optical axis. An adjustable worm gear controls the rotation 15 degrees each side of vertical. However, by rotating farther, thereby disengaging the worm from the gear, the projector head can be revolved to any position within 125 degrees each side of vertical. The head is locked in place by a clamping screw on the coupling ring.

The relay lens (described in more detail later), Fig. 3, is located in the light-tube casting behind the projector head. This unit is mounted with the necessary controls so that it can be adjusted horizontally, vertically, and axially for focus. The condenser lenses in the arc house have a similar set of controls.

The relay lens holder is a hard, chrome-plated, aluminum casting and is provided with a 2-inch space between the two elements. This space is filled with boiled distilled water for the purpose of removing much of the heat in the condenser-light beam.

To remove the heat from the distilled water, ordinary tap water is circulated in a hollow space around the periphery of the relay lens holder. This circulating water also passes through the cooling jacket in the Mole-Richardson lamp, then to a vertical flow-type radiator located under the lamphouse. The radiator unit includes a four-bladed fan driven by a $^1/_4$-horsepower, direct-current motor. This motor circuit is interlocked with the lamp control in a manner which makes it impossible to operate the arc unless the cooling fan is running.

The fan operates normally at 1700 revolutions per minute, but drops to a reduced speed when the projector driving motor switch is on. This procedure reduces the noise level during a "take."

Also included in the radiator unit is a circulating-water pump direct-connected to a small alternating-current motor. This motor circuit is also interconnected in a manner to prevent the lamp from being operated unless the circulating motor is operating.

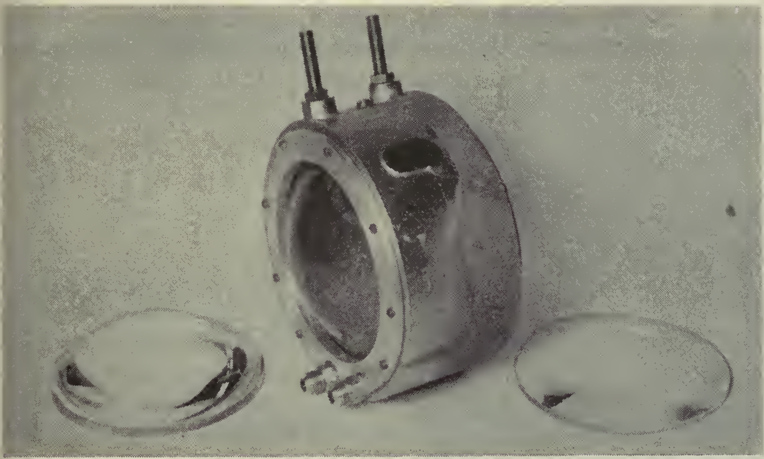

Fig. 3—Relay lens.

CONDENSER OPTICAL SYSTEM

For background projection work it is very essential that the screen illumination be adequate, uniform across the screen, and of the proper color quality. To achieve all three of these characteristics requires a somewhat more complicated optical system than normally used in theater projectors.

In the development of our optical arrangement, the previous art on condenser systems as developed by Bausch and Lomb, Technicolor, Paramount, and others was investigated. From the literature covering this art, it appears that the basic ideas underlying such optical systems are not too new, and it seems that most of the recent improvement is due to more careful designing and the use of more precisely made optical parts. In Fig. 4, it may be seen that the Mitchell system makes use of a relay lens (already mentioned) used in conjunction with a standard condenser unit with a collecting angle of nearly 90 degrees. An image of the arc crater is projected by the two-element condenser to an image point located at *A*. This enlarged image is again focused by means of the relay lens at a point *B* which in general is close to the rear surface of the projector objective lens.

In transferring the crater image from point *A* to the objective lens, an interesting intersection of light rays takes place which is of prime importance to the quantity as well as the quality of the screen illumination. Starting at point *3* of image *A*, three rays can be traced through the relay lens, through the film aperture and to point *3* of image *B*. It should be particularly noted that these three rays pass

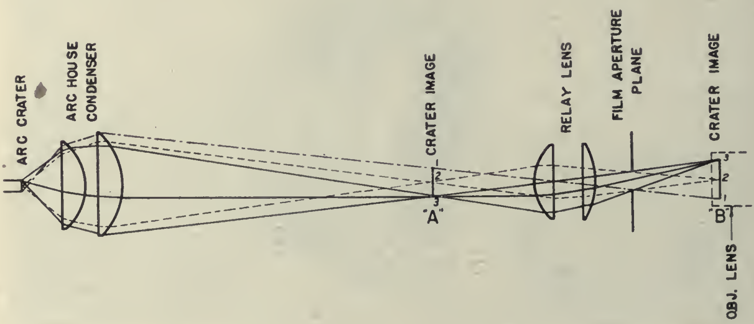

Fig. 4—Condenser-lens optical schematic.

through the film aperture at the top, center, and bottom. In other words, the light emanating from point *3* of image *A* covers the entire area of the film aperture. If now a similar bundle or cone of light rays is traced from point *2* of image *A* to point *2* of image *B*, it will be found that as before this point radiates a light cone which covers the entire film aperture. Thus every point of the image plane *A* will individually cover every portion of the entire film aperture. The resultant effect is a uniform light intensity over the entire area of the film aperture regardless of the light uniformity of the image source at *A*.

In tracing the light rays back from the image plane *A* to the arc crater, another interesting feature may be observed. Starting at point *3* of image *A* it should be noted that the lower ray intercepts the larger condenser element very nearly at the rim and progresses through the other condenser element to the upper edge of the arc crater. The central ray from point *3* passes through the condenser element at a point approximately in the center, whereas the upper ray passes through the condenser element close to the outer rim. Thus point *3* of image *A* is for practical purposes illuminated from rays emanating from the entire surface of the condenser element.

In a similar fashion, if one traces a series of rays from point *2* of image *A* to the arc crater one will find that the illumination of the center point of the image at *A* also depends on the entire surface of the condenser element. All this can be summarized by saying that this optical system is so designed that it will provide very uniform illumination over the aperture area and in addition makes effective use of all the light that can be picked up by the condenser system.

FIRE SHUTTER

An automatic fire shutter, Fig. 5, is located behind the relay lens in the light-tube casting, and is mounted from the top of the casting. The shutter unit is composed of a cast-Inconel dowser blade to withstand the heat of the light beam. A direct-current solenoid holds the shutter open when energized through a circuit controlled by the fire-shutter governor. The governor unit includes the necessary adjustments to operate the fire-shutter solenoid when the projector motor reaches 700-revolutions-per-minute speed. It releases the shutter when the motor speed drops to 600 revolutions per minute, thus protecting the film from the excessive heat of the arc. A handle is also provided for manually operating the fire shutter, thereby enabling the projectionist to flash the light on the screen without the necessity of running the projector.

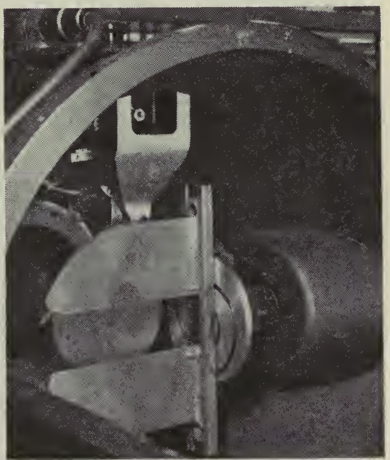

Fig. 5—Variable aperture and fire shutter.

A variable-light aperture of cast Inconel is mounted in the light-tube casting immediately behind the governor-controlled fire shutter. This aperture is controlled by an eccentric coupled to an operating knob on the outside of the light tube. An indicator dial is provided to allow accurate setting of the light aperture.

Variation of the light aperture does not affect the uniformity of the light intensity on the film and therefore the arc carbons can be burned at the maximum amperage consistent with good operating efficiency and steadiness of light.

ARC LIGHT

The light source is a Mole-Richardson Type 250 arc lamp designed and built for the Mitchell Camera Company. The details of the construction and operation of this lamp have been covered in this JOURNAL for July, 1947, in a paper entitled "Recent developments of super-

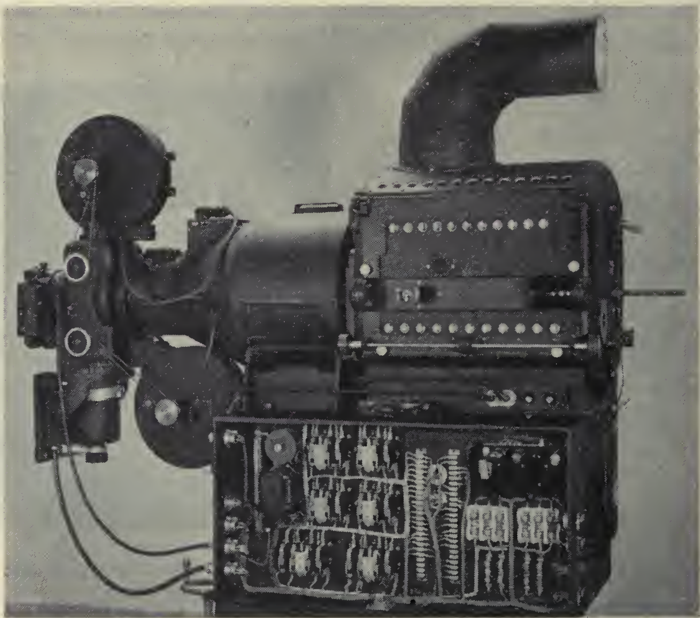

Fig. 6—Electrical control box.

high-intensity carbon-arc lamps," by M. A. Hankins. As described in this paper, the lamp is used in conjunction with a ballast grid and automatically maintained at the proper operating position by a photoelectric control system, thereby insuring very constant operating characteristics without the necessity of constant vigilance on the part of the projectionist.

ELECTRICAL CONTROLS

The electrical-control-circuit layout for the background projector is based on the general over-all requirements as requested by several studios. In general, the circuit arrangement allows the projector to run either forward or backward in interlock, or "wild." In an emergency all the leads to the driving motor can be broken simultaneously. The actual switching is done by Leach relays which in turn are under control of heavy-duty snap switches.

All electrical connections are brought into or out of the background projector unit by means of Cannon plugs. Consequently it is a relatively simple matter to replace complete assemblies or to disconnect power supplies for routine maintenance. All important circuits are supplied with fuses to eliminate the danger of equipment overload.

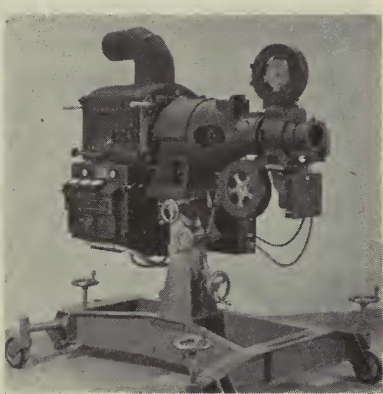

Fig. 7—Single-head projector.

Mechanically, the various components of this electrical system are disposed as follows:

All the electrical relays, fuses, rectifier, and the intercommunication amplifier are located in a large metal box, Fig. 6, located just below the arc house and on the nonoperating side of the projector. The snap switches used for controlling the various circuits are located on the arc-light control panel on the operating side of the projector, Fig. 7. The 3-phase rheostat used for "wild" operation of the driving motor is also located on this panel.

720-Revolution-per-Minute Operation

The photographing by means of a standard motion picture camera of an image projected from a background projector necessitates that the shutter on the camera be properly synchronized with the shutter on the projector both as to rotational speed as well as phase or instantaneous angular position.

Assume the use of 2-pole, 3-phase interlock driving motors on both the camera as well as the projector, both electrically coupled to a common distributor. If the stators of the motors and the distributor are excited from a common 60-cycle, 3-phase power supply and all the rotor circuits are properly interconnected, each rotor will align itself in some mechanical position so that electrically there is no transfer of power from any one rotor to either of the others. If one rotor is mechanically rotated or displaced to some new position, the other rotors will follow mechanically, in order to rebalance themselves electrically.

If now the shutters of the camera and projector are mechanically aligned, while all the interlocked rotors are in electrical balance, it can readily be seen that if the distributor (assumed to be 4-pole) is rotated by means of a mechanically coupled driving motor, say at 720 revolutions per minute, the 2-pole interlocked motors will operate at 1440 revolutions per minute, and both the shutters will rotate in synchronism as well as maintain their relative angular phase while rotating.

Now it so happens that with a 2-pole motor there is only one mechanical alignment position for an electrical power balance of the rotor. With 4-pole motors there are two mechanical alignment positions 180 degrees apart where the rotor can be electrically in power balance with the distributor. However, if the shutter shaft is coupled to a 4-pole driving motor by means of a 2-to-1 gear unit, it will act as though it were coupled directly to a 2-pole motor.

Practically, there is an advantage in using a 4-pole interlock driving motor for the background projector, namely, that of availability. In general, 2-pole interlock motors are available only for camera drives and, because of the small frame size and the low resultant power output, this type of motor was not considered adequate for driving the background projector and thus a 4-pole motor was used instead. Since the camera and projector shutters must both run at 1440 revolutions per minute, a 720-revolution-per-minute, 4-pole, or a 1440-revolution-per-minute, 2-pole distributor has to be used.

From the foregoing discussion it becomes rather apparent that the use of a 720-revolution-per-minute interlock driving motor electrically coupled to a 4-pole, 720-revolution-per-minute driven distributor always insures the proper shutter alignment after the initial adjustment. If some other driving speed such as 1200 revolutions per minute were used, this would not be the case.

It should be mentioned that the use of the 720-revolution-per-minute interlock motor-drive system for background projection use was not original with the Mitchell company. Several studios, notably Paramount and Warner Brothers, have used this method for interlocking for some years and therefore should be given due credit.

SINGLE- AND TRIPLE-HEAD BASE

The projector head and associated lamp unit are so designed that they are interchangeable for either single- or triple-head assembly. The triple-head unit (Fig. 8) of course requires two reflecting mirrors for two of the three heads. This facility of being able to disassemble a triple head readily into three separate projectors greatly increases the range of activity for the process department.

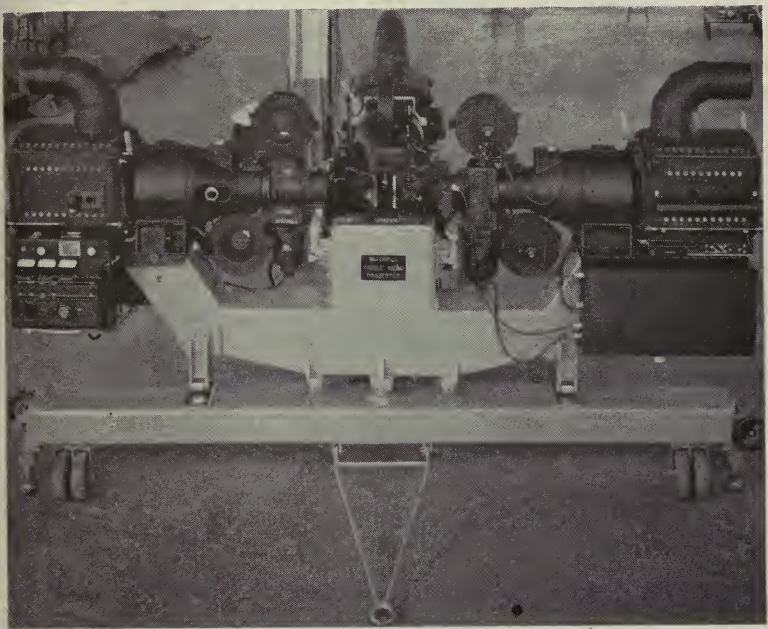

Fig. 8—Triple-head projector.

The "dolly" base of the single-head projector provides "rocklike" stability when "locked off" for operation, and yet it can be easily moved about the stage by two men. The panning and tilting mechanism operates with smoothness and precision.

Four solid-rubber-tired wheels are attached to the fabricated steel base of the single-head projector, Fig. 7. The rear wheels are mounted on swivels and hinged to the frame. They are connected by a tie-rod, enabling the base to remain level when moved over an uneven surface.

By means of a handwheel on the center column, the optical axis can be raised from 4 feet 9 inches to a height of 6 feet 3 inches. The column is also equipped with a handwheel to pan over an arc of 180 degrees. A third handwheel tilts the projector 12 degrees up or down from horizontal.

In order to provide levelness and stability during the operation of the projector, the base is equipped with three screw jacks.

The T-shaped base of the triple-head projector, Fig. 8, is constructed of fabricated steel, and equipped with solid-rubber-tired swivel wheels and screw jacks at each end of the T base. It is equipped with two handwheels to pan 22 degrees and tilt 11 degrees up or down from horizontal. The height of the optical axis of the three projectors on this base is 5 feet 6 inches when parallel to the floor. Both bases are equipped with removable tow bars.

ACKNOWLEDGMENT

In conclusion, the Mitchell Camera Corporation wishes to acknowledge the valuable help and suggestions made by the process department personnel of the various studios. In particular, we wish to thank Mr. Farciot Edouart and Mr. Hal Corl of Paramount Studios for their efforts in obtaining data of various sorts and for their technical suggestions during the development of this process projector.

FORTY YEARS AGO

It is alleged that many of the moving picture theaters in this city are still having their machinery operated by boys under sixteen years of age, especially on the lower East Side. The scheme is said to be to have some matured operator go before the authorities and pass an examination and then turn the license over to the youngster. The Board of Fire Underwriters and the Fire Department had better look into this and if found to be correct to lock the offending manager up, send the person who took the examination to Blackwell's Island and send the "kid" operator to the Reformatory. No punishment is too severe for people who conspire to do things that put human life in jeopardy.

—*The Moving Picture World, May 30, 1908*

New Theater Loudspeaker System*

By H. F. HOPKINS

Bell Telephone Laboratories, Murray Hill, New Jersey

and

C. R. KEITH

Western Electric Company, New York, New York

Summary—**The new system employs sectoral high-frequency horns and a crossover frequency of 800 cycles. Improvement is obtained in uniformity of distribution and reduction of size and weight.**

A loudspeaker system of the excellence required for motion picture applications must be founded on sound fundamental principles, many of which are understood fully only as a result of a considerable background of experience in the field. Such a background must be established before the application of technical skill can be successfully applied to the development effort. Since the interpretation of the basic principles is so important to the success of the venture, it seems appropriate to discuss briefly the considerations upon which the new Western Electric loudspeaker designs were based. The description of the physical embodiment which follows later will then have greater significance.

Before setting the course for a specific development of this type, many diverse and complex phenomena must be weighed, and the various merits and demerits of certain opposing characteristics must be reconciled. The following paragraphs will attempt to rationalize such a procedure. Where possible, data illustrating the effects discussed as well as the performance of the final loudspeaker system will be presented. In order to simplify the discussion, the various general attributes of a loudspeaker will be considered individually, and their relation to practice defined.

Frequency Response

It is quite generally agreed that one of the more important yardsticks in the determination of loudspeaker performance is the frequency-response characteristic. In the development of speakers for

* Presented October 24, 1947, at the SMPE Convention in New York.

any specific use, therefore, it becomes necessary to determine what response characteristic is needed to fulfill the requirements of the situation best. The employment of shaped, or "distorted" response to provide certain desirable characteristics such as high intelligibility in the presence of high ambient noise is well known. The commonly

Fig. 1—Arrangement of horn and loudspeaker for outdoor response measurements.

accepted criterion for high-quality or "natural" reproduction such as is required for motion picture applications is flatness of response over the whole audible frequency range. This presumes, however, that the conception of flat response, or uniform pressure-frequency relationship is adequately understood.

The so-called free-field pressure measurement is the only type in which complete uniformity of pressure with frequency is at all likely to be found, and exact free-space conditions are very difficult to realize. Fig. 1 shows a satisfactory arrangement of horn and microphone for outdoor measurements. Furthermore, except in the ideal case where the pressure distribution is identical at all frequencies, uniform free-field response at a point does not indicate a uniform power-radiation condition, which is probably nearer to the desired characteristic when the loudspeaker is to be used in an enclosed space. Since practical low-frequency speakers now in use are all less directive at low frequencies, a flat free-field response which might be excellent for outdoor situations is not at all desirable for indoor use.

Indoor measurements, on the other hand, are rather difficult to

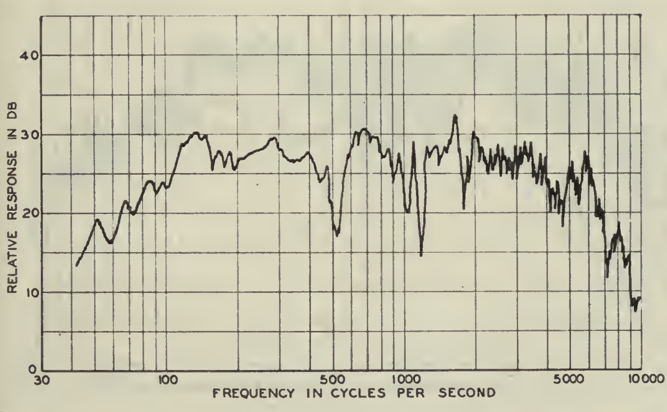

Fig. 2—Free-field response of loudspeaker phased for optimum performance as judged by listening tests.

make. Rotating microphones, multiple microphones, and various other devices are resorted to, but all have their shortcomings. The use of rooms with staggered wall surfaces which tend to increase the number of reflections, but to reduce the severity of the interference effects appears to have some advantages. A rather ragged response curve is obtained in such a room, but the peaks and dips are so close together that a reasonable response trend may be inferred from the data. Unfortunately, however, such measurements are useful only for a rough evaluation, for the room in which the speaker is actually to be used probably will have different characteristics. A great deal can be learned about frequency balance from data of this type, but the limitations of the measurement must be understood.

Ideally it would seem that a speaker should have a perfectly smooth free-field pressure response whether its trend be flat or otherwise. It is recognized, however, that reflections and standing waves in rooms cause raggedness in response that is far in excess of that exhibited in the free-field response of high-grade loudspeakers, and that in many cases the speaker having a smoother outdoor response does not appear superior when measured under indoor conditions. Under listening conditions where music or speech is involved, the transient nature of the reproduced material makes the audible effect of reflections and standing waves less evident than they are with the single frequencies used in measurements. Reflected sound, however, constitutes the greater part of the energy audible to the observer under indoor conditions, so that a certain amount of "raggedness" must be present in

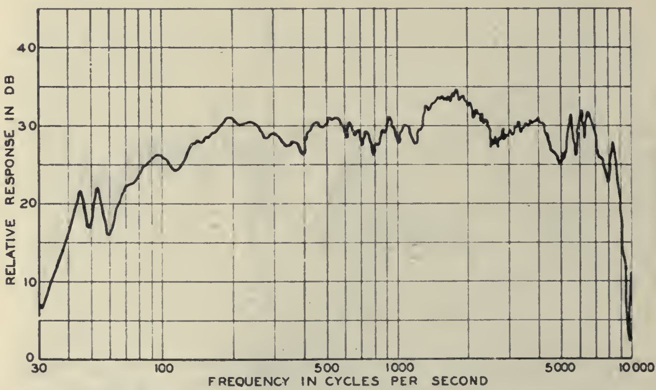

Fig. 3—Free-field response of loudspeaker of Fig. 2 phased for smoothest free-field response.

what is heard. This is true, of course, whether the sound source is "live" or whether it is radiated from a loudspeaker. In many instances, where multiple- or dual-loudspeaker systems are used, free-field response dips caused by out-of-phase radiation from the various sources may be completely obscured under an indoor setup. It is the opinion of most experienced observers, however, that while the ear tolerates a certain degree of nonuniformity, a loudspeaker having a smooth response will generally be more acceptable under all listening conditions.

In connection with the free-field dips in response which may result from the relative phasing of the sources in a multiple-unit speaker, Figs. 2 and 3 are of particular interest. The free-field response of a loudspeaker system phased for optimum performance as judged by listening tests is shown on Fig. 2. The same speaker phased for the smoothest free-field response is shown on Fig. 3.

In regard to the "flatness" of response and the frequency range, present-day high-quality speaker systems do not, in general, follow the pattern of idealized response. In practically all high-quality reproducing systems, the high-frequency response is purposely "drooped" to provide the most natural and pleasing quality from the listener's viewpoint. In many instances "tailoring" is provided to enhance "presence" or to compensate for some defect in the recording or reproducing medium. It is interesting to note, that while the ear

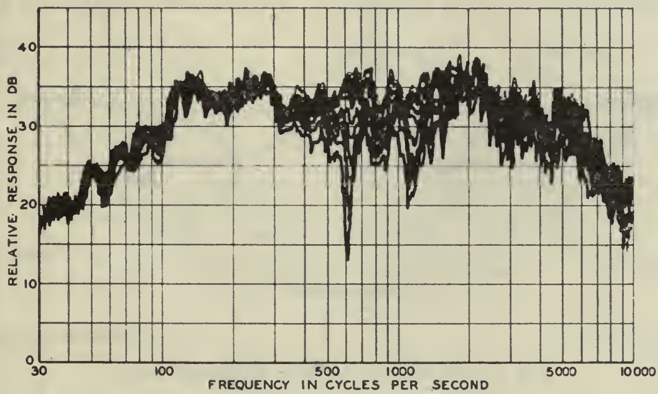

Fig. 4—Superposed response curves taken every 5 degrees off axis in horizontal direction.

bears a certain tolerance for sharp variations in sound pressure, it is able to discern rather small changes in response trend. It has been demonstrated that a "hump" 1 decibel in magnitude at about 2000 cycles tapering to zero at 1000 and 3000 cycles is easily detectable on an *A-B* test (direct comparison of "with" and "without" conditions). Many engineers are of the opinion that a "hump" in this frequency range is desirable for the enhancement of "presence." This leads to the conclusion that while measurement is an essential part of loudspeaker development, the ear, as the final judge, must be resorted to for the last adjustment to take care of subjective reactions under the actual conditions of use.

On the other hand, the importance of the response curve to the development engineer must not be minimized. For example, let us consider Fig. 3 showing the outdoor axial response of the new Western Electric RA-450 60-watt system. The engineer, who is familiar with the acoustic environment of the setup used, will recognize this as one of the smoothest response characteristics that has been attained in the highest-quality loudspeaker systems. He will appreciate from experience that the relatively small irregularities which appear closer together with increasing frequencies are caused by reflections which he has been unable to avoid even in a very careful setup. The low-end response is found to be rising at a rate of approximately 6 decibels per octave which indicates a uniform radiation of power over this range. At higher frequencies, where uniform distribution is obtained the response is flat which indicates a uniform power radiation in this

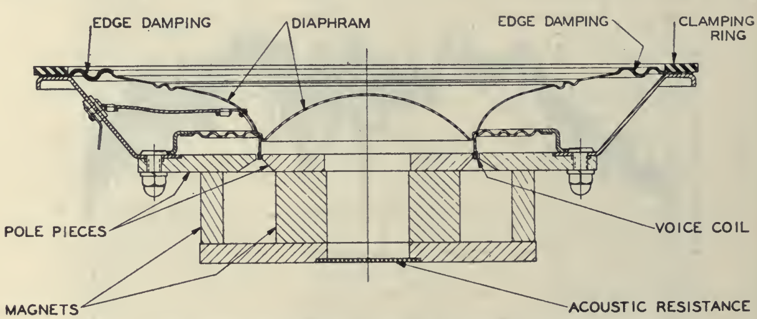

Fig. 5—Cross section of low-frequency unit.

range. In measuring this response curve, the diaphragms of both low- and high-frequency units have been located so as to be the same distance from the measuring microphone, and, therefore, no irregularites around crossover are indicated. The engineer realizes, however, that he could have separated the diaphragms by a distance equal to a half wavelength at crossover frequency and obtain an outdoor curve indicating irregularities in response around crossover. He also recognizes that while the outdoor response of such a setup would look inferior, the speaker would sound just as satisfactory under listening conditions. His indoor response curves will not show these phasing difficulties due to crossover.

DISTRIBUTION

The most frequently published loudspeaker frequency-response curves are those measured on the axis of the speaker in free space. Such data are a measure of a very minute portion of the total energy radiated by the device, and were nothing more known about the speaker, they would provide a very incomplete picture of the performance of the instrument. For most applications it is conceded that the response of the speaker should be uniform over an angle encompassing the area in which listening is to take place. For outdoor installations this is usually a simple and logical requirement to set. When the device is intended for use indoors, however, the situation is not so clear-cut. No loudspeaker known at the present time will provide uniform response over a desired area and zero response outside this area. Thus, in a room such as would be suitable for listening,

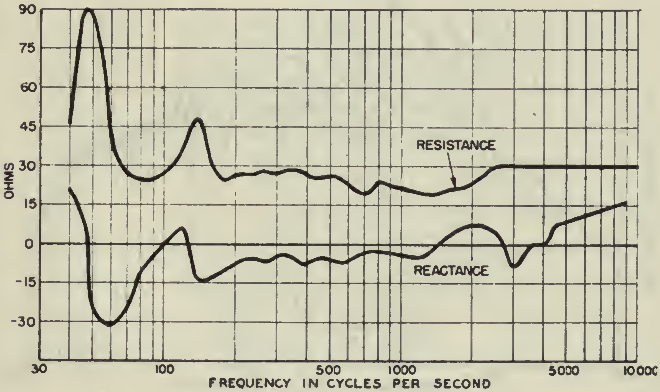

Fig. 6—Impedance of low-frequency unit computed at high side of 24- to 4-ohm transformer.

much of the sound reaching an observer's ears will be reflected energy. and the effect of the directional characteristics minimized. In spite of this situation, most experienced observers agree that a uniform directional characteristic is a desirable attribute even for indoor listening.

It is very difficult to design a practical loudspeaker which is capable of producing the same directivity pattern for all frequencies in its radiation spectrum. Multiple-unit devices approach this objective by limiting the frequency range reproduced by the individual units. As will be evident from an inspection of Fig. 4, two unit systems may be made to produce a remarkable uniformity of distribution. Wide variations of pressure are observed to occur at only one or two frequencies throughout the range at the extremes of the coverage angle.

Sectoral horns, if carefully designed, are capable of producing uniform radiation patterns over wide frequency ranges. The desirable directional characteristics are obtained at frequencies where the wavelength of the radiated sound is small compared to the width of the sector measured at the horn mouth. For this reason they are excellent devices for use with high-frequency units. Because of the size involved, it becomes economically impracticable to use sectoral horns as low-frequency radiators. Flat-mouth, rectangular section, low-frequency horns are commonly used because of their structural simplicity, but they have the disadvantage that their directionality increases with frequency. This may be compensated by proportioning the mouth so that it provides the desired distribution of sound at the

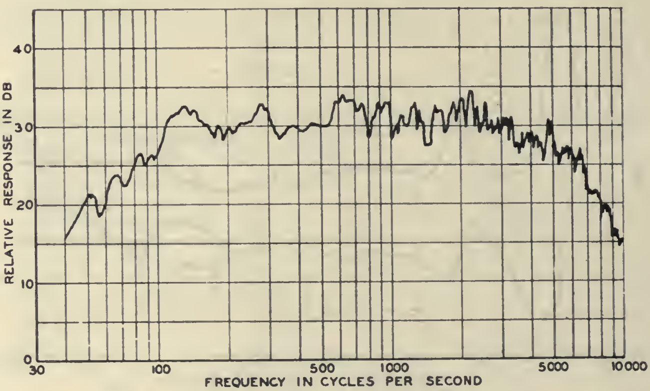

Fig. 7—Free-field response of low-frequency unit in box baffle.

crossover frequency. If the low-frequency loudspeaker is then designed with a drooping low-end response under free-space conditions, the energy radiated may be made to be approximately uniform. Under indoor conditions, a satisfactorily uniform spread of energy will be apparent when these design objectives are attained.

EFFICIENCY AND POWER CAPACITY

The acoustic output available from a loudspeaker at which acceptable freedom from distortion exists and at which no mechanical failure occurs, is, in general, limited by the mechanical design. An increase in the efficiency of the device can only make it possible to achieve this limiting output with lower-powered amplifiers. A compromise between the cost and weight of amplifier and loudspeaker must be struck in the interests of over-all system economy. Obviously efficiency, power capacity, and amplifier power must be considered in determining the needs of a given installation.

A method of determining the loudness-efficiency rating of loudspeakers, and of applying it to power requirements in enclosures has been described at a meeting of this Society,[1] and published in the *Proceedings of the I.R.E.* When measured in accordance with this method, a loudness efficiency rating of 20 per cent is indicated for the loudspeakers described herein. This efficiency is based on the acoustic power radiated over a 300- to 3000-cycle sweep-frequency band and is

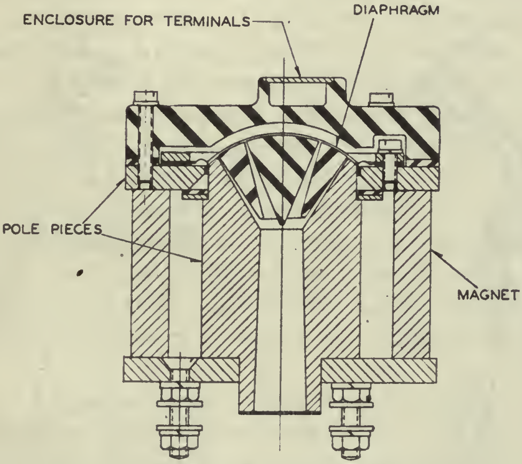

Fig. 8—Cross section of high-frequency unit.

higher than the figure for previous commercial Western Electric systems. An accurate comparison with other systems is not possible until they are measured on the basis given in the above paper.

While the efficiency of loudspeakers is generally regarded as an important consideration in determining their suitability, it is a term which is frequently misinterpreted. Axial-response data are often exhibited as an indication of efficiency, whereas, as has been pointed out, this is a measure of a very small portion of the energy radiated. The directivity must be taken into account in any determination of efficiency based on pressure response.

Damping

Horn-type speakers, if used for the frequency range well above the designed cutoff frequency of the horn, usually have well-damped mechanical systems. Because of size limitations, however, it is customary to use low-frequency horns at frequencies down to, and even below, cutoff. At these extremely low frequencies, the air loading will be small, and other means must be resorted to. Acoustical and mechanical resistance elements have been built into the Western Electric speakers to provide the required low-frequency damping. Such features result in a "firmer," less boomy, bass response. The use of bass "booster" devices is, in general, inimical to well-damped response.

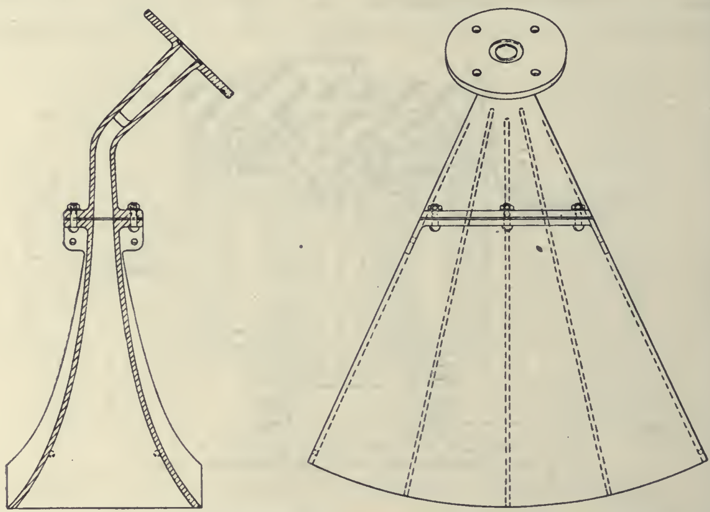

Fig. 9—Sectoral high-frequency horn.

DISTORTION

The problem of distortion ratings for loudspeakers is rather complex. Speakers do not, in general, exhibit uniform distortion–frequency characteristics, and, therefore, the choice of frequencies on which to base distortion measurements is likely to be different for each type of instrument. Furthermore, loudspeakers may produce relatively large amounts of distortion in one or two narrow-frequency bands, and it is difficult to evaluate the subjective effect due to such a condition as compared to a smaller degree of distortion over a wide-frequency range. It would seem reasonable to base a distortion rating on total acoustic power output, which makes it necessary to search wide-frequency bands over wide-dispersion areas, or to compute the acoustic outputs at the various frequencies through the use of a theoretically derived directivity index. The problem of distortion measurements in loudspeaker systems is not insoluble, but up to the present time only limited work in this field has been undertaken, and no standardized procedure has been worked out. It must be pointed out, too, that the results of steady-state measurements may not be a proper indication of the performance of a device intended to reproduce chiefly transient material.

Certain facts are obvious, however, and qualitatively, at least, the distortion may be controlled. It is known, for instance, that nonlinearity must exist in a system in order for distortion to be present. Consequently, control of stiffness and utilization of a linear flux field over the amplitude range required will control the first-order effects. Since various modes of diaphragm vibration may show up within the frequency range, and since nonlinearity may exist in some of these modes, distortion may result. Such modes, however, may be controlled by the judicious use of damping material. Listening tests usually will evaluate the efficacy of the measures taken. The effect of such damping on both the steady-state and transient response plays a large part in the clean performance of a high-quality loudspeaker system.

Design Features of New Systems

With the above considerations in mind a series of theater loudspeakers has been designed to cover the range of power input and angular distribution needed for theaters of various sizes and shapes. In designing these horn systems, a crossover frequency of 800 cycles was chosen as the result of listening tests on systems having various crossover frequencies. It has been found an advantage to have any effects due to out-of-phase conditions between the low- and high-frequency loudspeakers come above the region of maximum energy transmission rather than in the middle of this range. This relatively high crossover frequency makes it possible to use smaller high-frequency units since less power is transmitted in the high-frequency horn system. It also makes possible the use of a smaller high-frequency horn due to its higher cutoff frequency. However, such a crossover is possible only through the use of a low-frequency unit and horn designed to transmit adequately the wider low-frequency band. A new type of low-frequency unit and a special low-frequency horn make this possible.

The low-frequency units, Fig. 5, utilize a comparatively flat diaphragm in place of the usual cone in order to reduce phase differences in the sound radiated from different portions of the diaphragm. The diaphragm surface is designed to provide high rigidity with light weight and to reduce "breakup" of the diaphragm at higher frequencies. This is accomplished by means of an approximately spherical central dome and an outer portion in the form of a surface of revolution of a logarithmic curve. The voice coil is attached at the junction of the central dome and the curved outer surface. The arrangement

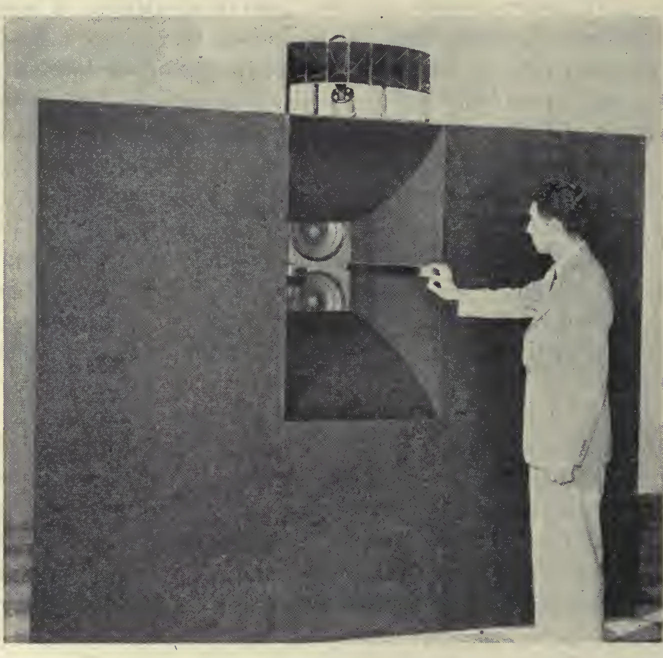

Fig. 10—Front view of 60-watt theater system.

of permanent magnets (Alnico 5) is shown in Fig. 5, consisting of two cylindrical magnets, one inside of the other. This provides high flux density with minimum weight and depth. Special acoustic and mechanical resistance elements provide relatively high damping. This is illustrated by the impedance curve, Fig. 6. The unit has excellent high-frequency response as shown in Fig. 7 and is used in many instances as a full-range loudspeaker, but in this system it is utilized only for the range between 50 and 800 cycles.

The low-frequency horn has an exponential taper with a sector-shaped horizontal section. This makes possible the combination of two low-frequency horns side by side for additional power output without making the combination too directional. The low-frequency units are mounted in an enclosed cavity back of the horn which obviates the difficulties due to back radiation, such as an increase in response at certain frequencies and a decrease at others with attendant "hangover." Sound-absorbing material within the cavity prevents

Fig. 11—Rear view of 60-watt theater system.

standing waves, which might react on the diaphragm and cause irregularities of response. Flat baffle sections are provided to improve the response at low frequencies without producing resonant effects.

The high-frequency units used in this system are similar to units previously used except for increased power capacity and efficiency. The former is accomplished by the use of a phenolic diaphragm and the latter by an improved permanent magnet. As shown in Fig. 8, sound waves created by motion of the diaphragm are conducted through expanding channels to a throat extending through the central pole. These units are capable of excellent reproduction up to considerably above 10,000 cycles.

High-frequency horns are designed as single units with exponential taper and a horizontal section of uniformly increasing width. This sector-type construction is simple and capable of giving smoother response at high frequencies and better distribution than previous types. The design is such that two horns, designed for a horizontal distribution of 50 degrees, Fig. 9, each with a driving unit, may be combined to give one horn of 100-degree distribution. This combination avoids the possibility of impedance irregularity which may occur when a double throat is used on a single horn. An 80-degree horn of similar design is used where this distribution angle is required.

The dividing network is designed to operate from an amplifier having an output rating impedance of 24 ohms although both low- and high-frequency units have impedances of 4 ohms each. This reduces the size of the network and the wires leading to it from the projection booth. Step-down transformers are incorporated in both low- and high-frequency circuits to provide a proper impedance match whether one or two units are used in either low- or high-frequency circuits. An adjustable attenuator having 1-decibel steps between 0 and 5 decibels is included in the high-frequency circuit.

Outdoor measurements on a typical system (60-watt, 100-degree) are shown in Figs. 3 and 4. Fig. 3 shows response on the axis while Fig. 4 consists of superposed curves taken every 5 degrees off the axis in a horizontal direction. It will be noted that except in the neighborhood of the crossover frequency, 800 cycles, the curves for the various horizontal angles fall very close together. The departures near crossover are only at the extreme angles and cover such narrow-frequency bands that they can be neglected. The general construction of a typical system is shown in Figs. 10 and 11.

Reference

(1) H. F. Hopkins and N. R. Stryker, "A proposed loudness-efficiency rating for loudspeakers and the determination of system power requirements for enclosures," presented April 24, 1947, at the SMPE Convention in Chicago; *Proc. I.R.E.*, vol. 36, pp. 307–315; March, 1948.

Modern Film Re-Recording Equipment*

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Summary—**Here is described a recently installed modern cabinet-type re-recording equipment, having a completely new approach in design and operation. Radically new, but proved features have been incorporated for ease and economy in installation, operation, and maintenance. The over-all functional design is based on original concepts by Metro-Goldwyn-Mayer and includes the manufacturer's recent basic developments in film-pulling mechanisms and optical systems.**

The recent completion of the new film re-recording installation at the MGM Studio in Culver City and the progress of the parallel installations in the Elstree Studio in London and the various MGM International Studios suggest it may be an opportune time to describe the installation and apparatus components and to comment on the underlying philosophy of the design concepts involved.

Some preliminary work was done several years ago resulting in the completion of experimental models of apparatus units described at that time[1]. As a result of the experience gained from operation with these models, and also to take advantage of the improved film motion developed by Western Electric, for which recognition was recently given by the Academy of Motion Picture Arts and Sciences, further design work has resulted in the present MGM units. This paper primarily will be concerned with the re-recording machine, and although a number of special features were custombuilt for the MGM installations, the basic design principles are incorporated in the standard Western Electric units.

Motion picture re-recording has many ramifications. It is a part of the picture-making technique which reflects the sound engineer's ingenuity in finding answers to the many problems, suggestions, and

* Presented May 17, 1948, at the SMPE Convention in Santa Monica.

inspirations presented by all of the other individuals and groups who contribute to the finished product. It is also the place where the soundman ceases to be an engineer and becomes a controlling and creative factor in the successful presentation of the product to the public. To an increasing degree the interpretations of the producer, the director, the musician, and the editor are dependent upon the re-recording processes and upon the skill and understanding of the re-recording mixer.

There was a time when a single domestic release negative would be re-recorded from perhaps three or four sound tracks, made up of a dialog track, one or two music tracks, and one or two effects tracks. Such simplicity sometimes would be welcome now but the requirements and demands of the modern product require a great deal more complexity. Eight re-recording tracks are probably a fair average requirement and the need to use ten or twelve tracks arises frequently. In particularly complicated reels or sequences there are many cases where twice this number of tracks may be used.

It is common practice to make sound effects and music negatives for foreign synchronized versions at the same time that the domestic release version is re-recorded. This involves additional recording machines together with the amplifier channel extensions needed for the multiple job. Moreover, a 16-mm version is now standard practice. Added to these requirements is the need for several productions to be in work at the same time, together with all of the routine preparation of playback material for production stage use, temporary re-recording for immediate editorial purposes, publicity and broadcast material, and other irregular but continuing demands. This variety of requirements obviously presumes a large amount of equipment. For the MGM Culver City Studio this necessitates forty-one film reproducers, or film dummies as they are commonly known, and eight film recorders, of which some are for theater release 100-mil variable-density track, others for 200-mil push-pull for various studio and international uses, one is for 16-mm release and another for variable-area release when required. These machines operate with any one of four re-recording channels and from corresponding re-recording auditoriums and projection rooms. To these film facilities is added the necessary disk equipment for recording and reproducing which are constantly in demand. Later there will be magnetic equipment as well.

The artistic phase of re-recording and the technique of equalization, balance, and editorial construction are of such nature that it may well be expected that they will be changing continually to conform to current and future requirements. While there are certain elements of uniformity, departures from the uniform pattern are not only expected but are to be desired in the attempt to produce improved entertainment and technical quality.

On the other hand, the physical handling of film material from which re-recording is done is a matter which should be undertaken on a basis which is largely routine and which can be semiautomatic in character. It is with this phase of the work that the present discussion is principally involved.

Equipment Requirements

Some of the more important attributes of re-recording equipment which will meet present requirements and which may be expected to continue to meet these requirements for many years to come may readily be listed as follows:

(1) Virtually absolute uniformity of film motion, regardless of film or drive irregularities.

(2) Consistent and dependable operation of all electrical and optical elements.

(3) Simplicity and rapidity of operation and manipulation.

(4) Ease and economy of maintenance.

(5) Installation simplicity and economy.

The experience of the past few months with the installation at Culver City has shown that the design concept is admirably suited to the operating requirements. Similar reports have been received from the smaller installations.

MGM Installation

Three kinds of equipment units are involved; a film recorder, its associated control cabinet, and the film reproducers, or re-recorders. Fig. 1 shows the form which the equipment takes. Each unit is housed in a rectangular sheet-metal cabinet containing all of the equipment associated with the unit. The height and depth of all units are the same, with the width varying with the nature of the unit. This permits arranging the units in rows of any desired length and in any pattern which floor plan and operational procedure suggest.

Inasmuch as all of the elements associated with a given unit are in the same cabinet, the complete unit can be completely assembled, wired, and tested under shop manufacturing conditions. The installation thus becomes very simple as it requires a minimum of external wiring to terminal blocks in each cabinet.

Past experience has shown that the installation costs are very high when it is necessary to install and wire a number of individual

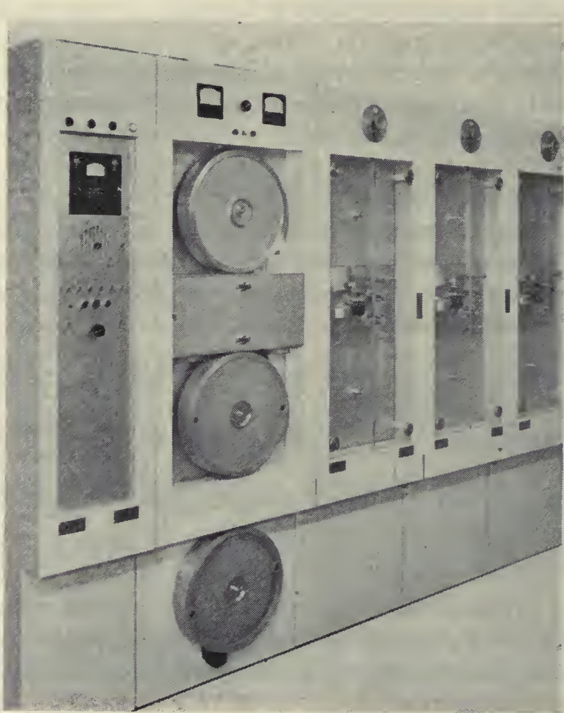

Fig. 1—Typical arrangement of control cabinet, recorder, and re-recorders as used at MGM Studio, showing similarity of the units.

mechanical units, amplifiers, and all of the associated items when the work has to be done as a matter of individual installation. As compared with this the installation of complete equipment units can be done quickly and inexpensively.

In this connection, as will be shown in more detail later, one difference between the MGM re-recorders and the standard Western Electric units lies in the arrangement of the panel above the film compartment of the re-recorder. An MGM requirement was the use of a six-position rotary switch in this location, arranged to switch the re-recorder interlock motor to any one of six separate distributor trunks. With a suitable safety provision in this switch it then becomes practicable to shift a reproducer rapidly from use with one re-recording system to any other. This facility of interchange is important in saving time as assignments in various rooms are constantly changing.

To accommodate these switches some fifty-odd trunk lines of power capacity are involved and with normal cabling and connection

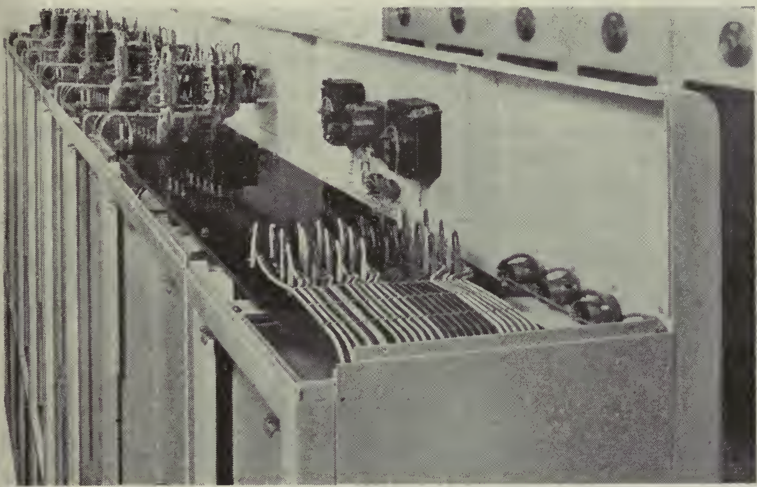

Fig. 2—Top view of equipment shown in Fig. 1, with covers removed to show the distribution of wiring and switching arrangement used at MGM.

methods this would have been an expensive installation item. Fig. 2 shows the solution attained. A flat bakelite-supported form was constructed before installation. At each junction point in the trunks and also at each switch connection appropriate Stakon connections were employed. When the equipment units were in place, the prefabricated flat form was dropped in place and the Stakon connectors plugged together. For a row of six reproducers and their associated recorder and controls the number of connections is of the order of 1200 so that this substitution of Stakons and the prefabricated form for soldered connections and standard cable forms results in an appreciable saving in initial installation. The standard Western Electric machine uses this space for drawer-type mounting of the phototube amplifier available from the rear, and the front area is used for lamp and other controls. In the MGM form the phototube amplifier is placed in the bottom compartment, also accessible from the rear.

The floor plan for the MGM installation is shown by Fig. 3. In this case, each row of units includes six film reproducers, one film recorder, and one control cabinet, so that in the two opposing rows there is the direct association of twice this number of units. This choice of numbers and arrangement is based upon the particular experience and requirements at MGM. It varies, of course, among studios, and the use of existing building space is an important consideration. In the case of the MGM installation all of the units are finished in white enamel to accentuate the impression of cleanliness. This feature has created favorable comment and is of course a departure from what has heretofore been thought of as standard practice for this type of equipment.

The conventional overhead sprinkler system is used for fire protection. However, high-temperature heads are installed to minimize the possibility of sprinkler operation at the wrong time. In this connection it should be noted that there is no potential fire-producing element in the machines themselves, barring the remote possibility of a static condition.

RE-RECORDING MACHINE

The film motion and mechanical drive are identical in the reproducer and recorder. Minor changes provide for the use of 17.5-mm film in the reproducer and of 35-mm film in the recorder. Aside from this there are, of course, the expected differences which permit the use of the proper modulator and of unexposed film in the recorder, whereas the reproducer is adapted for positive track and for the reproducing optical and phototube systems. A pair of the standard re-recorders is shown by Fig. 4 and the most unique features are perhaps the disappearing doors, the removable mechanism unit, the film path, and the optical system. A two-section cabinet permits the choice of a separate base cabinet unit, which may be either a plain unit or one containing a series of fixed and adjustable rollers for handling a loop up to 25 feet long. However, the loop may extend from one lower loop rack area into adjacent machines if desired. The cabinet itself is of rigid construction, well ribbed to avoid panel vibration, and has removable rear doors for accessibility to all components.

In spite of the fact that the room in which this equipment is

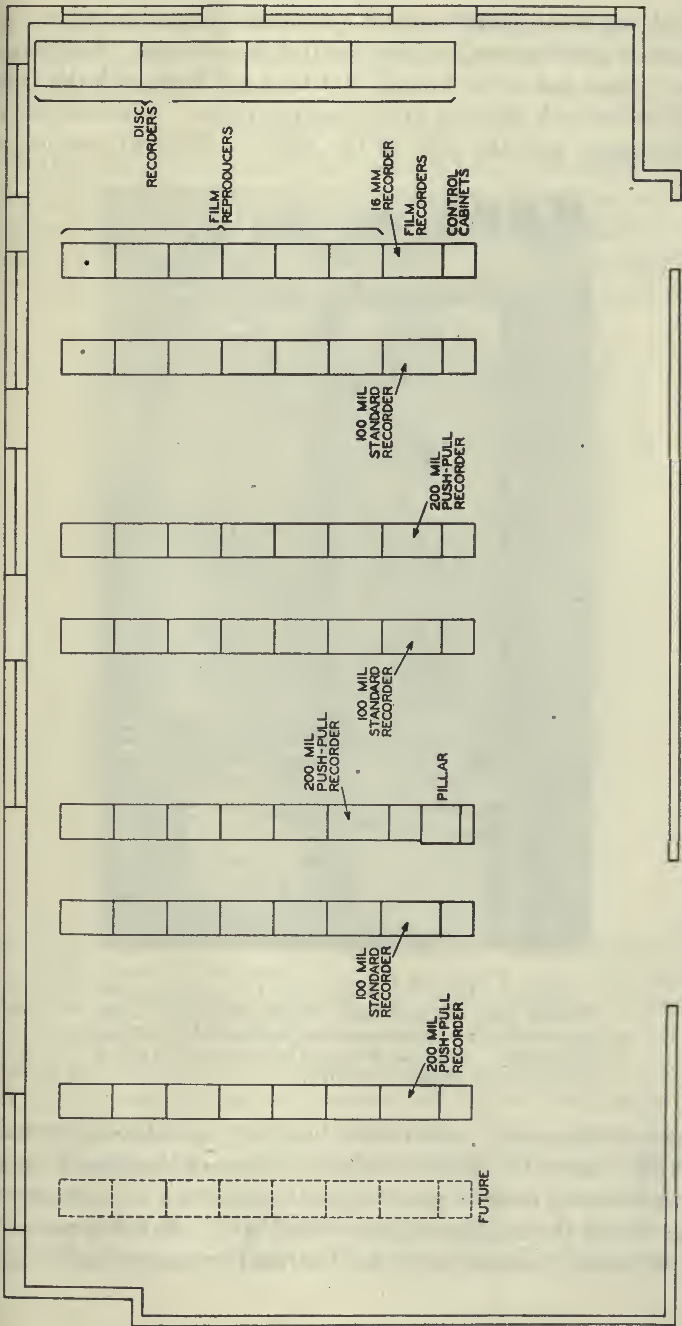

Fig. 3—Floor plan of the MGM re-recording equipment room showing arrangement of re-recording recorders and reproducers

installed may be air-conditioned it was deemed desirable to have doors which close the film compartments of the reproducers. The doors are of heavy glass and are so hinged that they are flush with the front of the cabinet in both the open and closed positions. When swung open they disappear into the sides of the cabinet. These doors normally

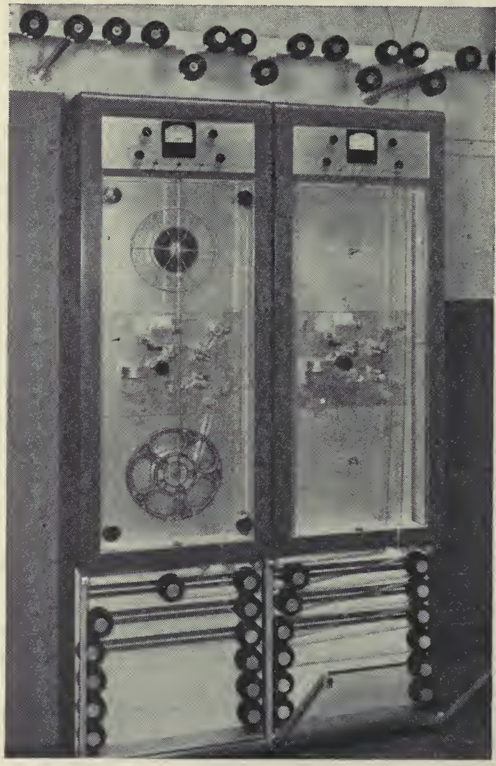

Fig. 4—Two RA-1251-type re-recording machines with the standard control panel and loop-rack cabinets. Left machine threaded for normal operation; right machine for loop operation using upper or lower racks or both.

are operated manually with rubber bumpers provided for protection, but in the case of the MGM machines, they are electrically operated by a momentary contact push button located at a convenient height on the side of the machine as shown in Fig. 1. Suitable precautions have, of course, been taken so that the hand or any obstacle caught in the door will cause the door to stall without damage or excessive force. These cabinets are intended to be anchored to the floor with wiring coming up through the floor.

MECHANICAL DESIGN

Attention is particularly invited to the unusual arrangement whereby the actual film-motion unit and its associated accessories for both reproducer and recorder are readily removable from the cabinet. The film-motion unit slides in and out from the rear and is arranged to be kept in mechanical alignment when it is pushed into place, and to

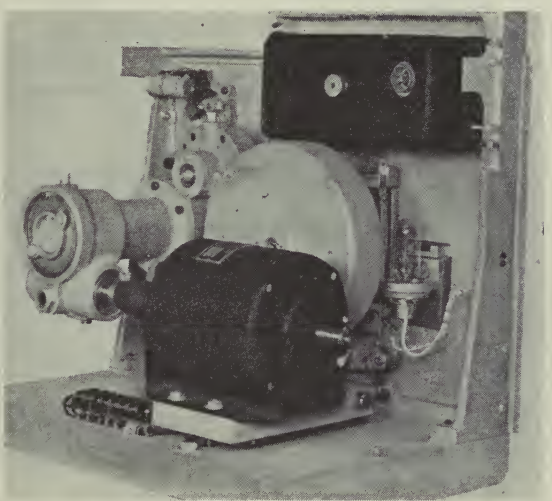

Fig. 5—Rear view of removable mechanism unit of the RA-1251-type re-recording machine.

make the necessary electrical connections, with the exception of a plug to the phototube amplifier. In addition, each of the major mechanism components is removable as a complete subassembly and all such assemblies are interchangeable in case of emergency. This complete mechanism unit is shown by Fig. 5, and facilities are provided for the removal and replacement of the various major subassemblies without loss of precison adjustments. For example, the motor position is adjustable vertically and laterally for shaft alignment, after which the adjustments are locked and the motor and its base may be removed thereafter and replaced without losing the alignment. The same principle is applied to the flywheel and drum assembly to retain optical adjustments related to the portion of the optical system which is mounted within the scanning drum.

The scanner assembly, shown by Fig. 6, contains a scanning drum driven by the film, and it is rigidly connected to a solid flywheel, the shaft being supported on two very small ball bearings so that the friction is held to a minimum and in addition, any moderate imperfections in the bearings are negligible, thereby avoiding a high degree of bearing selection. Fig. 7 shows the gear-drive assembly which also contains the sprockets and associated pad rollers. The gear re-

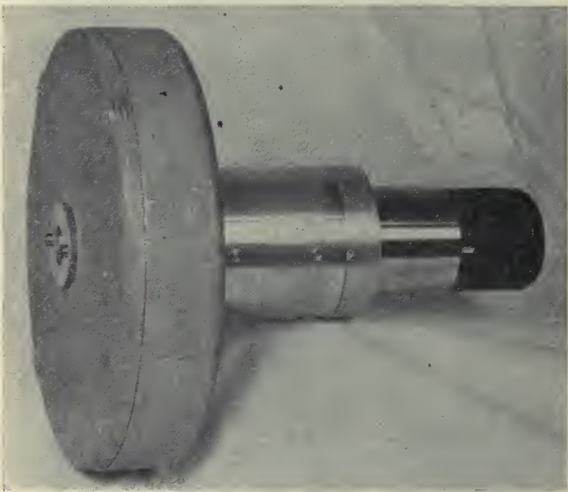

Fig. 6—Complete scanning drum and flywheel assembly, including optical subassembly under cap at end of scanning drum.

duction is accomplished in two stages with the rear section containing a high-ratio, right-angle drive for which gears are available to accommodate motor speeds of 720, 1000, or 1200 revolutions per minute, or other ratios as might be required for 16-mm operation. This assembly also contains a built-in clutch to disconnect the motor from the recorder mechanism so that the latter alone may be turned over by hand. It has been found to be a great convenience to be able to thread rapidly and then register the start mark on the film without disturbing the motor from its interlock position. The clutch is, of course, of the positive type which does not permit any slip during normal operation. The sprockets have flanges to facilitate threading and improve film guiding. The sprocket teeth are unusually large, having a base of 74 mils in the direction of the film. With a base diameter of 0.942 inch, this sprocket permits nearly optimum operation over a shrinkage range of 0 to 0.8 per cent and considerably greater shrinkage can be accommodated without significant damage to the film. These sprockets reduce to negligible amount the so-called "crossover" effect, which is the erratic motion of the film over the sprocket within the limit of sprocket-tooth clearance in the sprocket holes. The sprocket pad rollers are of unique design in which the pad-

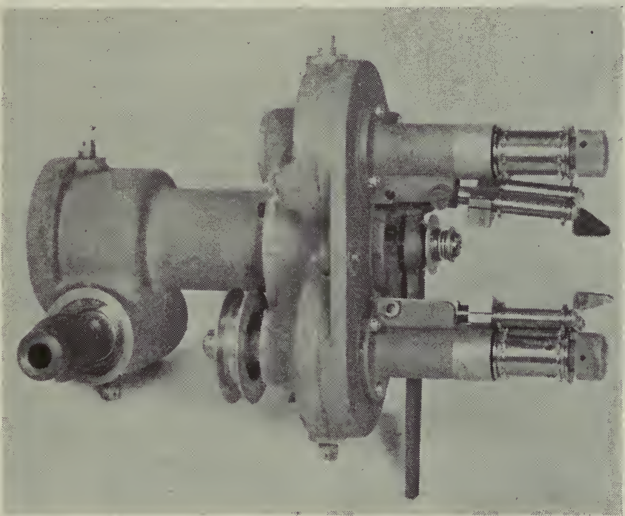

Fig. 7—Complete drive-unit assembly from motor coupling to sprockets. Vertical lever releases built-in clutch for threading release.

roller assembly pivots in the same plane as the sprocket axis and the finger pads are located so that the two pad-roller assemblies may be opened simultaneously by the thumb and first finger. Fig. 8 shows the filter-arm subassembly consisting of two rollers mounted on pivoted arms controlled by springs and arranged so that only the rollers appear through slots on the front of the panel. One spring provides for the tension in the film path between two sprockets. The other spring compensates for the total accumulated friction of all rotating components in the path between the two sprockets. This is sometimes referred to as the "gravity spring" and is anchored to the frame through a cam control appearing on the front of the panel This cam then becomes a vernier adjustment of synchronization whil the machine is running or stationary, and a range of approximatel ±2 sprocket holes is available. The filter rollers as well as the fixed rollers in the film path are, o course, ball bearing with pre cautions taken to reduce frictio to a low value. The lower arm is provided with a fluid dashpo for proper damping and is ar ranged to prevent spillage of th fluid at any angle.

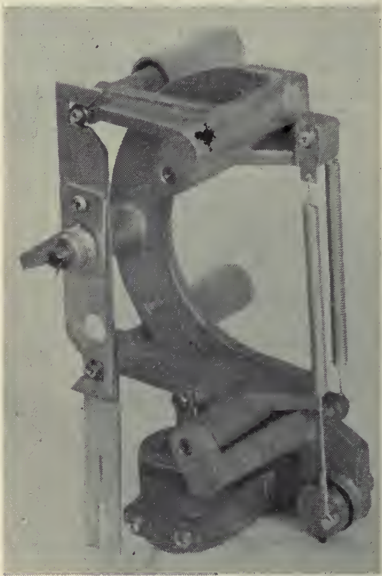

Fig. 8—Filter-roller assembly showing damping device attached to lower roller arm and locking lever which is actuated by the lower sprocket pad roller. Spring at right determines film tension in filtered path and that at left is anchored on cam for synchronization adjustment.

Film rewinding is provided b a motor and gear-reduction uni located behind the upper pane and connected to the feed-ree shaft with an automatic cutof assembly located in the uppe right-hand corner of the angle plate assembly. This facilit provides automatic rewind onc the film is threaded and rewinding started by the operator throwing a small idler roller into contact with the film. The rewind time is adjustable between 3(seconds and one minute for 100(feet of 35-mm film and the film velocity is reasonably constant as provided by the usual characteristics of a high-speed, series-type motor.

Film Motion

The film propulsion of this machine is essentially the same in principle as that previously described in the Journal.[2] As shown by Fig. 9, a taut film path between two 16-tooth sprockets drives a scanning drum and flywheel by belt action, and passes over two compliance rollers, one to the left of each sprocket. One of these rollers is provided with viscous damping and this film-propulsion system has demonstrated its ability to suppress all mechanical disturbances generated in the drive mechanism as well as those caused by film splices.

As an aid in threading, the two filter rollers are locked in the normal operating position when the lower sprocket pad roller is open for threading. Threading is therefore reduced to a very simple and fast operation since no loops are required. As the film is placed over the lower sprocket and the pad roller closed, the filter arms are thereby

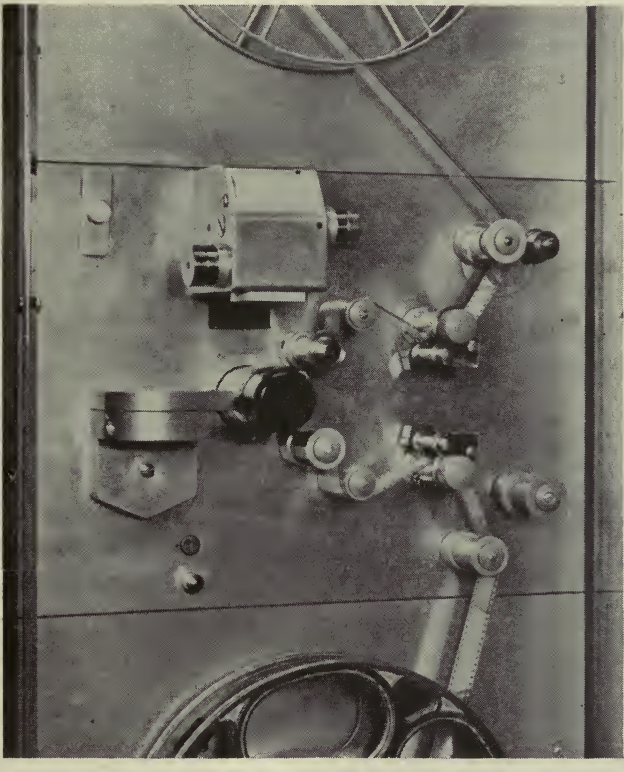

Fig. 9—Front view of mechanism unit showing film threaded for operation.

released and ready for operation. As previously described, the clutch button may then be used for setting the start mark.

OPTICAL SYSTEM

The optical system employed in this re-recorder is somewhat of a departure from previous optical systems and was designed to meet the requirements of convenience in operation, relatively high efficiency, freedom from fire hazards, and versatility in scanning any type of track in current use, with a high degree of uniformity in light intensity and definition in the scanning beam. Years of practical experience in optical systems have demonstrated the safety of so-called front-scanning systems, but these systems are not readily observed for scanning performance and require frequent use of various types of alignment or test tracks. The convenience of rear-scanning systems for visually determining scanning is well known, but many

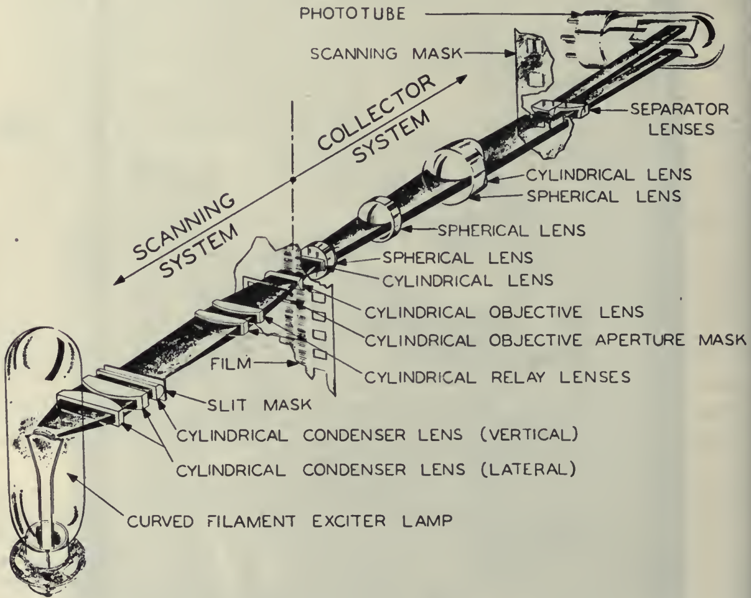

Fig. 10—Optical schematic, with omission of prism and mirrors used only for turning optical axis by 40 degrees.

such systems have contained fire hazards because of the relatively large amount of light placed upon the film by the condenser-lens system. In order to retain the advantages of each of these systems, the one used in this machine combines the convenience of rear scanning with the safety of front scanning. This is accomplished by using the front-scanning method of placing a scanning line upon the film in which the width of the line determines the frequency characteristic in reproduction, but which is of sufficient length to more than cover the area occupied by all sound tracks in current use. A rear-scanning type of system is employed whereby an enlarged image of the film and this scanning line is produced upon a mask so that the limits of scanning are readily observable and adjustable at any time. Fig. 10 shows this system schematically, omitting a prism and mirrors which merely turn the optical axis by 90 degrees for mechanical convenience.

The basic requirement of the front-scanning section was that of producing a line in which the intensity and the definition were to be reasonably uniform throughout its length as well as being highly efficient. This was accomplished by the use of cylindrical lenses only and the scanning line is an image of a physical slit produced by a relatively short focal-length cylinder. The height of this line is equivalent to an ideal scanning slit of approximately 1.0 mil and its quality and definition are quite uniform throughout its length. The illumination is uniform to within ±0.5 decibel. The light source is a 10-volt, 5-ampere, curved-filament lamp and the optical constants are such that its vertical position is not critical, thereby permitting prefocused lamps and essentially eliminating microphonic noise generated by lamp vibration. The stereopticon type of system is used and the advantages of the curved-filament lamp have been described by Carlson.[3]

The rear-scanning system consists of a combination of spherical and cylindrical elements, the design of which is primarily dependent upon the ability to collect and control all of the light coming from the scanning assembly and to meet the physical requirements of the machine design. It consists of three spherical lenses with the addition of two cylindrical elements between the film and the scanning mask. The first cylinder is located just behind the film to collect the relatively large vertical angle of light, and this cylinder in combination with a negative cylinder located on the rear of the third spherical lens produce a vertical enlargement of the scanning line of the order of 100:1 to permit more convenient observation of the scanning limits relative to the mask. Although not shown on Fig. 9, there is a prism located between the first two spherical lenses for the purpose of offsetting the beam to clear the scanning drum. Other mirrors are used to bend the light depending upon the particular application. The three spherical lenses produce an image at the mask which is magnified laterally approximately 3:1 and a scanning mask contains three sets of openings, one of which is registered with the projected light beam to limit the scanning. These openings provide for 200-mil push-pull in either the standard or offset positions and for 100-mil single or push-pull. In the vertical direction all of the projected light beam being scanned passes through the opening in the mask and appropriate field lenses are located just behind these openings to direct the light into the phototube. An RCA 920 tube is used and the patterns on the cell cathodes represent filament images about $^1/_8$ by $^3/_8$ inch long so that they are readily accommodated by the standard cathode construction. These images are essentially variable in intensity only, regardless of the manner in which the light is attenuated at the film plane. Fig. 11 shows the mechanical embodiment of the optical assembly between the lamp and the film. In this

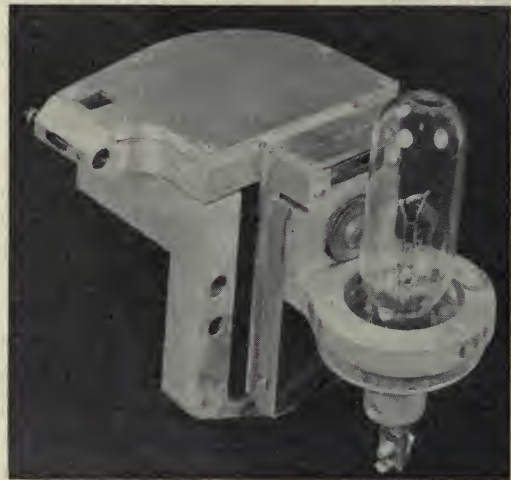

Fig. 11—Complete scanning optical system from lamp to film, which places the lamp behind the front panel and produces a line of light on the film 1 mil high by 230 mils long.

machine the lamp is located behind the front plate to eliminate all heat and fire hazard. A mirror turns the axis 90 degrees and this complete subassembly contains lateral and vertical lamp adjustments as well as focus and azimuth adjustments. The latter is attained by a rotation of the entire subassembly about its optical axis. The scanning assembly contains the third spherical lens of the collector system, the scanning masks, field lenses, and associated controls. The left-hand knob controls the position of the mask for the type of scanning desired. The right-hand knob moves the mask laterally for proper scanning registration and this knob is calibrated to indicate the normal scanning position or the departure from this normal with calibration in mils. A viewing window is provided on the front of this assembly with a sliding cover. This system has met the design objectives and gives an output signal at the phototube which results in an unusually high signal-to-noise ratio relative to mechanical disturbances which frequently have been so troublesome in the past.

This optical system has also been applied to theater-type soundheads and a typical example is shown by Fig. 12. The same facilities

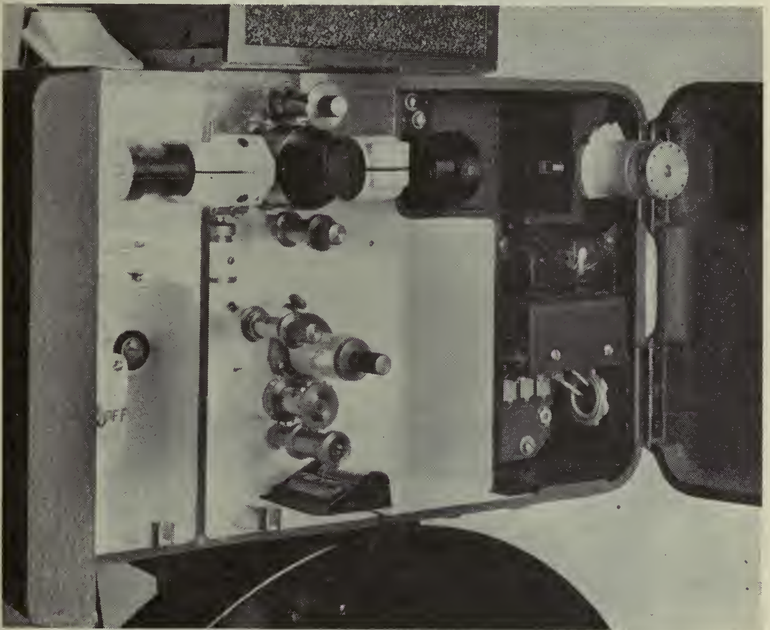

Fig. 12—Theater-type reproducer using the same optical system as Fig. 10.

are available and the performance is essentially equivalent. In this case the elements between lamp and film are contained in a circular tube, and are designed to conform to the usual distance between lamp and film, which is approximately $4^7/_{16}$ inches.

PHOTOTUBE AMPLIFIER

The phototube amplifier employes a new feature heretofore not used on this type of equipment. This consists of a special feedback input circuit which permits several feet of shielded cable to be used between the phototube mesh and the amplifier. By locating the amplifier away from the congested area around the machinery, greater freedom of design is obtained both for the mechanical system and for the amplifier. Also less microphonic noise and other noise disturbance generally will be obtained with the separation. Ordinarily the capacitance associated with a cable connecting phototubes and amplifier

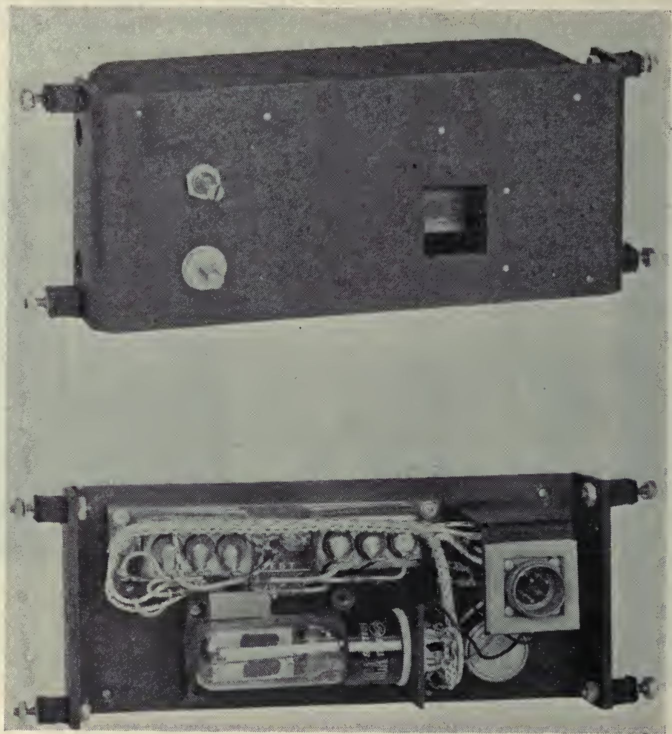

Fig. 13—Phototube coupling unit showing front view with phototube switch and balancing controls, and rear view with cover removed.

would cause a serious loss of high-frequency response. However, in this application the feedback from plate to grid of the first tube effectively cancels the capacitance of the cable so that an approximately flat frequency characteristic is obtained up to about 8000 cycles per second. No appreciable loss in signal-to-noise ratio is incurred over that of more conventional methods. The amplifier has three stages with feedback around the last two stages as well as the first stage. In the standard machine, it is mounted on a drawer arrangement which plugs in, thus providing for good accessibility and quick change in case of emergency.

Fig. 13 shows the phototube-coupling unit consisting of a complete assembly mounted on rubber. It contains all of the electronic components necessary for coupling the phototube through a single unbalanced, shielded line to the amplifier which is several feet away. A push-pull to parallel switch and a balancing potentiometer for push-pull balance adjustment are available through the front of the panel, but normally are under a cover since they are merely routine maintenance adjustments and are not required during operation.

CONCLUSION

At present the re-recording operations throughout the industry are almost entirely from film reproduction to film recording. However, there are good prospects of the adoption of magnetic methods for all original studio recording and for all editorial work. The adaptation of this new equipment to magnetic methods was kept in mind during its design so that the change can be made with a moderate amount of difficulty and expense. It is anticipated that magnetic methods will be useful for every phase of studio work up to, but excluding, the actual release negative.

The experience thus far with this new equipment at MGM and elsewhere has been remarkably good. Uniformity of operation from machine to machine had heretofore been difficult to attain with a large number of machines. At MGM the machines are now assigned to any class of work by number and any departure from uniformity is virtually unheard of. The arrangement of machines and the rapidity of threading and rewinding have greatly reduced the time between successive rehearsals and takes. This is of importance to the mixers and the producing group since it increases the amount of production material which can be completed in each room each day and thereby reflects directly on the operating economy of the re-recording work.

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Motion Picture Research Council*

By W. F. KELLEY

Secretary-Treasurer, Motion Picture Research Council, Hollywood, California

Summary—The purpose of this paper is to explain the organization, functions, and activities of the Motion Picture Research Council, Inc. A brief résumé of the Council's history and the reasons for its reorganization will be given as an introduction.

Shortly after the organization of the Academy of Motion Picture Arts and Sciences in 1927, a technical bureau was formed within the Academy. The technical bureau, under the chairmanship of Irving Thalberg, collected and published information on the use of incandescent lamps on sound sets, conducted courses in industrial education, and contributed materially to the solution of many problems encountered in establishing sound in motion pictures.

In 1932, the Academy was reorganized. The Research Council replaced the technical bureau and functioned under the Academy bylaws, but was sponsored and financed by the Association of Motion Picture Producers. The governing body of the Research Council consisted of one technical representative from each of the ten studios, plus an executive-producer chairman. These chairmen have been S. J. Briskin, William Koenig, Darryl Zanuck, and Y. Frank Freeman.

Experience in the operation of the Academy Research Council demonstrated the restrictions of its particular organizational structure. Its activities were limited by lack of funds and staff, and the necessity of operating through committees of technicians volunteering their time. However, the work of the Academy Research Council demonstrated unmistakably the need and the possibilities of a properly organized and adequately financed research and development program.

Several proposals for a research program were presented to and discussed by studio executives, both in Hollywood and in New York.

* Presented May 17, 1948, at the SMPE Convention in Santa Monica.

A committee of Herbert Freston, Peter Rathvon, and Y. Frank Freeman, was appointed to decide upon a plan for the producers. Two recommendations were made and approved. First, it was decided to appropriate sufficient funds to establish an expanded program with proper organization and adequate staff. Second, it was decided to use the existing Research Council as the nucleus of the new organization.

As a first step, it was necessary to secure a director for the new program. In August, 1947, the services of Wallace V. Wolfe were obtained. His executive ability, engineering background, and broad knowledge of the motion picture picture industry made him particularly well qualified for this position.

The second step was the establishment of a proper organization. Operation of the Academy Research Council under the Academy had been entirely satisfactory and practical, but limited. The new organization needed greater freedom of action. It had to be able to negotiate contracts, obtain patents, grant licenses, buy and sell property. It had to be responsible directly to its sponsors for the expenditure of funds.

This was discussed with the Academy and the necessity for a change in the organization of the Council was recognized and approved by Jean Hersholt, president of the Academy, and the Academy Board of Governors. As a result, Herbert Freston drew up articles for a new corporation and the Motion Picture Research Council was established as a nonprofit California corporation on October 14, 1947. Under its bylaws, its purposes are to engage in engineering development and research, to find solutions to common problems, to develop and improve equipment and methods, to promote standardization and the interchange of ideas and information, and to act as a liaison between studios and suppliers.

The corporation has ten company members: Columbia, Goldwyn, Loew's, Paramount, RKO, Republic, Roach, Twentieth Century-Fox, Universal, and Warner Brothers. These company members elect a board of twelve directors. As presently constituted, the board consists of one representative from each member company, plus an executive-producer chairman and the president of the corporation.

The management of the corporation is vested in a board of directors, the officers, and committees.

OFFICERS

WALLACE V. WOLFE, *President* R. A. KLUNE, *Vice-President*
W. F. KELLEY, *Secretary-Treasurer*

BOARD OF DIRECTORS

Y. FRANK FREEMAN, *Chairman*
THOMAS MOULTON, *Vice-Chairman*

JOHN AALBERG	GERALD F. RACKETT
DANIEL J. BLOOMBERG	ELMER R. RAGUSE
FARCIOT EDOUART	GORDON SAWYER
BERNARD HERZBRUN	DOUGLAS SHEARER
NATHAN LEVINSON	WALLACE V. WOLFE

Committees are of three types: permanent committees, special committees, and task groups or subcommittees. Permanent committees, appointed by the board, represent each major technical division of motion picture production. There are fifteen such permanent committees:

Art Direction	Electrical	Set Grip Equipment
Color	Laboratory	Sound
Directors of Cinematography	Photographic	Standards
Editorial	Production Managers	Subgauge Film
Effects	Set Construction	Television

These committees are charged with the responsibility of acting in a technological advisory capacity to the board and staff on all activities pertaining to that committee's particular phase of production.

Special committees, also appointed by the board, advise on particular projects not within the scope of any permanent committee.

Task groups, subcommittees of permanent committees, are appointed to act in an advisory capacity on a single phase of a project, and to make recommendations directly to its permanent committee.

The next step in the program was to secure proper quarters and staff personnel. Office and laboratory space was obtained at 1421 North Western Avenue in Hollywood. This location has the advantage of being adjacent to studio facilities where operating tests can be made.

Personnel requirements were based on the recognition that production problems embrace every phase of the engineering profession. We, therefore, employed an engineer for each of the major phases of our program, consistent with the budget limitations of a new organization. At present, in addition to Mr. Wolfe and myself, we have on the staff eight engineers with practical experience in chemistry, physics, construction, standards, electricity, lighting, and mechanical design.

As the organization was being set up, specific activities were being outlined. Our program is still in its formative stage, but our present activities indicate our future program.

First, the staff is analyzing new ideas and new inventions submitted for possible application to motion pictures. Since the first of the year we have considered such items as three-dimensional systems, television patents, special cameras, color systems, aerial and underwater photography, and universal focus lenses.

Second, we are searching for and examining equipment and materials developed by other industries for adaptation to the motion picture industry. Included are such items as magnetic recording, "liquid-envelope" materials, static eliminators, wall coverings, shellac substitutes, nylon products, and molded screens.

Third, we are disseminating information to our member companies through reports and bulletins and by discussion in committee meetings.

Fourth, we are promoting standardization through the establishment of industry practices and with a recommendation for American Standards where these industry practices apply. We are presently concerned with the standardization of screen illumination, dimensions and speed of magnetic-recording mediums, pitch of sound-recording negative, laboratory procedures for 16-mm release of 35-mm material, elimination of frame lines, Dubray-Howell perforation, and fused plugs and cables.

Fifth, we are actively engaged in short- and long-range projects. Short-range projects may cover a period of a few days to a year or two, while long-range projects may cover from one to five years. We are now carrying on two long-range projects: set construction and set lighting.

The purpose of the set-lighting project is to provide improved lighting methods and tools to enable production crews to accomplish their job with greater flexibility and improved efficiency.

A review of the literature is in progress and a survey of present methods and techniques has been undertaken. This survey, partially completed, includes light sources, lamphouses, optical systems, filters, control equipment, power supply and, most important, the manner in which such equipment is used on the set. At the same time, an investigation was initiated to determine the possibility of employing new light sources which might be available. We are actively following the development of the mercury-cadmium compact light source and the zirconium lamp, and we are presenting designers and manufacturers with broad operating specifications for the motion picture use of these lamps. Since this project is still in the staff-investigation phase, results cannot be reported at this time.

The set-construction project is also in the survey stage. A survey of present methods and the literature is being carried on simultaneously with an investigation of the possibility of adapting products of other industries to the construction of motion picture sets.

We have a number of short-term projects and it will suffice to explain one of these in some detail and merely list the others.

One of our short-term projects is the design and construction of a small camera crane. There has been greater and greater need for camera flexibility as production methods have progressed. The camera has advanced from the stationary tripod to the dolly and to cranes or booms. The dolly is somewhat limited in its use and the large crane unwieldy and expensive to operate. Therefore, there is a need for a crane with the mobility and flexibility of a dolly, but with the camera range and broader application of the large crane. Several small cranes had been developed previously. Metro-Goldwyn-Mayer built, and still has in use, several cranes of intermediate size. Subsequently, Twentieth Century-Fox developed a small, motor-driven crane. The Council's crane is similar, differing mainly in the type of construction and accessories.

Acting under the direction and advice of our Camera Crane Committee, and taking advantage of the previous knowledge and experience gained in the use of the small cranes, a staff engineer designed a crane which was acceptable to all of the studios.

Normally, we would provide manufacturing firms with performance specifications or a complete design, and they would manufacture and sell directly to the industry. This would complete the Council's project. Equipment required by studios, however, is often so specialized that manufacturers are reluctant to produce the item for sale on the open market. Such was the case with the crane. We were unable to find a firm willing to undertake the manufacture because of the risk involved compared to the possible market for such specialized equipment. The Council, therefore, found it necessary to correlate studio orders and arranged for the manufacture of an initial order of twenty-five.

As a part of the crane project, we are building a prototype of a dual camera head and have in the design stage a location carriage for the crane.

Some other short-term projects under consideration are polonium for static elimination, red-sensitive photoconductive tubes, materials and equipment for simulating fog, more efficient wind machines, duplication of color stills for stereopticons, and nonfading dye agents for plaster.

In conclusion, I should like to point out first, that we are engaged in applied research, rather than in the opposite extremes of pure research or manufacture. We are working closely with research groups in and outside the industry and bringing to their attention problems of importance to our industry.

Second, we are acting as a liaison between studios and suppliers. On one hand suppliers are using the Council to distribute directly to those concerned in the studios, information on new products. This informational service is set up and working. On the other hand we are correlating studio needs and desires and presenting such information to the suppliers. This procedure saves time, standardizes methods and practices, and results in better and less expensive equipment.

Third, our effort is an industry effort. The Research Council has been set up by this industry for this industry. To quote Mr. Freeman, our chairman, "we have in the motion picture industry one of the largest reservoirs of competent and experienced engineering and technical personnel of any industry." The Council needs the benefit of this experience and knowledge. We not only welcome, but request your help, your suggestions, and your advice.

Use of 16-Mm Motion Pictures for Educational Reconditioning*

By EDWIN W. SCHULTZ

Army Medical Center, Washington, D. C.

Summary—This paper will cover in a general way some of the things which have been done at the Walter Reed General Hospital with 16-mm films and at the same time will offer a few suggestions which, it is believed, will help to improve the motion picture industry so far as the 16-mm nontheatrical field is concerned.

Great impetus has been given to the development of visual educational methods as a result of the demand for accelerated training programs in the Armed Services. Training films, documentary reports, and general informational subjects to aid in the orientation of the soldier have established the value of motion pictures in supplementing other media of learning; also research studies have shown the motion picture to be one of the most popular forms of entertainment and diversion among American servicemen.

Within each hospital there are wide opportunities for educational reconditioning personnel to develop programs well implemented with carefully selected screen subjects that will aid in the psychological reconditioning and contribute to the resocialization of individual patients.

The film program must be planned in a way that will accomplish the following four objectives:

(1) To contribute to the individual's personal adjustment by providing information and fostering understanding of the hospital program and providing local orientation to restore confidence, establish respect, and develop a "sense of belonging."

(2) To develop the concept that the struggle in which we were engaged required the total and continued effort of all, not only to win in the field but also to secure a society dedicated to the principles of democratic living.

(3) To offer occupational information co-ordinated with the programs of counseling and vocational guidance to aid in the exploration

* Presented October 15, 1945, at the SMPE Convention in New York.

of job opportunities and benefits available to the prospective discharged soldier, should he require further education or vocational rehabilitation.

(4) To supplement the content of specific courses of instruction offered in educational reconditioning or the convalescent training program.

The building of a film program, that will adequately serve the objectives of reconditioning, demands skillful balancing of films with a serious purpose and those of a diversional and entertaining nature.

In order to carry out the film program as outlined, the Surgeon General of the Army established a Visual Aids Center at the Walter Reed General Hospital in Washington, D. C. It is the responsibility of the Center to (1) provide necessary films, projectors, screens, and other film equipment; (2) train projectionists and maintain equipment; (3) determine all film sources and secure films for the programs from all fields, insuring proper screening technique; (4) assist in the proper utilization of films in the reconditioning, information, and educational programs; (5) assist in the adoption and improvisation of equipment for all such purposes in the hospital; (6) advise military personnel of the hospital on the most effective ways of using motion pictures and other visual aids in the programs; and (7) recommend to the Surgeon General production of visual material which can be utilized in all Army Service Forces Hospitals to further reconditioning activities.

So far has been outlined the plan for the use of the 16-mm film in the reconditioning program. Now let us talk a little about how it is used at Walter Reed General Hospital and later some of the problems which confront us.

First, the theme at Walter Reed Hospital has been "If the man cannot come to the movies, take the movies to the man." In other words, we believe that, what we in the hospital know as the "class four" or bedfast patient is just as entitled to see entertainment and educational movies as the "class three" or ambulatory man, who can go to the places where motion pictures are shown. In order to do this portable carts equipped with 16-mm sound projectors and screens have been provided. These can be wheeled into the wards and films shown for the men confined to their beds. These units, in the hands of trained projectionists, give remarkably near-professional shows. The lighting is good and the sound adequate. Audiences number from a dozen or so up to 50 or 60 depending on the number of men in the ward. The reconditioning service confines its shows to educational, documentary, and vocational-type films primarily, while the Red Cross furnishes the full-length entertainment features.

Fig. 1—Cabinet-type booth for the 16-mm projector which is in use at the Walter Reed General Hospital. This booth is on the balcony of the Auditorium of the Red Cross building at the hospital. The amplifier of the 16-mm projector is jacked into the permanent 35-mm sound system on the stage which makes it possible to show 16-mm sound pictures on the big screen on the stage and get maximum tone qualities. This provides a more or less permanent setup in the auditorium for showing 16-mm pictures at any time to the ambulatory patients.

Second, a daily information-education program is conducted in a large theater auditorium which is attended by wheel-chair, crutch, and walking patients. These programs usually last an hour and are package or unit programs, a week being assigned to a subject during which outstanding speakers are brought in to discuss the subjects along with which films are shown dealing with the various phases of the subject. The sessions usually draw large audiences and the program is broadcast over the hospital radio system so that men in bed can hear it over their individual bedside headsets.

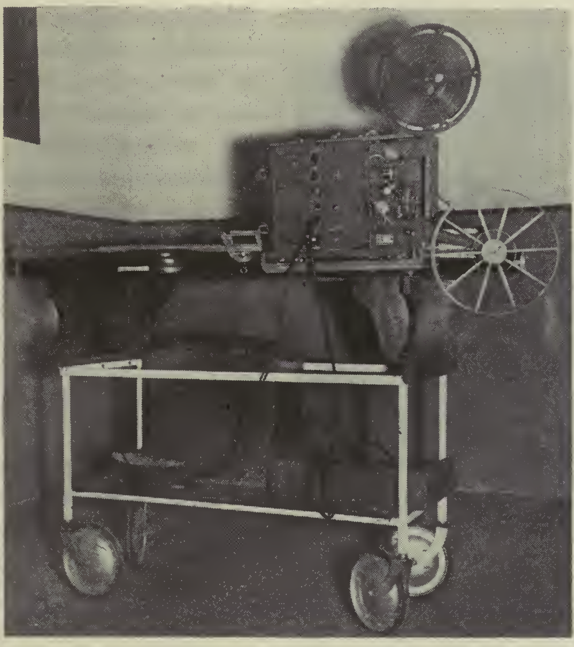


Fig. 2—A discarded wheeled stretcher has been utilized to make a cart for carrying complete projection unit to the wards for ward showings of films at the Walter Reed General Hospital. The addition of a bottom shelf and the wooden top converts the stretcher into an easily handled, practically silent, rolling cart. There's sufficient room for projector, amplifier, speaker, screen, films, and extra reels and is easily handled by one man.

The third place where films are used is in the various crafts and vocational shops. Among these shops is included carpentry, music, art, leather tooling, and typewriting and business machines. Films covering many phases of work in these crafts are shown to the patients in a specially provided "little theater." While no attempt is made to go into actual vocational training, an effort is made toward doing exploratory work to help the patient find his fitness for a certain craft or trade, and at the same time occupy his mind while the medical officers are curing him of his physical ills. Here we can only touch on the immense problem which we faced, and which still faces us, and the progress that has been made. It will require a visit to Walter Reed Hospital to see how the job is being done.

Films are being employed in the treatment of the neuropsychiatric patients with very good results. Men mentally disturbed react extremely well toward films which are shown them, and they have motion pictures almost every day.

Fig. 3—A class in auto mechanics see a film on first echelon maintenance in the auto shop of the Educational Reconditioning Section of the Walter Reed General Hospital. More than 30 films are used continually by this course during classes.

As an indication of the use of 16-mm films at Walter Reed Hospital, it might be well to give you the figures on utilization during the 3-month period of June, July, and August, 1945. During those three months, 598 films were shown with a total of .1470 showings and a total attendance of 46,760.

Among the problems which were faced in bringing a film program to the patients, was first, the lack of the right kind of 16-mm films available. Of the many film subjects that are available today in 16-mm sound, a majority of them are unsuitable, the sequences are bad, the photography poor, and the sound inadequate. The films made by the Signal Corps Army Pictorial Service, were all excellent but were unsuited for use in the hospital as they were filmed for military training and our patients are through with that phase of their career.

The Surgeon General's Office started work on the evaluation and procurement of available 16-mm films suitable for hospital use, but only a few were acceptable. That office also launched certain productions. The Visual Aids Center at Walter Reed started a campaign to borrow from *any* source such pictures as could be used in these programs. We faced the rental-fee problem right off, but we were not in a position to pay rentals on all the films we wanted to use. In most cases the firms having 16-mm films were most co-operative and we secured the use of literally hundreds of prints with no charge other than transportation.

In speaking of the lack of quality subject in 16-mm, let me make it clear that I am not speaking of the 16-mm Hollywood feature pictures which have been released, but those of an educational or documentary nature. It has been my experience that there is a very definite need for more high-class, well-produced films of an educational and documentary type. It offers a great field, and educational institutions consistently will demand a better quality product; which is where an organization such as the Society of Motion Picture Engineers can play a very definite part. Regardless of what some of the 35-mm producers want to believe, the substandard 16-mm film is here to stay and the sooner all men in the industry realize it and make an effort to see that only the best quality 16-mm films are produced, the better off the entire industry will be.

It may be worth while to look ahead somewhat and consider the great need the Veterans' hospitals will have for 16-mm films to carry on the work of rehabilitation, resocialization, and vocational training which eventually will be their responsibility. The work that is being done is small, compared to what faces the Veterans Administration in the years to come. While only a very small percentage of the total number of veterans of World War II are in our hospitals, later there will be tens of thousands seeking the help of the Veterans Administration.

Should we not look ahead and be prepared, and not face a "Pearl Harbor" situation with respect to this matter?

Should we not use the experience we have gained and the time we now have to prepare, rather than procrastinate and have to make a mad dash later?

If pioneer groups such as the SMPE and other agencies, both private and governmental, will carry on while the momentum is rapid, there will be much accomplished; certainly, the future outlook for 16-mm educational films was never brighter.

The third and last phase is that of projection equipment and the shooting of pictures in 16-mm sound rather than the 35-mm to 16-mm reduction method.

Considerable difficulty has been experienced during the war years with 16-mm projection equipment. Many of the available projectors were made so rapidly and out of such poor material that maintenance became a major problem because of rough handling and lack of well-experienced operators. Again a scarcity of repair parts and good repairmen was a problem. The remarkable fact is that they stood up as well as they did.

Now that the war is over, there should be an over-all improvement in the quality of projection production, servicing, and a lowering of costs, not only in the purchase prices of new projectors but in the cost of replacement parts and maintenance. These facts are mentioned as it is believed that 16-mm projection equipment must be priced at such a figure as to make projectors within the reach of other than the wealthy individual, the school, or the industrial concern with unlimited funds.

Sixteen-millimeter projection equipment also must be improved to make maintenance a minor problem for schools and industrial concerns and improvements made in the amplifier systems in order to give better quality sound. If the quality of the equipment can be improved and the cost reduced, the future of the 16-mm film as an educational medium is assured. The next aim should be an improvement in 16-mm productions for educational use. All 16-mm educational films should be filmed in 16-mm with original sound to get away from bad effects caused in reduction of prints from 35-mm film. This will not only mean a reduction in cost but will mean better prints in my belief.

A great field seems open to enterprising business concerns willing to sponsor good-quality educational films as an advertising medium, provided they do not ruin the sustained interest by too much advertising. This is especially true with the outlook of present-day trends as regards television, since already a number of 16-mm films have been produced and televised.

Acknowledgment

The photographs used to illustrate this article were furnished by The Visual Aids Center, Army Medical Center, Washington, D. C.

Report of Studio-Lighting Committee*

THIS REPORT describes motion picture studio-lighting power sources and completes a series of reports covering all phases of studio-lighting equipment.[1-4]

Direct-current motion picture studio-lighting power sources may be divided into three general types: (1) Permanent installations con-

Columbia Pictures Corporation

Fig. 1—Main generator room. 500-kilowatt General Electric motor-generator sets.

sisting of motor-generator sets usually installed in a centrally located powerhouse and with suitable underground cable connecting them to the stages. (2) Portable motor-generator sets mounted on trucks or trailers which may be located outside stages for extra power where heavy loads are used, or which may be sent out on location. (3) Internal-combustion engine-driven generators which find their greatest use on locations where power from electric lines is not available.

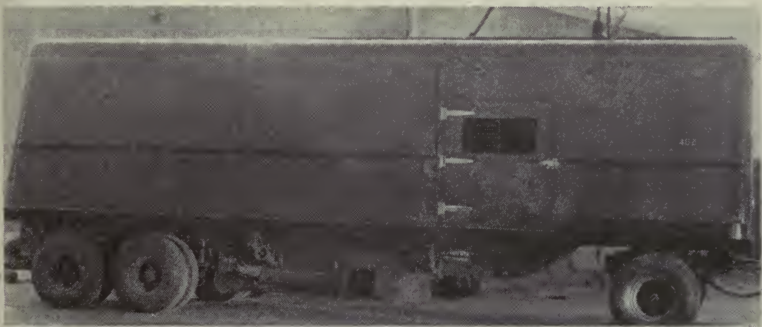
* Original manuscript received October 11, 1947.

Table I
Typical Motion Picture Motor-Generator Sets

No.	Set	Generator	Motor
1.	500 kilowatts—4000 amperes Fixed installation A 3-unit set of two 250-kilowatt generators operated in series for 3-wire distribution driven by synchronous motor	250 kilowatts 900 revolutions per minute, 120/125 volts, direct current, compound-wound. Alternating-current ripple characteristic not over 1/2 of 1 per cent of rated voltage. Rating: 100 per cent load continuous 200 per cent for 15 minutes	700 horsepower 2300-volt, 3-phase, 60-cycle, 8-pole, 0.8 power factor, synchronous
2.	300 kilowatts—2400 amperes Fixed installation A 3-unit set of two 150-kilowatt generators operated in series for 3-wire distribution driven by synchronous motor	150 kilowatts 1200 revolutions per minute, 120/125 volts, direct current, compound-wound. Alternating-current ripple characteristic not over 1/2 of 1 per cent of rated voltage. Rating: 100 per cent load continuous 200 per cent for 15 minutes	450 horsepower 2300-volt, 3-phase, 60-cycle, 6-pole, 0.8 power factor, synchronous
3.	300 kilowatts—2400 amperes Portable installation Same as No. 2 above, but with self-supporting base	150 kilowatts Same as No. 2 above	450 horsepower 2300/4160 volts, 3-phase, 60-cycle, 6-pole, 0.8 power factor, synchronous
4.	300 kilowatts—2400 amperes Portable installation A 3-unit set of two 150-kilowatt generators operated in series for 3-wire distribution driven by induction motor	150 kilowatts 1150 revolutions per minute, 120/125 volts, direct current, compound-wound. Alternating-current ripple characteristic not over 1/2 of 1 per cent of rated voltage. Rating: 100 per cent load continuous 200 per cent for 15 minutes	450 horsepower 2300/4160 volts, 3-phase, 60-cycle, 6-pole, 0.88 power factor, induction
5.	200 kilowatts—1600 amperes Fixed installation A 3-unit set of two 100-kilowatt generators operated in series for 3-wire distribution driven by synchronous motor	100 kilowatts 1200 revolutions per minute, 120/125 volts, direct current, compound-wound. Alternating-current ripple characteristic not over 1/2 of 1 per cent of rated voltage. Rating: 100 per cent load continuous 200 per cent for 15 minutes	300 horsepower 2300 volts, 3-phase, 60-cycle, 6-pole, 0.8 power factor, synchronous
6.	200 kilowatts—1600 amperes Portable installation [illegible]	100 kilowatts Same as No. 5 [illegible]	300 horsepower [illegible]

The types of studio-lighting power sources in present use are legion and it is outside of the scope of this report to catalog all of them. Table I gives the characteristics of typical units and includes such factors as desired ripple characteristics which may not be present in some equipment, but which are desirable to minimize the necessity of choke coils and filters when using carbon-arc lamps.[5]

Metro-Goldwyn-Mayer Studios
Fig. 2—Portable motor-generator set, 300 kilowatts as in No. 3, Table I.



Metro-Goldwyn-Mayer Studios
Fig. 3—Same as Fig. 2 except unit in closed position.

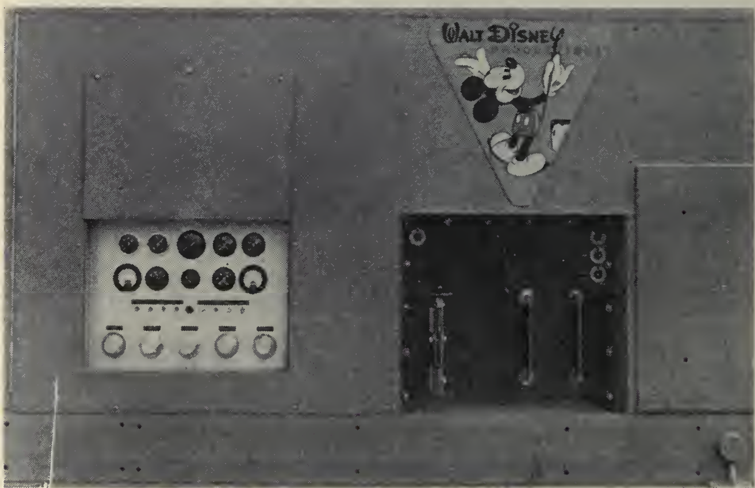
Compound-wound generators are used because of their ability to maintain voltage under widely fluctuating load conditions. Compound-wound generators may be, and often are, paralleled by the use of an equalizer, or low-resistance connection, between the machines which places their series fields in parallel. However, in order to accomplish the foregoing the generators must be of identical, or similar, electrical characteristics. Either similar or dissimilar compound

Walt Disney Productions

Fig. 4—Portable internal-combustion engine-driven generator. 150-kilowatt generator, 290-horsepower motor, 1400 amperes, Thiotron automatic voltage control.

generators may be paralleled by the use of automatic voltage regulators.

Permanent-installation motor-generator sets are mounted on concrete bases. Approximate weights for one known installation are 34,000 pounds for the 500-kilowatt set and 20,000 pounds for the 300-kilowatt set without bases.



Walt Disney Productions

Fig. 5—Same as Fig. 4. Control panel.

Drive motors on portable motor-generator sets are usually made for operation on more than one voltage and those used in Hollywood are capable of operation at both 50 and 60 cycles.

Internal-combustion engine-driven generator sets may be made up of any combination of generator and gas or diesel engine provided the generator characteristics conform to the speed-horsepower characteristics of the engine. It is desirable that the generator be capable

Mole-Richardson Company

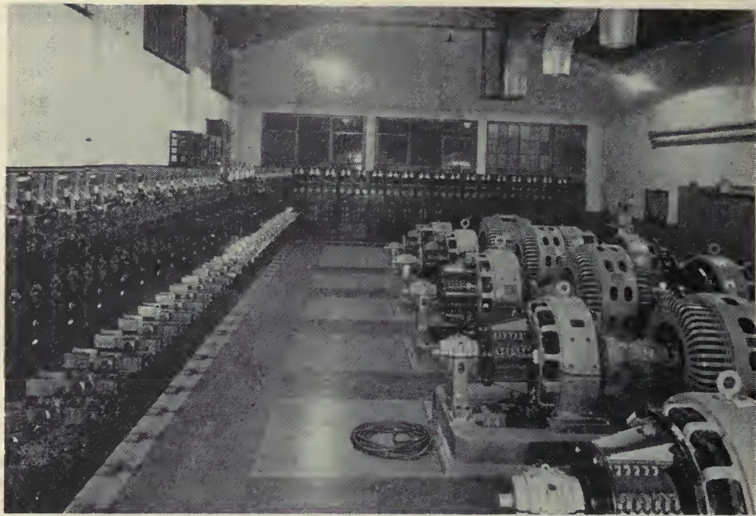
Fig. 6—A part of fleet of rental internal-combustion engine-driven generators. Rated at 1400 amperes, 120 volts, 230-horsepower engine.

of maintaining voltage with approximately 65 per cent load at around 65 per cent of its rated speed.

These sets usually have a capacity of between 750 and 1400 amperes at 125 volts. For design estimates a basis of 5 amperes of generator output per engine horsepower may be used. Engine horsepower so estimated includes that necessary to drive the water pump, fuel pump, and other usual engine accessories. As a protective measure, engine horsepower should be below that capable of driving the generator at an injurious load.

Incandescent lamps may be, and sometimes are, operated on alternating current to relieve a heavy direct-current load. This practice is not common, however, because of the difficulties encountered with two types of power being delivered through similar distribution systems on the sets.

Mercury-arc rectifiers have been considered as a direct-current source of power for motion picture studio lighting but no installations have been made to date.[6]



Westinghouse Electric Corporation
Fig. 7—Warner Brothers Studios powerhouse, 500-kilowatt Westinghouse motor generators.

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Proposed 16-Mm and 8-Mm Sprocket Standards

THE PAPER entitled "Proposals for 16-Mm and 8-Mm Sprocket Standards," by J. S. Chandler, D. F. Lyman, and L. R. Martin, was published in the June, 1947, issue of the JOURNAL OF THE SMPE for the purpose of inviting comment on the work that has been done on the design of sprockets. Discussion by letter was received from Mr. E. W. Kellogg of the Radio Corporation of America in which he questioned the propriety of the sprocket proposals as American Standards. Mr. Kellogg's letter was not received in time to be published at the same time as the paper; however, a notice appeared with the paper stating that Mr. Kellogg's discussion and a reply from the authors would appear at a later date. These two letters are published here.

JOHN A. MAURER
Engineering Vice-President

MR. E. W. KELLOGG: Much as I admire the work which the authors have done, I think that the title given the paper is not well chosen. There are, of course, many possible titles. One might be "A Method of Designing Sprocket Teeth for Minimum Flutter." We do not see any reason for suggesting that the resulting tooth shape be made a "Standard." In fact, the fundamental purpose of Standards is to make interchangeability possible. Obviously films must be interchangeable so that they will run on all machines, but if a manufacturer puts out a machine which performs well with a standard film, and the film is not subjected to undue wear, and his customers are happy, he has complied with all of the conditions which are important. Subject to the above conditions we might say that it is no one else's business what shape tooth he uses. The occasion for attempting actually to standardize sprocket designs would come only when and if it becomes the practice of projector and camera manufacturers to procure their sprockets from certain sprocket manufacturers who specialize in stock designs which are interchangeable and are to be used by various equipment manufacturers. We do not foresee such a development.

There is, on the other hand, a definite objection to giving the Society's official sanction to a specific design when sprocket teeth of other designs are in wide, successful use. The argument against such standardization has been well stated in correspondence between members of the present Subcommittee on "8-Mm and 16-Mm Projector Sprocket Standards." Messrs. Sachtleben and Isom of RCA pointed out

> that while the plan to extend the usefulness of existing sprocket-design information, by putting it into the form of formulas including several of the variables of projector design, was highly commendable, standardization of design

on the basis of such formulas was not desirable. This was because the growing prestige of standardization automatically would put a projector employing nonstandard sprockets at a competitive disadvantage; whereas it could be possible that under actual test the nonstandard sprockets would exhibit superior performance.

Mr. Isom emphasized

from his experience in the educational field, the prestige and authority standards enjoy among persons charged with the responsibility for institutional purchases. These people make their choices on the principle of elimination, and seize upon published standards as their aid and authority in this process.

For a number of years the Society has published information on the basis of which a designer can produce sprocket teeth which have been found to be satisfactory.

These designs have been published under the caption "SMPE Standards." While we hold to the position that such information should be designated as a recommended design procedure rather than a standard, we would not hesitate for a moment to say that the information has been useful to the industry. If the Society wishes to continue to call any sprocket-tooth design "Standard," it would be justified in changing to a new standard only if the new design had been shown, after prolonged use, to be definitely superior. We think for the present the Society should go no farther than to include it among acceptable designs and let experience provide the ultimate answer as to superiority. Although RCA engineers are not at the present time in a position to pass on the performance of the proposed tooth, we may say the following in regard to the tooth design which we have used practically without change for a good many years. This design corresponds very closely to the old SMPE "Standard" as published in 1934.

Many thousands of projectors have been in service for years in the Army and elsewhere where the service is severe. In all this experience practically no complaints have been received of trouble with sprockets. Mr. del Valle has given me the story of a series of tests of film life made, for the most part, during the summer of 1944. Twelve-foot loops were run through our projectors (including the intermittent) in a setup having a tensioning roller which put about 4 ounces tension each on the supply and takeup lines. The average life of a number of loops of film run in different machines, properly adjusted, was of the order of 25,000 passages, and one loop ran 86,000 passages before slight cracks appeared at the corners of the perforations. It cannot be said that this was a case of perfect fit because the test of this loop extended over many weeks during the summertime, and there must have been some shrinkage.

If we compare a tooth designed for a typical case, according to the formula given in this paper, with one designed according to the previously recommended practice, there is a striking difference in that the sides of the new tooth slope much more near the bottom, whereas the sides of the old tooth start more nearly vertical. The effect of this difference would be to give the film much more tendency to climb up the tooth or to make it necessary to resort to special measures to hold the film down against the sprocket body. It does not seem to me practical to force the film all the way down. Shoes must offer sufficient clearance to permit splices to pass. The film can still climb 5 or 6 mils up the tooth if it wishes to, and even ride at that position throughout its engagement with the sprocket.

We might expect then, in spite of the very well worked-out theory, that the new tooth, which under ideal conditions would minimize flutter, would give more erratic results, or require greater niceties of design and construction in order to realize the possible benefit. Although the old tooth undoubtedly would give more flutter at the sprocket than the new tooth when working at its best, we depend on mechanical filtering to take out the flutter, and it is a serious question whether other desirable properties should be sacrificed to reduce flutter at the sprocket. The actual 24-cycle or 96-cycle flutter is very effectively filtered. Much harder to filter out would be variations in the manner in which the film rides on the sprocket which might result in random phase shifts at the sprocket, having components of much lower frequency.

While my remarks are based largely on theory and it may well be that the authors of the paper have gotten excellent results from their sprockets, I think that there is abundant reason for a very cautious attitude on the part of the Society with regard to recommending the new design as superior, or of giving it the special sanction of calling it "Standard," especially when the former designs are giving such excellent satisfaction.

There are special cases where mechanical filtering is not employed, such as sprocket-type printers and certain recorders, and for these applications the authors' approach to the problem of minimizing flutter deserves careful consideration.

J. S. CHANDLER, D. F. LYMAN, AND L. R. MARTIN: The authors are grateful to Mr. Kellogg for the careful attention he has given this subject, and for his comments, which serve to re-emphasize some of the important points in the paper. We agree that the desirability of standardizing sprockets on the basis of insuring good performance is open to question, since the usual function of standards is to provide for interchangeability of parts. But the present ASA standard for 16-mm sprockets, Z22.6-1941, deals with dimensional specifications that are related not only to interchangeability but also to performance. We agree also with Mr. Kellogg's statement that the information in the present standard has been useful to the industry. It has been realized for some time, however, that the existing standard is inadequate in that the same tooth profile is recommended for all sprockets, regardless of the number of teeth on the sprocket. Moreover, no account is taken of such related and dependent factors as the range of film shrinkage for which accommodation is to be made and the shape of the path followed by the film as it approaches and leaves the sprocket. If for these reasons the current standard is allowed to lapse and no substitute is made available, the industry will soon be keenly aware that it lacks an authoritative source of information on this important subject.

It was largely because of these latter considerations that a committee on sprockets was formed and the project leading to the present proposals was instigated. One point should be emphasized: the profile recommended for the tooth is designed to give maximum film life, not necessarily minimum flutter. The fact that the recommended tooth would, theoretically at least, result in less flutter than would be obtained with the alternative shape shown in Fig. 9 of our paper is incidental; it follows from the basic principle that if the acceleration of the film is kept low as it strips off the driving tooth, the impact of the film against the next tooth is less severe.

As Mr. Kellogg points out, the recommended tooth slants more at the base than does the tooth in the existing ASA standard. This criticism was offered early in the work on the proposals, and that is why the alternative profile was included in Fig. 9. Experiments have demonstrated that the flexing of the film in the region of the loaded edge of the perforation, rather than impact loading, determines the life of the film. If further studies show that the alternative tooth shape, which is steeper at the base but more sloping at the tip, affords longer film life, it should be the one that is recommended and the formulas should be changed accordingly.

The purpose of submitting this proposal is to encourage more trials by a number of investigators, since sprocket specifications resulting in optimal performance can be determined only after extensive tests. The form of the proposal is such that the equations can be altered readily to make them comply with the results of such tests, the importance of which cannot be overemphasized.

Incorporation of American Standards Association

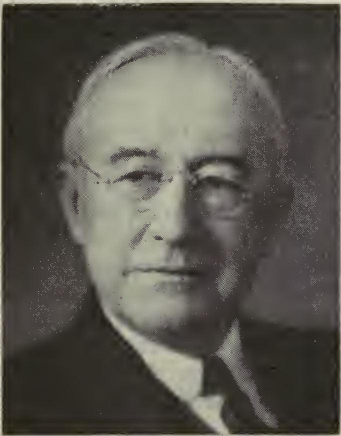
THE AMERICAN Standards Association became the American Standards Association, Incorporated, August 2, 1948, through incorporation under the laws of the State of New York. This is the third in a series of changes which have consistently recognized the enlarging scope of the Association's work.

Organized in 1918 as the American Engineering Standards Committee, a co-ordinating committee for the standardization work of five of the country's important technical societies, the scope and organizational setup were soon broadened to include associations and government agencies. This led to the extension of the work into the field of safety standards. In 1928, an entire reorganization took place, changing the Committee into a full-fledged "American Standards Association," the nation's clearing house for standards and the United States medium for international contacts on standardization. The present change to an incorporated Association again recognizes the enlarged activities and responsibilities of the organization, giving it and its members the protection and benefits which corporation law affords and which is considered essential in the light of the scope of the Association's activities.

Bills seeking Federal incorporation are now before Congress, having been introduced in the House by the Honorable Kenneth B. Keating of New York, and in the Senate by the Honorable Ralph Flanders of Vermont.

The Association's co-ordinating functions now extend to standards in the mechanical, electrical, building, photographic, mining, safety, and consumer-goods fields, as well as such general work as that on office equipment and abbreviations and symbols for use in engineering and scientific literature.

Frederick R. Lack, vice-president, Western Electric Company, is president of the Incorporated Association. Vice-Admiral G. F. Hussey, Jr. (United States Navy, retired), is secretary and adminstrative head, and Cyril Ainsworth is technical director.



Thomas Armat

Thomas Armat, pioneer inventor of the motion picture projector, who died on September 30, 1948, received a special award this year from the Academy of Motion Picture Arts and Sciences for his contributions to the development of the motion picture. The statement of the Academy reads as follows:

> "Academy Special Award to Thomas Armat, one of the small group of pioneers whose belief in a new medium, and whose contributions to its development, blazed the trail along which the motion picture progressed, in their lifetime, from obscurity to world-wide acclaim."

In 1946, on the occasion of the Fiftieth Anniversary of the first exhibition of motion pictures in a theater, Mr. Armat was awarded a Citation by the Society of Motion Picture Engineers in recognition of his distinguished inventions which were outstanding features of his first projecting machine.

Mr. Armat was born in Fredericksburg, Virginia, on October 26, 1866, and in February, 1896, he demonstrated a motion picture projector of his own design to Thomas A. Edison at his laboratory in West Orange, New Jersey. This projector, known then as the Vitascope, was the first to incorporate a loop-forming means and a longer period of rest and illumination than the time required to move the film from one frame to the next. These features were a major step in the development of modern motion picture projectors and were incorporated subsequently in most commercially successful projection machines.

Mr. Armat was elected an Honorary Member of the Society of Motion Picture Engineers in October, 1935.

Louis Lumiere

Louis Lumiere, 83, foremost Frenchman of the cinema, died on June 6, 1948, at Bandol on the Riviera.

M. Lumiere and his brother, Auguste, were among the pioneers outside the United States who developed the possibilities of the motion picture Kinetoscope. On December 28, 1895, they opened an exhibition in the basement of the Grand Cafe in Paris. This marked the beginning of commercial motion picture exhibition in France.

The Lumieres were manufacturers of photographic materials at Lyon, in France. They set to work, as did so many others, to join the Kinetoscope's peep-show pictures with the magic lantern to achieve projection. Lacking film base, which could only be had from their American competitor, Eastman, they sent to New York for a makeshift material, strips of celluloid from the American Celluloid Company. Being economically minded, also, they cut the rate of motion picture photography from Edison's 48 frames a second to 16 frames.

After the demonstration of his motion picture camera Lumiere experimented with color photography and developed a number of photographic appliances. So outstanding were his contributions that on April 22, 1935, he received a tribute from the Motion Picture Producers and Distributors.

M. Lumiere was, for a short time, a member of Marshal Petain's advisory council of State. He was honorary president of the French Chamber of Cinema, a member of the French Academy of Sciences, a grand officer in the Legion of Honor, and an Honorary member of the Society of Motion Picture Engineers.

Terry Ramsaye

Thad C. Barrows

Thad C. Barrows, 59, president of Boston Local 182 from 1918 until 1947, died as a result of a heart attack on June 2, 1948.

Until the day of his death he was actively engaged in his craft in Boston's Metropolitan Theater, and his interest in technological developments in his work was unflagging.

Recognition of his enthusiastic devotion to his field came in 1929 when he was unanimously elected the first president of the Projection Advisory Council, a national organization which contributed greatly to the industry during the difficult years of transition to sound motion pictures. He was an Active member of the Society of Motion Picture Engineers for 20 years.

His sincerity, courage, and honesty won the affection and respect of all who knew him.

Book Reviews

Enlarging—Technique of the Positive, by C. I. Jacobson

Published (1948) by the Focal Press, Inc., 381 Fourth Ave., New York 16, N. Y. 307 pages + xx pages + 9-page index. 77 illustrations. $5^1/_4 \times 7^1/_2$ inches. Price, $3.50.

The culmination of the photographer's work is the print. Involved in its preparation is a whole series of events including materials, techniques, and equipment. These are the negative, the printing media, the enlarger, the processing technique, and the aftertreatment. Involved also are psychophysical and physiological aspects such as perspective and other distortions, definition, and visual acuity. All of these topics are treated in a chatty manner which makes for easy reading. As with the companion volume (see the review on "Developing," by the same author, published in the July, 1948, issue of THE JOURNAL, page 105), the emphasis has been laid on description without the use of technical language, and without the presumption of a technical background. And yet an adequate panorama of the field is given.

The book will be valuable to all who desire to learn what is involved behind the scenes, when a camera record is converted into a final print. After a discussion of the negative material and its characteristics, as examplified by the negative to be printed, it goes on to treat in detail the printing media upon which the negative is to be copied. The first quarter of the book is therefore concerned with the materials used. But equipment and techniques are also involved in the cycle of events. The discussion of these incidentals is the subject matter of the remainder of the book. One obtains a working knowledge of the intricacies of enlarging equipment, of the various printing techniques, of tone separation processes, montages, and other matters. All in all it is a darkroom man's elementary handbook on printing, and it will serve him as an excellent guide to help him solve old problems, or indicate to him new ones.

JOSEPH S. FRIEDMAN
Ansco
Johnson City, New York

Camera and Lens, by Ansel Adams

Published (1948) by Morgan and Lester, 101 Park Ave., New York 17, N. Y. 117 pages + 3-page index + viii pages. 77 illustrations. $6^1/_4 \times 9^1/_4$ inches. Price, $3.00.

This book is the first in a series of six volumes on basic photography to be written by Ansel Adams. It is intended to acquaint the aspiring still photographer with those fundamentals of camera operation which the author considers essential in creative photography. However, there are six short chapters pertaining to darkroom layout and construction, darkroom equipment, the finishing room, negative storage, print storage, and print-display devices, none of which has much relation to the camera and lens.

Mr. Adams is a photographer of repute. Some of his pictures rank among the best that have ever been produced, which attests his ability as a competent judge of aesthetic and photographic quality. It is unfortunate that he did not choose to write a book in these fields, for he does not appear to be sufficiently versed in the technical aspects of photography to discuss them authentically.

For a beginner's book too many terms are used before they are defined, and in some instances the terms are nowhere properly defined. For example, on page 5 the term "parallax" is used without being defined, and not until page 15 is it stated that lens speed is expressed as *f*/8, *f*/3.5, etc., although this designation is used freely on previous pages. And in the chapter beginning on page 88, *f* number is improperly defined.

Mr. Adam's discussion on composition is considerably better than one finds usually in the photographic literature.

Lloyd E. Varden
Pavelle Color
New York 19, N. Y.

Informational Film Year Book 1947

Published (1947) by the Albyn Press, 42 Frederick St., Edinburgh 2, Scotland. 174 pages. 25 illustrations. $5^1/_2 \times 8^3/_4$ inches. Price, 10*s*. 6*d*. net.

The rapid growth of the nontheatrical film in recent years is indicated clearly in several of the articles in this Film Year Book. Twelve short articles by well-known writers such as Paul Rotha, John Grierson, Andrew Buchanan, Forsythe Hardy, and Basil Wright comprise about one half of the book. Subjects discussed include documentary films, the conditions in nontheatrical film industry in America, the services rendered by the film in industry, the classroom film and films for children, and the use of films by the United Nations Educational, Scientific, and Cultural Organization (UNESCO). Summarizing the place of the nontheatrical film in the world today, Norman Wilson states, "It should be the aim of everyone who believes in democracy to make the freedom of the screen as much a reality as the freedom of the press."

The latter half of this interesting volume contains a "Buyers' Guide" on new substandard apparatus; a group of stills from documentary films of the year; a list of the informational films of the year; also lists of film-producing organizations, cine societies, studios, laboratories, libraries, manufacturers of cine apparatus, specialist cinemas, and film periodicals.

Glenn E. Matthews
Kodak Research Laboratories
Kodak Park, Rochester 4, New York

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

29, 6, June, 1948

The Application of Motion Picture Technique to Television (p. 194) R. B. Austrian

U. S. Navy Develops Super-Speed Cameras (p. 207)

29, 7, July, 1948

Photography for Television (p. 229) F. Foster

29, 8, August, 1948

Transition Lens for Television Cameras (p. 266) F. Foster

The New "Spectra" Measures Color Temperature (p. 267) F. Gately

3000 Frames Per Second (p. 269)

British Kinematography

12, 5, May, 1948

Sound-on-Film Reproducing Equipment:

I. The Sound Head (p. 155) A. T Sinclair

II. Electrical, Electronic and Acoustic Design (p. 159) H. J. O'Dell

Television Production in Contrast to Film Production (p. 164) P. H. Dorté

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A New Television Film Scanner (p. 174)

Improving Circuit Diagrams (p. 175) L. H. Bainbridge-Bell

Electronics

21, 7, July, 1948

Design Factors for Intercarrier Television Sound (p. 72) S. W. Seeley

Photometry in Television Engineering (p. 110) D. W. Epstein

Ideal Kinema

14, June 10, 1948

Consistency and Colour of Screen Illumination (p. 20) R. H. Cricks

International Projectionist

23, 6, June, 1948

New Acetate Film for Release Prints (p. 5) C. R. Fordyce

Projection Factors of New Acetate Film (p. 6)

23, 7, July, 1948

Control of Sound-Film Reproduction (p. 5) R. A. Mitchell

New Century Sound Systems Feature Fundamental Reproducer Advances (p. 8)

Television: How It Works (p. 10) W. Bouie

Theater Television: A General Survey (p. 19) A. N. Goldsmith

23, 8, August, 1948

Television: How It Works. Pt. 2 (p. 9) W. Bouie

Projector Progress in Great Britain (p. 18) H. Hill

Proceedings of the I.R.E.

36, 6, June, 1948

The Application of Projective Geometry to the Theory of Color Mixture (p. 709) F. J. Bingley

36, 7, July, 1948

Avenues of Improvement in Present-Day Television (p. 896) D. G. Fink

Radio and Television News

40, 2, August, 1948

The Recording and Reproduction of Sound. Pt. 18 (p. 49) O. Read

RCA Review

9, 2, June, 1948

Motion Picture Photography of Television Images (p. 202) R. M. Fraser

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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:

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BOYCE NEMEC, Exec. Secy., Business Manager.

Sworn to and subscribed before me this 18th day of August, 1948.

(Seal) Elisabeth J. Rubino
Notary Public, Clerk's No. 2986,
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(My commission expires March 30, 1949)

Journal of the
Society of Motion Picture Engineers

VOLUME 51 NOVEMBER 1948 NUMBER 5

Subscription to nonmembers, $10.00 per annum; to members, $6.25 per annum, included in their annual membership dues; single copies, $1.25. Order from the Society's general office. A discount of ten per cent is allowed to accredited agencies on orders for subscriptions and single copies. Published monthly at Easton, Pa., by the Society of Motion Picture Engineers, Inc. Publication Office, 20th & Northampton Sts., Easton, Pa. General and Editorial Office, 342 Madison Ave., New York 17, N. Y. Entered as second-class matter January 15, 1930, at the Post Office at Easton, Pa., under the Act of March 3, 1879.

Society of Motion Picture Engineers

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Proposed Standards for the Measurement of Distortion in Sound Recording*

Organization and Plan of Work

On October 25, 1947, a meeting was held of the American Standards Association Committee on Standards for Sound Recording, under the chairmanship of George Nixon of the National Broadcasting Company. On this committee the Society of Motion Picture Engineers was represented by J. A. Maurer, C. R. Keith, Otto Sandvik, and E. W. Kellogg, who was asked to assume the chairmanship of a subcommittee to recommend standards with respect to the measurement of performance characteristics and distortion in sound recording and reproducing systems. The membership of the subcommittee is as follows:

Edward W. Kellogg, *Chairman*
RCA Victor Division
Camden, N. J.

W. S. Bachman
Columbia Recording Corporation
New York, N. Y.

Peter Chrzanowski
National Bureau of Standards
Washington, D. C.

L. C. Holmes
Stromberg-Carlson Company
Rochester, N. Y.

G. B. Meyer
Westinghouse Electric Corporation
Baltimore, Md.

K. B. Lambert
Metro-Goldwyn-Mayer Pictures
Culver City, Calif.

G. T. Lorance
General Precision Laboratories
Pleasantville, N. Y.

R. A. Lynn
National Broadcasting Company
New York, N. Y.

Otto Sandvik
Eastman Kodak Company
Rochester, N. Y.

Harry Schecter
Air Matériel Command
Cambridge, Mass.

R. R. Scoville
Electrical Research Products
Los Angeles, Calif.

W. H. Offenhauser, Jr.
New Canaan, Conn.

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

The work had been carried on largely by correspondence, with one meeting held at ASA headquarters on January 21, 1948. The method for the most part has been for the chairman, with the help of the members, to attempt to ascertain what standards already exist, or what procedures are current, and then to formulate proposals for the subcommittee members to criticize or correct. The circular letters with proposals, discussions, and questions have also been sent to numerous qualified persons who are not members of the subcommittee, and many valuable letters have been received. It is appropriate to acknowledge here the thoughtful comments plus information received from Howard Chinn of the Columbia Broadcasting System, New York; R. C. Moyer of the RCA Victor Division, Indianapolis; W. R. Furst, of Furst Electronics, Chicago; J. W. Bayliss and Kurt Singer of the RCA Victor Division, Hollywood; John T. Mullin of W. A. Palmer Co., San Francisco (representing also views of Ampex Corporation, San Carlos, Calif.); J. K. Hilliard of the Altec Lansing Company, Hollywood; Captain R. Bennett of the Navy Electronics Laboratory, San Diego; H. H. Scott of H. H. Scott, Inc., Cambridge; S. J. Begun, of Brush Development Company, Cleveland; and A. R. Morgan of the RCA Laboratories, Princeton. Few of the proposals here outlined have had final approval of the subcommittee membership for submission to the main committee, but it seems desirable to take advantage of the opportunity offered by the Spring Convention of this Society to obtain a wider consideration of the questions on whose answers any standards must depend. This method is similar to what the SMPE Sound Committee did last year in submitting their proposals on Flutter Standards in a report, for consideration by the entire Society membership. This afforded them the benefit of wide discussion and many viewpoints before the proposals were taken up by the Standards Committee. We hope to have a similar experience with respect to the proposals submitted here.

TYPES OF DISTORTION

Distortion in reproduced sound may be broadly divided into four types.

(1) Inaccuracies of pitch or frequency, especially fluctuations in pitch relative to the original, which are generally called "flutter" or "wow."

(2) Inequalities in the amplification of sounds
- (a) depending on their frequency (lack of flat frequency response);
- (b) depending on their amplitude (volume expansion or compression);
- (c) variations with time (fluctuations in level relative to original).

(3) Phase distortion. In the reproduced sound certain components of complex sounds are delayed with respect to others. Transient distortion due to equipment resonances is one type of phase distortion, in that energy is absorbed from the sound for a short period of time and then released. Irregularities in frequency-response characteristics (as, for example, peaks due to resonance) are nearly always accompanied by phase distortion.*

(4) Production of spurious sounds, not in the original
- (a) overtones, due in general to nonlinearity in the instantaneous (or dynamic) output-to-input relationship in one or more of the elements of the system;
- (b) beat tones, also due in general to nonlinearity, resulting in rectification, but also caused by proximity effects in the record as in high-frequency variable-area recording;
- (c) noise, generally divided into that due to hum, mechanical vibration, and microphonic elements, and that due to the granular character of the record, plus foreign particles and minor injuries or abrasions. There are also noises of thermal and tube origin.

TOPICS COVERED

The assignment of our subcommittee does not include attempting to set standards of performance, but only to recommend such standards as can be agreed upon for the measurement of performance characteristics and distortion. This may, however, involve specifications for the measuring equipment itself.

Standardization in measurements has, for its main object, the enabling of persons in different laboratories to check and compare measurements; but a second and no less important object is to prevent

* If phase distortions of this kind produce any audible quality changes, they are usually so overshadowed by the variations in response as to be of secondary importance. Moreover, measures which correct the response irregularities usually also correct the phase distortion.

the misunderstandings which result from use of different systems, and especially from use of the same term with different understandings of its meaning. In many cases it may not be possible to get people in various organizations to adopt a single standard method of making tests and, when this situation is encountered, it still should be possible to prevent misunderstandings, by establishing definitions of terms and by calling for adequate information to accompany reports of tests, so that the reader may know when certain figures are not directly comparable. Hence, two important parts of the standards toward which we are working are definitions of terms and stipulations about reporting results.

Although, to the listener, distortion is anything which makes the sounds reaching his ears different in quality from those produced by the original source, the present work is limited to the quality changes which are caused by the operations of recording and playing back or, in other words, the differences between direct and transcribed sound.

The principal topics so far discussed are:

1. Flutter or wow.
2. Frequency-response characteristics.
3. Distortions of the type which cause changes in wave shape.
4. Noise and signal-to-noise ratio.

STANDARDS FOR FLUTTER MEASUREMENT

The Sound Committee of the SMPE, under the able chairmanship of J. G. Frayne, worked out a series of standards proposals with respect to "flutter" or "wow," and these were published in the JOURNAL for August, 1947. A great deal of thought and work had gone into these proposals, and comments by many individuals representative of different organizations had been invited and considered.

There was thus available to our ASA subcommittee a draft of specifications dealing with this important problem, which could well be made the basis of the ASA specification, provided they were likewise acceptable to makers and users of sound-recording equipment in other fields, especially equipment for use with disk records. Broadcast stations and disk-record manufacturers are represented on our subcommittee and opinions have been invited from others. We believe that the proposals submitted by your Sound committee will find general acceptance by all groups interested in sound recording perhaps with some additions and changes of wording, but with no essential changes of meanings.

On one item, however, our subcommittee took the position at the February, 1948, meeting, that recommendation as an ASA standard would be premature, namely, the quantitative part of the definition of the term "Flutter Index." While it is admitted by all that the information given in the formulation is interesting and valuable, several of our members questioned whether it is directly applicable to recorded sound in general, the perception threshold for continuous tones in a live room being much lower than for ordinary music under average listening conditions. In view of the divergent viewpoints, recommendation of a standard for Flutter Index may be delayed as compared with the remainder of the flutter standards, but it is not our intention to postpone action any longer than is needed to arrive at an all-around understanding.

Although none of the subcommittee members has objected to specifying flutter in terms of root-mean-square magnitude, a number of people have expressed the idea that the peak values of flutter are more significant with respect to quality damage than the root-mean-square values. The chairman of this committee wishes to take advantage of this opportunity to present his personal discussion of this and one or two other questions. For better continuity of the report of the ASA work, this discussion is put in an Appendix.

PARAGRAPH NUMBERING

In what follows, the paragraphs which are numbered, as 3.1, 3.2, etc., and the "Notes" directly under them, are the proposed definitions or specifications, and notes of explanation which would, if approved, be incorporated in the standards with substantially their present wording. Paragraphs not numbered in this manner, or in other words the remainder of this paper, are the writer's explanations or discussions, which have not been put into the form of standards. The numbering employed is part of a topical system, and is of no concern to the reader except as he may find some cross references.

FREQUENCY-RESPONSE CHARACTERISTIC

It has seemed to the chairman unnecessary to go into details of measuring methods for this determination, since the main requirements are rather obvious. However, if any are of the opinion that material should be added to what is here suggested, it is hoped that we shall hear from them. A definition is in order, and the requirements to avoid errors due to measuring harmonics or noise instead of the true useful output, and it is necessary to specify something about the levels at which the tests are to be run.

3.1 Definition—Frequency-Response Characteristic.

The frequency-response characteristic (sometimes shortened to "frequency characteristic") of a sound system, or any portion of a sound system, is the output level (or "response") as a function of frequency for constant sine-wave input, the output being usually expressed relative to some arbitrary level, for example, the level at 1000 cycles.

3.2 All distortion components (harmonics or noise) must be excluded from the output measurement.

3.3 The input level chosen shall be high enough so that at no frequency within the range covered is the true output less than 10 decibels above noise, and low enough so that at no frequency, within the range covered, will overloading occur in sufficient degree to affect the reading appreciably.

3.3a Another way of stating the second requirement is that the input level must be sufficiently below that which would cause overload, so that a characteristic taken at a slightly (say 2 db) lower level will, if plotted on a decibel scale, have identical shape.

3.4 It is permissible, provided the above conditions are met, to take part of the measurements with a different input level than the remainder. This may be advantageous in testing systems in which a large amount of pre-emphasis of high frequencies is employed.

3.5 The output-input relationship shall be that which occurs under steady-state conditions. Thus, if the practice is followed of employing a continuously variable input frequency and changing this rapidly, the rate of sweep shall be slow enough to give results identical with those obtained with a slower sweep.

NOTE 1: It is customary to express input and output levels in amplitude terms (not power) or else in decibels above or below a chosen reference.

NOTE 2: The frequency-response characteristic may include intentional departures from uniformity as, for example, a rising recording characteristic by way of pre-emphasis of high frequencies.

FREQUENCY CHARACTERISTIC OF A RECORD

For testing the characteristics of reproducing systems, it is necessary to employ test records whose characteristics can be definitely specified. It is not always possible to make a logical distinction between the losses or distortions which are to be attributed to the record and those which should be charged against the reproducing system. Whenever it is possible to state the characteristics of the record without specifying anything about the reproducing system, this is desirable. Hence, it is proposed that

3.6 The recorded level on a disk record is the velocity (maximum of cycle) corresponding to the slope of the centerline of the groove.

Or, as an alternative definition,

3.6a The recorded level on a disk record is $2\pi fa$, in which f is the frequency and a is the amplitude of the recorded wave.

NOTE 1: In the case of records cut in wax and properly processed, the velocity of the recording stylus is the recorded level. In the case of a lacquer disk, recorded with a cutter having a burnishing surface, there is some springback in the record material, and the cutting stylus velocity is not a safe guide to the recorded level.

The amplitude of the recorded waves can be measured microscopically. The light pattern method of checking a record calibration is believed to be, when carefully carried out, a reliable indication of the recorded level.

3.7 The recorded level on a film is the amplitude of the fundamental (sine-wave) component of the sound-track transmission.

NOTE 1: A photographic record may be calibrated by measuring the reproduced level, using a reproducing system whose performance and characteristics are known. The scanning beam should form on the film a rectangular image of uniform intensity, having a length equal to the standard for the type of track under test and a height which is small in comparison with the wavelength, and not more than 10 per cent of the total light should fall outside the boundaries of the rectangle. Correction is then made for the finite width of the scanning image, by multiplying the output by $x/\sin x$ where $x = \pi w/2\lambda$, w being the width (or height) of the scanning image and λ the length of the recorded waves. It is recommended that this correction be made small by making w as small as will afford adequate light and satisfactory stray-light ratio.

Specification of recorded level in terms of the cyclic peak is, to the best of the writer's information, more widely current than the use of root-mean-square figures. The probable reason is that it is more simply related to the overload point. The fact that electrical levels are specified in root-mean-square terms might be thought to lead to possible confusion, but that danger is lessened by the fact that the recorded level is not an electrical quantity. However, statements of recorder or reproducer response must be so worded as to avoid possible misunderstanding.

3.8 In the case of a magnetic recording no way of specifying recorded level seems feasible at present, except as the record is tested with a specified reproducing system.

WAVE-SHAPE DISTORTION

Since the problem of measuring distortion in recording and reproducing systems is in general the same as in any audio transmission system (for example, in an amplifier), existing standards are applicable. Test systems tend to crystallize around developed and available equipment. Four types of distortion-measuring equipment have found wide use.

(1) *Wave Analyzers*, by which the amplitude of each overtone or harmonic, relative to the fundamental, can be measured.

(2) *Distortion-Factor Meters*, which suppress the fundamental and measure the sum total of what is left (overtones, rumble, hum, and surface noise), expressing the root-mean-square magnitude of this residue, relative to that of the fundamental. At the higher levels, and with reasonable control of rumble and hum, distortion-factor meters serve to measure total harmonic distortion.

(3) *Intermodulation Analyzers*, which measure the fluctuations in level of a low-amplitude, relatively high-frequency tone when superimposed on a high-level, low-frequency tone. Levels 20 and 80 per cent, respectively, of normal full sound-track amplitude have been widely employed. Intermodulation is a more sensitive test (higher readings for the same distortion) than total harmonic distortion. It has been especially useful in variable-density photographic recording, and has been employed in a limited way in studying distortion in disk recording systems. Equipment now in use gives the choice of several frequencies for the low- and high-frequency components.

(4) *Cross-Modulation Analyzers*—A high-frequency tone modulated at a relatively low frequency is recorded. The high-frequency tone is suppressed in reproduction, and only the output (if any) at the modulation frequency is measured. This is essentially a test for rectification. It has been especially useful in variable-area photographic recording.

There does not appear to be any serious danger of confusion or misunderstanding of the results of the test methods listed above, provided the practice is followed of stating the results as "total harmonic distortion," "intermodulation distortion," and so forth. Hence, our committee may not be called upon to recommend any modification or amplification of existing standards. It is altogether likely that in the application of intermodulation testing to disk recording (and perhaps to magnetic recording) results may prove to be more informative when other frequencies are employed than those adopted for variable-density sound tracks. Thus, it would be inadvisable to recommend present standardization of frequencies. However, it is desirable that intermodulation measurement figures be accompanied by statements of the component frequencies.

Up to the present, trouble has been experienced in making wave-analyzer measurements of reproduced tones, because in the available meters the filters are so sharp that speed imperfections in the recording or reproducing machines have prevented the proper functioning of the wave analyzer. We understand that instruments with broader filters will, in the near future, be available. The same problem can occur in distortion-factor meters, but several models have been on the market which have been entirely satisfactory in this respect.

Noise and Signal-to-Noise Ratio

In the measurement of noise there has been considerable variation of practice, and still more divergent practices are followed in specifying the signal level with reference to which the noise is to be stated. In some cases the noise is measured with a "flat" reproducing system, and in others with a reproducing system which has purposely been given a drooping characteristic to lessen the noise. Filters to eliminate hum and rumble are sometimes employed, especially when the purpose is purely a study of record materials. In stating signal level it has been customary in the film industry to use practically the maximum permissible recording level. The same practice will probably be followed in magnetic recording. On the other hand, in the field of mechanical or disk recording it has long been customary to employ a reference level or 1000-cycle standard signal which on a volume indicator gives a reading that safely may be equaled when recording regular program material. In this there is an allowance of about 10 decibels for peaks. The standard reference signal generally adopted is two inches or five centimeters per second, maximum velocity. The recordist notes the reading on his volume indicator produced by the standard signal, and then knows that if he does not let his volume indicator (which is somewhat sluggish) go above that reading, he is reasonably safe with respect to the sudden peaks. Such a reference signal has unquestioned utility, but it does not have to be identical with the reference for specifying the signal-to-noise ratio of which a given recording system is capable. The difference in practice may readily lead one not familiar with the situation to think that a mechanical system is about 10 decibels worse than it is actually is, in comparison with other systems.

Fully conscious of the difficulties of inducing groups of people to change any of their practices, we have nevertheless thought it worth while to raise the question whether unified practice and terminology are attainable and, in order that those who are interested may judge better what might be involved, an attempt has been made to draw up some specific proposals which, it is hoped, might be acceptable as not upsetting established practices, while reducing the likelihood of misinterpretations When it is not feasible to have all people follow identical procedures, it should at least help prevent misunderstandings if certain information is given when reporting results, a requirement to which scarcely anyone could object In the first place, it is proposed that the present 5-centimeter-per-second tone be called the "recording reference signal," and that another signal, to be called "maximum signal," be employed for determining the signal-to-noise ratio of a system. Since the recording reference signal would not be directly employed in signal-to-noise determinations, its definition does not belong in the present specification, but a note is included to point out the distinction.

Proposed definitions and specifications for signal-to-noise determinations are as follows:

5.1 *Noise*—The term noise, as applied to a sound-reproducing system, means any output power which is not of the same frequency as the input, except that distortion products (harmonics or rectification terms) are not usually regarded technically as noise.

NOTE 1: Noise is commonly comprised of hum, rumble, or the effect of mechanical vibrations, microphonics, thermal noise (in low-level input circuits), tube noise, phototube hiss, and, in recorded sound, surface noise in the case of mechanical records or graininess plus scratches and dirt in photographic records.

Noises such as thermal noise, phototube hiss, record surface noise, and graininess in film sound tracks have an energy distribution such that the power within any frequency band is approximately proportional to the width of the band in cycles.

NOTE 2: The usual method of measuring noise in any type of sound record, is to reproduce from an unmodulated record and measure the noise in the reproducing system.

5.2 *Modulation Noise*—The presence in a record of the factor which produces output (light transmission in a film, slope of a groove, or a magnetization in a wire or tape) results in an increase in noise as compared with the condition of no modulation. This extra noise, which is modulated with the signal (generally at double signal frequency) is called "modulation noise." The increase in noise due to removal of ground-noise reduction bias in photographic sound tracks is not true modulation noise.

NOTE 1: Modulation noise may be measured by recording a tone (usually of relatively low frequency) and measuring the reproduced output with the recorded tone eliminated by a band-suppression filter of sufficient bandwidth effectively to eliminate the recorded tone.

5.3 The frequency characteristic of the reproducing system used for measuring noise in recorded sound should be the same as that of the reproducing systems with which the record is designed to be used, except that if the reproducing systems include compensation for loudspeaker characteristics, such compensation should be omitted for the measurement.

5.4 A statement of the frequency range covered by the reproducing system used in a noise measurement should accompany a report of the measurement. If the frequency characteristic is approximately flat between the droops at the ends, the range may be stated as between the frequencies at which the response has dropped 6 decibels below the average within the effective range. If the reproducing characteristic used in the noise measurement is one that has been standardized (as in the case of theater systems) reference to the standard may serve as description of the reproducing characteristic.

5.5 If a high-pass filter is used for excluding hum and rumble when measuring record noise, this should be stated, and the cutoff point of the filter.

5.60 *Maximum Signal*—Maximum signal is a pure tone of the maximum level that can be recorded without overload.*

* This is to be distinguished from *Recording Reference Level* employed in mechanical systems, which has been standardized as 2 inches or 5 centimeters per second (maximum velocity of cycle) and is about 10 decibels below maximum signal.

5.61 The level of maximum signal is the highest compatible with the condition that if the input is varied as specified in 5.62, at no frequency will the distortion exceed a specified amount (for example, 10 per cent intermodulation).

The distortion permitted in this determination should be specified in reporting the value of maximum signal.

5.62 In view of the fact that in nearly all program material components of high frequency are rarely present in magnitudes as great as the components of lower frequency, it is permissible for establishing maximum signal level to reduce the input level in the high-frequency range in accordance with the following rule: the input shall be maintained at constant level from the lowest frequency comprised in the recording range, up to 1500 cycles, above which the input level may be reduced at the rate of 4 decibels per octave.

NOTE 1: The purpose of Specification 5.62 is to permit the employment of a safe amount of pre-emphasis of high frequencies in recording. By "safe" is meant that only in exceptional cases will material to be recorded have peak high-frequency components with magnitudes (relative to the peak magnitudes in the low-frequency range) any greater than indicated by the characteristic described in 5.62.* It is anticipated that the figure, 4 decibels per octave, and perhaps, also, the 1500-cycle transition point, should be reviewed from time to time in the light of accumulated experience. It should be recognized that this characteristic is to be determined solely by the nature of the spectra of music and speech, and that it does not and should not make any allowance for properties of recording systems which may cause overload to occur at lower levels in one portion of the frequency range than in others. It is, however, in order, that this permitted droop should take account of distortion tolerance, provided experience justifies such an allowance. (For example, harmonics of high-frequency tones may not be reproduced, and if cross-modulation is not encountered, the tolerance may be greater in this range.)

5.7 *Signal-to-Noise Ratio*—Signal-to-noise ratio is the ratio of maximum signal to noise.

* Allowable pre-emphasis is discussed in a report by J. K. Hilliard and J. P. Maxfield in *Audio Engineering* for April, 1948. Permissible pre-emphasis has been well expressed by Hilliard as "that which causes equal probability of distortion at any part of the important frequency range covered by the record." It is also pointed out that compensation for reduced response of some element of the recording channel (such as high-frequency droop of a microphone) is not a part of pre-emphasis.

5.71 The limiting distortion (as, for example, 2 per cent total harmonic distortion or 8 per cent intermodulation distortion) permitted for the purpose of determining maximum signal should be stated when reporting signal-to-noise ratio, and also the information with respect to the noise measurements, called for in 5.4 and 5.5.

NOTE 1: It is evident that a high-quality system which sets a low limit to permissible distortion, and which reproduces a wide frequency range, cannot realize from a given record material or surface quality, as large a signal-to-noise ratio as a system in which more distortion is permitted and a limited frequency range covered.

APPENDIX

(Discussion of some of the proposals on which there have been differences of opinion.)

SPECIFICATION OF FLUTTER IN TERMS OF ROOT-MEAN-SQUARE

Although the proposal to define flutter as the root-mean-square deviation in frequency has had the approval of both the SMPE sound committee and the ASA subcommittee, a number of engineers have expressed the belief that the peak deviation is likely to be a better measure of the quality damage than either the root-mean-square or average deviation. I believe that the thought behind this view is that we tolerate small fluctuations in speed and may be quite unaware of them, but the larger deviations from average speed are quickly noticed; therefore, it is reasonable to suppose that maximum deviations are what count. This reasoning is quite logical, but when comparing a peak-reading meter with a root-mean-square meter, the question is not whether extra importance should be attached to the largest deviations, but whether everything else should be ignored and no consideration given to the duration of the large deviation. Fig. 1 shows several types of flutter curve, all having the same peak value. In curve *B*, there is little beside the one high peak, while curve *A* shows numerous other fluctuations of only slightly lower amplitude than the peak, and curve *C* shows deviations which last many times longer. Should these three be rated alike?

Someone comparing these curves may bring up the point that if the flutter-measuring system is provided with a weighting network such as the "Flutter-Index" idea suggests, thus emphasizing flutter of rather slow rates, the peak-reading meter would give much larger readings for the flutter shown by curve *C* than curve *B*, since the short sharp peak of B could be produced only by high-frequency components. The reply to this is that if and when such networks come into general use, there will be much less difference in the actions of peak, root-mean-square, and average-reading meters. Such a network narrows the band of flutter rates to which full weight is given (with attenuation on both sides of the range 1 to 5 cycles). Were only a single flutter rate to be considered in any one measurement, it would make no difference which type of meter is used, for their indications would be in fixed ratio, and agreement in readings is only a matter of calibration or scale. (A pure sine wave with a peak value of unity has a root-mean-square value of 0.707 and an average value of 0.64.) But grave errors would result from assuming that these ratios would hold for the ragged waves shown by ordinary flutter records.

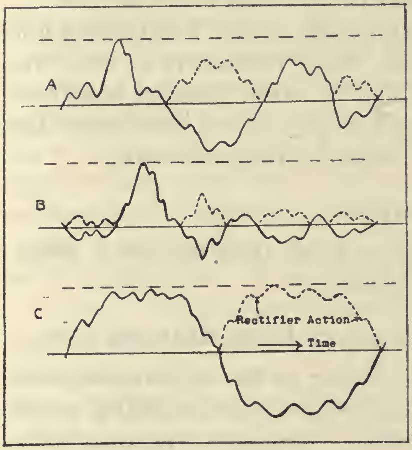

Fig. 1—Three frequency-deviation curves for which a peak-reading meter would give the same reading.

The characteristic of a root-mean-square meter is admirably adapted to giving special weight to the larger frequency deviations. A 1 per cent deviation of given duration has four times the effect on the meter that a 0.5 per cent deviation of the same duration would have. Why then does it not read four times as high? The answer is that, in general, the effect which deflects the needle does go up as the average square of the quantity being measured, but the meter is provided with a nonuniform scale which in effect extracts the square root.

There is reason for believing that the square law is a fairly good approximation to the noticeability of flutter of any given rate. At least we can say this, there is a threshold magnitude below which no one notices the flutter, but with small increases, it seems to get bad very rapidly, and the number of people who notice it increases rapidly. For example, in a letter on the subject, Kenneth Lambert wrote "We have observed here that 24-cycle flutter may become rapidly objectionable with an increase from perhaps 0.1 to 0.13 per cent (on a root-mean-square basis) and 96-cycle flutter in much the same degree." If you were to attempt to draw a curve which would represent the harmful effect of flutter as affected by its magnitude, you would draw something that looks a good deal like a parabola.

But what about a meter of the rectifier type, which reads the average of the waves? I think I can give an illustration of a case in which such a meter would be decidedly in error. Suppose you were comparing two machines, one of which produced every second a 1 per cent deviation that lasted a tenth of a second, while the other produced every second two deviations of 0.5 per cent each lasting a tenth of a second. The root-mean-square meter would rate the former as twice as bad. The averaging meter would say they were equal.

You will notice that the flutter specifications as they now stand, although stating the standard as a root-mean-square reading, sanction the use of meters of the rectifier type. Meters of this type actually show something between the root-mean-square and average values of the waves, and therefore it is believed that the difference ordinarily will be small. In view of that consideration, and the fact that equipment is in wide use having various types of indicating instruments, it has not appeared practical to call for strict adherence to the root-mean-square standard, but it is an urgent requirement that the type of measurement be clearly stated when a measurement is reported.

Examination of a flutter oscillogram (or "wowgram") does not enable one to arrive at a root-mean-square figure, hence the widespread practice on the part of those who have recording meters, of reporting flutter as the peak-to-peak value. It is hoped that future recording meters will also be equipped with root-mean-square indicating meters, so that simultaneous readings may be taken. Meantime it is important, in order to avoid confusion, that statements of flutter magnitude, based on inspection of a wowgram, should be accompanied by enough information to make clear how the wowgram was read, such as "peak deviation from average," or "range positive to negative peak," and to make certain that the figure will not be taken as a root-mean-square measure.

FLUTTER INDEX

The subject of "Flutter Index" as proposed by the SMPE sound committee has met with many questions and indications of doubt. Not that many doubt the correctness of the tests for the conditions under which they were made, but they doubt the applicability of the formula to the actual conditions under which reproduced sound is heard.

For what bearing it may have on the questions in people's minds, I would like to call attention to a curve published by Shower and Biddulph in a paper on "Differential pitch sensitivity of the ear," in the *Journal of the Acoustical Society of America*, October, 1931. Their curve showed the threshold of perception of rhythmic frequency changes of a 1000-cycle tone at rates from 0.7 to 5.5 cycles per second, the listening being done with headphones. The interesting thing is that this curve, although having a minimum some 10 times higher than the minimum for a 1000-cycle tone as found in the live-room listening tests, was very nearly the same shape.

If flutter rate affects perception threshold in the same manner under the two extreme conditions of complete absence of reverberation on the one hand (headphones) and live-room listening on the other, the general shape is probably not far off for intermediate conditions.

Thus, although the evidence is still insufficient (the Shower and the Biddulph data should be supplemented with tests at higher flutter rates, and with other tones, and tests also made in moderately damped rooms), there is a presumption that a curve of the general shape indicated by the Flutter-Index formula would, to a fair degree of approximation, express the relative perceptibility of flutter under average listening conditions.

Ultimately, it is hoped, such a formula and weighting factor can be "proved in" for music. Recent experience has demonstrated to the writer's own satisfaction, that the tolerance for rapid flutter is much higher than for slow flutter. Thus, so far as this small item of information goes, it points to a similar relation for music as for steady tones, although again probably with a higher threshold throughout than for steady tones.

Rate of Reduction of Input of High Frequencies

In many systems of recording, the practice has been followed of increasing the amplification in the recording channel with increasing frequency. This has been called "pre-emphasis." In order that the final sound shall not have exaggerated high frequencies, the reproducing system is given a drooping characteristic and this has been called "postequalization." The result is a desired over-all frequency characteristic, but a large reduction in surface noise or in graininess noise due to the imperfections of the record. Pre-emphasis is possible without excessive overloading at high frequencies, for the reason that except in rare instances the program material itself contains the high frequencies, only in very much reduced amplitudes. There are two possible ways of ascertaining how much pre-emphasis is safe or in other words how much may be employed without resulting in any more overloading at high frequency than in the lower range. The first method is to make extensive measurements such as those reported by Sivian, Dunn, and White (*Journal of Acoustical Society*, April, 1931) and by Dunn and White in the January, 1940, issue of that Journal.

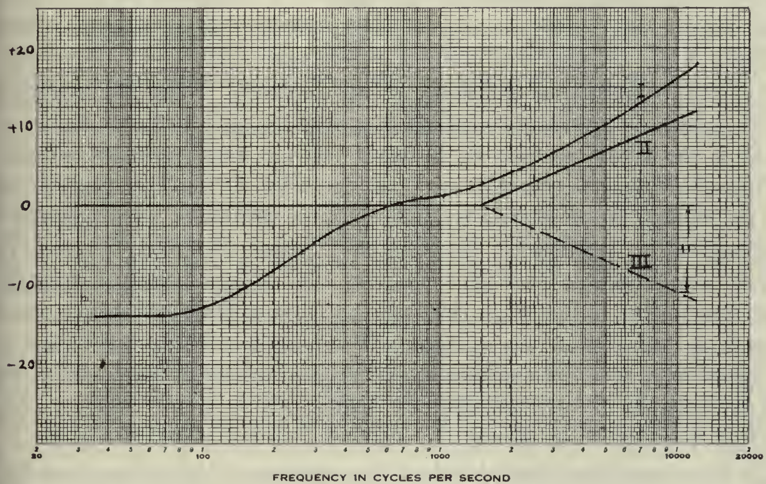

Fig. 2—Input droop for determination of maximum signal.
I. Orthacoustic-recording characteristic. II. Assumed safe pre-emphasis.
III. Permissible high-frequency reduction.

The other method is one of cut-and-try, namely, to make recordings with various amounts of pre-emphasis or "tip-up," and learn from general experience how much may be used. Because of the very extensive use that has been made of the "orthacoustic" recording characteristic (see Fig. 2), this appears to be the best general guide to possible tip-up. I have endeavored to obtain expressions from engineers who have had experience with this system, and while some express the opinion that the tip-up is excessive there does not seem to be any overwhelming evidence to that effect. The overloading at high frequency seems to be rather because of the fact that in disk recording the actual overload level (in terms of velocity) is lower at high frequency because of curvature effects, especially near the inside of the records. If the overload point were always at the same velocity the orthacoustic rate of tip-up probably would not be excessive, or in other words, it does not more than offset the droop in input as found in a variety of programs. Following this line of reasoning the writer suggested to the members of our ASA subcommittee that we propose, for testing purposes, holding the input constant to 1500 cycles and then dropping at the rate of 5 decibels per octave. This would be slightly less than the complement of the orthacoustic-recording characteristic. However, some of the committee thought we should be more conservative, suggesting 3 instead of 5 decibels per octave above 1500 cycles. For purposes of discussion I have called, in the present draft, for 4 decibels per octave. I hope to receive more expressions in regard to this question. The pre-emphasis used in film recording is too small to constitute a test of this factor.

If a recording system is designed with a large amount of pre-emphasis it may in practice be quite capable of handling high levels of recording, but if tested by means of an oscillator with constant-voltage input throughout the frequency range, obviously it would be badly overloaded at the high-frequency end, unless the input throughout the entire range were dropped to a level far below the power-handling capacity of the system. We therefore think it justified to suggest that the determination of maximum signal (especially for signal-to-noise determinations) be made with an input which droops at high frequency, as shown, for example, by curve *III* of Fig. 2.

If the actual overload level of the system is the same at all frequencies (as, for example, in a variable-area recording) a tip-up of 4 decibels per octave above 1500 cycles could, if curve *III* is what it should be, be employed without any greater likelihood of overload at high frequency than at low.

If a system overloads at a lower level in a certain frequency range than in another, then either the over-all level will have to be dropped in order to meet the specifications for determining maximum signal, or else the recording characteristic should be modified to reduce the recording level in this critical range. For example, assuming 4 decibels per octave above 1500 cycles to be the maximum safe pre-emphasis with constant overload level, disk-recording systems would, on account of the curvature troubles, either have to establish their "maximum signal" somewhat below the level which constitutes overload in the low- and middle-frequency range, or else stop short of applying the 4 decibels per octave all the way up to 12,000 cycles.

DISCUSSION

J. P. MAXFIELD: In connection with the matter of this equalization, I had the opportunity to obtain simultaneous cuts of records running 15 decibels at 10,000, around nine and around six. Those were all played with the standard droop for the higher present equalization. Astonishingly enough, the one with the 6-decibel rise in the recording reproduced, more highs and cleaner highs than the one with the 15, indicating that the overload on the latter was so bad that it was not being tracked. Unfortunately we have only some three sets of such records, but I think the situation should be carefully looked into before we pick as high a rise as 15 decibels to 10,000.

J. K. HILLIARD: I should like to make some comment along this line, in support of Mr. Maxfield's statement. There is other information that also verifies that we should be cautious in the matter of equalization. I think the experience of the studios in having parallel disk and film channels would indicate that if equalization is provided higher than the six or eight or possibly even ten at a maximum, we get into this bootstrap lift, the effect of having to lower the level or use excessive limiting at times and since present equalization is used primarily to increase the signal-to-noise ratio, if we have to lower the level on the disk or the film in a general case, then we are defeating the purpose we went out to obtain, and we have the two problems of having to lower the signal on the record at the time if we used higher amounts of equalization, and the effect that Mr. Maxfield talked about, improper tracking, leads to inferior results over that used with lower amounts of equalization.

CHAIRMAN C. R. DAILY: There is another point, that of excessive modulation at high frequency. Most types of recording systems lead to increase of cross-modulation production which may do more harm than the increase in signal level.

E. W. KELLOGG (by letter): The experiences recounted by Mr. Maxfield and Mr. Hilliard are just the kind of evidence which we are seeking, and I hope more experiences bearing on this subject will be reported. The suggested 4 decibels per octave above 1500 cycles gives a level difference between 1000 and 10,000 cycles of about 11 decibels which is 4 decibels less than that given by the orthacoustic curve, and much nearer the conservative figure which I think Maxfield and Hilliard would approve. But please notice that to say that the input *may* be drooped at a certain rate for test purposes, is not by any means equivalent to recommending a tip-up of equal amount. Our purpose is to try to arrive at a curve which represents the droop which may be expected to occur in average program material. If, as in disk recording, overload tends to occur at lower levels in the high-frequency range (due to curvature) it obviously would be inviting overload, to use a tip-up which completely offset the normal droop. Hence the figure suggested here may not be out of line at all with the observations just reported. The question then arises, how have the people who have used the orthacoustic-recording characteristic gotten by with it as well as they have? There are, of course, differences in microphones, but, more important, the recordist can exercise a wide control by such factors as orchestra arrangement, microphone placement, and room acoustics. The influence of these factors makes it impossible to say what the average or normal droop is, but some more or less arbitrary specification seems to be needed for putting testing systems on a common basis, and unless experience indicates clearly that it should be revised (and it is open to revision), the figure proposed in the paper seems to me to be reasonable.

Magnetic Recording for the Technician*

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Summary—The first half of this paper will present to the motion picture technician a review of magnetic-recording theory; the second half consists of experimental data taken with the new magnetic-recording equipment of the Radio Corporation of America. Input-output, frequency-response, and distortion data, which were taken under test conditions familiar to motion picture technicians, are presented. There are many excellent articles available which treat the various aspects of this subject. Those who are interested in the detailed scientific explanations are referred to these articles, listed in the bibliography, and to the extensive patent literature. This paper attempts to consolidate the information in these articles in simplified form and to provide a useful picture of the phenomena in magnetic recording and reproduction for those whose primary interest is in the application of the theory.

PART I—THEORY

Perhaps a good starting place for a discussion of magnetic recording would be the two distinct types of magnetic materials which are essential parts of the system. Materials are classed in three groups from a standpoint of magnetism. A vacuum has a permeability of unity, which means that the ratio of magnetic induction B to magnetizing force H is 1.0. Diamagnetic materials have a permeability less than unity. Paramagnetic materials have a permeability somewhat greater than unity. The ferromagnetic materials have a permeability very much higher than unity and this permeability is variable depending on the particular material and the magnetizing force applied to it. We are concerned only with these ferromagnetic materials. They can be subdivided further into two types; hard and soft, both of which are used in magnetic recording. Soft magnetic materials, which incidentally are usually soft physically, have low retentivity; that is, they are easily affected by a magnetic field and easily lose the effect when the exciting field is removed. This type of material is commonly used in transformers, galvanometer pole pieces, and magnetic heads.

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

The other type of magnetic material, which is called hard, has high retentivity; that is, it is not so easily affected by a magnetic field as the soft materials, but when affected, has the property of retaining a major portion of this effect after the exciting field is removed. An example of this is the familiar permanent magnet. Now it is obvious that if a long strip of this hard material were to be subjected to a magnetic field which was varying according to a voice signal, while the material was moving at a constant rate, a sound record would be impressed on the material. In order to confine the signal to a reasonable length or a reasonable speed for a given length, it is desirable to

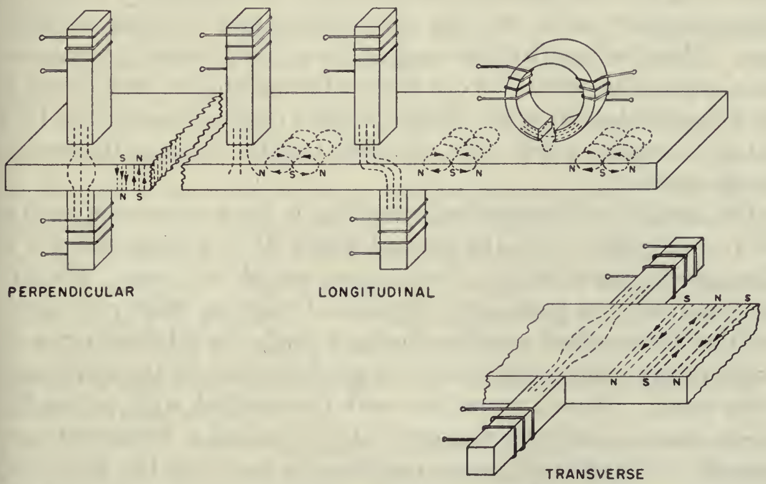

Fig. 1—Types of recording—longitudinal, perpendicular, transverse.

limit the exposing effect at a given instant to a small portion of the hard magnetic material. This is, of course, obvious, as in photographic recording.

The difficulties of confining the signal to a small portion when using a coil as the exciting field are apparent. Therefore, the coil is wound around a core which also increases its efficiency considerably. This core contains an air gap so that the magnetic lines of flux going around the core leak out at the gap. The hard material is pulled over the top of the gap, thereby recording and retaining the leakage flux which varies according to the audio signal. There are various methods of placing the film in the region of influence of the core or magnetic head, as shown in Fig. 1. With the perpendicular method, the film is actually passed between two pole pieces or is pulled through the gap. Here the length of the magnet from north to south is constant for a given film thickness. One advantage of this method is that the aspect ratio of the individual wavelengths, which make up the signal, is less effective in controlling the high-frequency response. One disadvantage of this method is that it is desirable for reasons of efficiency and quality to have the gap as narrow as possible, thereby necessitating a very thin film which then introduces the problem of strength and durability of the film.

The next method, shown in the right-hand corner, transverse recording, has the same advantage as the perpendicular method of constant-aspect ratio, but has the disadvantage of using a narrow tape. Here the length of the magnets from north to south is constant for a given film width. Very little information has been found in the literature on this type. There seems to be no practical use for it in tape recording and in wire recording it is the same as the perpendicular method.

The method of longitudinal recording is more commonly used at the present time. It is the method which RCA is using and will be discussed in more detail. Three types are shown here. The first type uses only one pole piece; the second uses two offset pole pieces; and the third method uses the ring-type head. In all three types the length of the magnets from north to south depends on the wavelength of the signal. It is apparent that with this method, wide, strong film can be used, as only the thickness of the coating is important magnetically. Sturdy pole pieces can also be used and the gap width can be very small. The principal disadvantage seems to be that the aspect ratio decreases with increasing frequency, resulting in high-frequency losses.

Now that we have covered very simply the method of recording, let us return to the type of materials used and a brief discussion of the properties of materials best suited for this purpose. The most desirable magnetic material for the core would be one which has a very high initial permeability, very low hysteresis loss, and very low eddy-current losses. .

For commercial purposes, MU metal meets these requirements satisfactorily. It is listed as having an initial permeability of 7000, hysteresis loss is acceptable, and the eddy-current losses are minimized satisfactorily by laminating the cores.

The characteristics of the high-retentivity material used for the film appear somewhat more involved. Any investigation of films is very complicated unless certain factors are kept constant such as tape speed, thickness of emulsion layer, and construction details of the heads. The obvious starting place for an investigation of films would be a study of the hysteresis loop of the iron-oxide material. However, there seems to be considerable controversy about the value of these curves for magnetic recording. It seems reasonable to doubt that the theory of magnetic recording could be traced out directly on this curve, if only because of the secondary effects introduced by the bias frequency (which will be discussed later). We believe that it will be essential to find some modification of this curve with which we can correlate practical experiments with theory. Several investigations are being carried out along these lines, but to date, we know of no theory which successfully explains all the factors involved in recording. The following hypothesis is presented with knowledge of the many deficiencies it contains. It is hoped it will provide a useful picture and a stimulus for more comprehensive work. The standards book[1] of the American Society of Testing Materials has been use as a reference for the definitions of magnetic terms.

Fig. 2 shows in a highly simplified manner the over-all transfer characteristics of magnetic recording and reproduction. This figure does not show any of the phenomena peculiar to the type of film, frequency, or speed of recording, but some of these factors will be taken up as individual steps.

Starting with the audio current, shown in the lower left corner, which is combined with a high-frequency biasing current, the currents produce magnetic flux by the action of the coil. The flux which then flows in the core and across the gap is proportional to the current if the core material has low losses and has a saturation value above the range required. For our purpose, we can assume that the head has a straight-line transfer characteristic, and the 45-degree line in the lower left corner represents this characteristic. The signal on the left represents the flux in the core. The magnetic flux across the gap causes a magnetic force to affect the film which is passing over the gap and this force results in the magnetic flux flowing into the film. The line in the upper left corner represents the film characteristic which is nonlinear. It is effectively straightened out by the biasing current. As the film is a permanent magnet and is being moved past the gap, this flux leaves the film in a magnetized condition. Now the film is a magnetized body and is effectively the same as the record head in that its force will produce a magnetic flux in the air surrounding it. It differs from the record head in that its force is permanent and varies with distance along the film while the force in the record head varies with time. The curves at the top show the forces on the film and the dashed line shows the resultant force.

The film is now ready for immediate reproduction if desired. When it is passed over another head the flux in the air around the film passes into the head and induces in the coil an electromotive force which is amplified in the customary manner. The line in the upper right

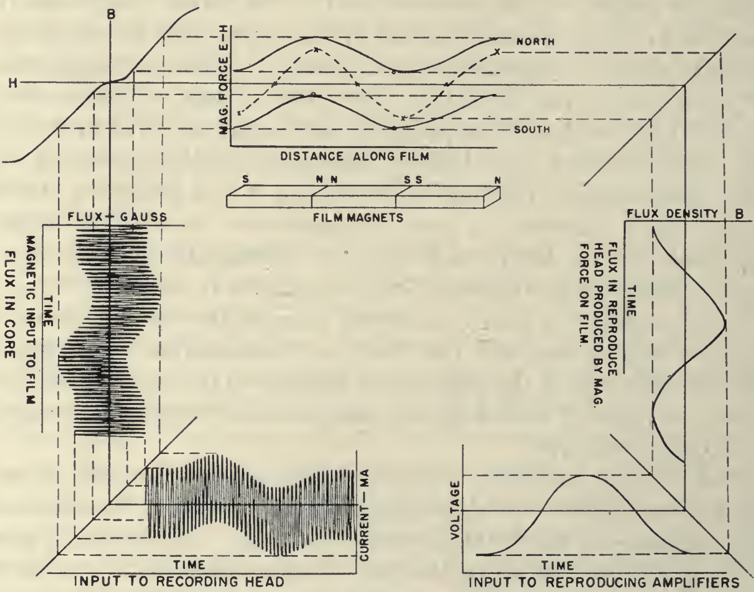

Fig. 2—Over-all transfer characteristics.

corner represents the transfer from flux around film to flux in the head. The line in the lower right corner represents the transfer from flux in the head to induced voltage.

Fig. 3 shows a way in which the recording action can be represented simply although it does not show some important effects. For the purpose of illustration, the input signal in the lower left corner is drawn as if it were a 9000-cycle audio wave with 27 kilocycles bias. The numbers indicate representative points on the signal which can be found on the magnetization curve. The arrows on the magnetization curve show the travel of the biasing action. The waves on the right indicate the magnetization on the film and the numbers represent the same points as on the original input wave. The resultant signal is formed by these two waves and is seen to be an undistorted signal. Directly above the biased input signal is an unbiased input wave and it is apparent that the jog in the magnetization curve will cause the output wave to be distorted as shown on the right. The bias current keeps the audio current above this jog or effectively straightens out the curve. If insufficient bias is used, distortion results and the output level drops. If too much bias is used the output level also drops.

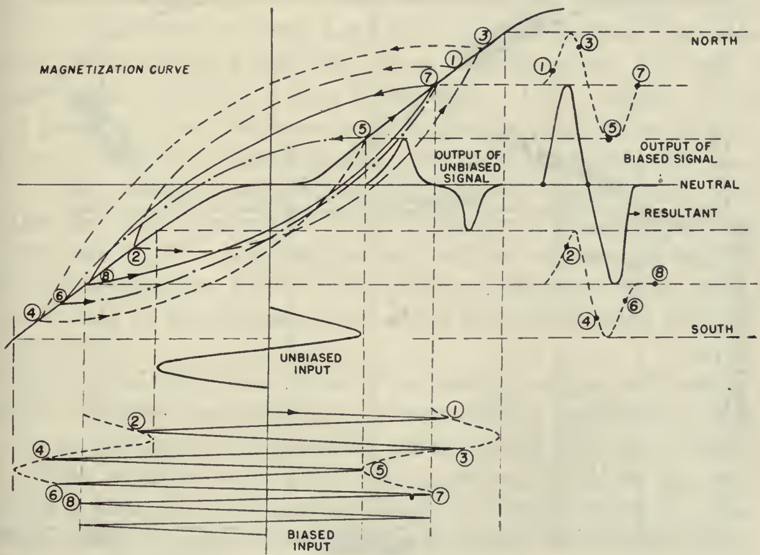

Fig. 3—Enlarged view of recording characteristic.

The effect of demagnetization, which was mentioned earlier, occurs in the recording operation. In longitudinal recording, the wavelength is recorded along the length of the film and at 9000 cycles the wavelength would be 0.002 inch at normal motion picture film speed. The width of the recorded track is 0.200 inch so a half wave consists of a rectangular magnet 0.200 inch wide and varying from north to south along a length of only 0.001 inch. This ratio is not at all to the liking of a magnet and it has a strong tendency to demagnetize itself. This ratio has been expressed[2] as "aspect ratio" and the example given above would have an aspect ratio of 0.005.

Manildi[2] has shown that an efficient magnet should have an aspect ratio of at least 8 for a certain permanent-magnet material. In order to determine with any accuracy the proper aspect ratio for our recording films, it would be necessary to know the effective hysteresis curve of the material. However, it is probable that a ratio of 0.005 is low enough to cause high-frequency losses comparable to slit losses or greater.

Camras[3] presents an interesting study of this effect on wire recording and points out that fortunately some of the effect is counter-

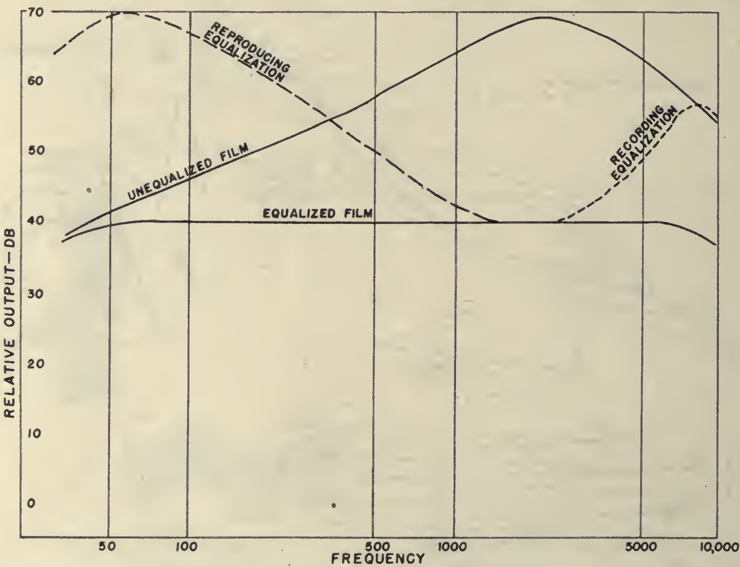

Fig. 4—Frequency-response characteristic with and without equalization.

acted by the action of the reproducing poles. Concerning this counteraction, Wetzel[4] shows that the present recovery during playback increases with increasing frequency, but that the sum of these opposing tendencies is a net decrease in output with increased frequency. Equalization is provided in recording to compensate for this loss as well as slit loss. A third factor which influences the high-frequency response is the penetration effect. Kornei[5] also discusses this. When the thickness of the recording layer is decreased, the output level of the low frequencies drops, while the relative high-frequency response improves. The penetration of the magnetization depends on wavelength, permeability, and gap width. However interesting this effect may be, there is little need to go into it further at this time, because, as Kornei[5] points out, the effect is extremely small with thicknesses in the order of 0.0005 or 0.001 inch. The amount of equalization required for demagnetization and slit loss is quite small compared to that required for the next effect.

In reproduction, the output voltage theoretically is directly proportional to frequency for constant-amplitude input. The pickup can be considered a generator with the head itself acting as a coil which remains stationary in a changing magnetic field. As the flux surrounding the film enters the region of the gap, the force causes flux to flow in the core of the head and as this changing flux links the electrical circuit of the coil, there is induced in the coil a voltage which tends to oppose the change. This voltage will be out of phase with the flux because when the flux passes through zero, the rate of change is maximum and, therefore, the voltage is maximum. The voltage is proportional to frequency because in a given distance the rate of change for a high frequency is greater than for a low frequency. The equalization required to compensate for this effect is 6 decibels per octave from whatever frequency is set as the low-end limit to the frequency at which demagnetization and slit loss take effect.

Combining these several causes of frequency changes, we have the familiar frequency-response characteristic without equalization (Fig. 4). As the equalization required for the low end is the larger amount, it will affect signal-to-noise ratio. Our experience has been that with most good films, the equalization brings the output down to about 50 decibels above system noise with the film noise below system noise. Care must be taken to keep system noise as low as possible. Another way to increase signal-to-noise ratio, is to tolerate a higher frequency as the lowest limit. For example, if the lowest frequency desired is 100 cycles, the output and consequently the signal-to-noise ratio is 6 decibels higher than it would be if the lowest frequency were 50 cycles.

PART II—EXPERIMENTAL DATA

All the test data presented here have been taken with RCA's new magnetic-recording kits. In the interests of users of these kits, they were designed, not to obtain optimum conditions for this type of recording, but to obtain the least possible difficulty in the studios caused by changing from photographic to magnetic film. Using an existing recorder created many constructional difficulties such as space for the heads, plugs, and mounting arrangements. Also, in the interests of users, the decision was made early to use 35-mm film with standard dimensions and perforations. In the fall of 1946, duPont was approached with a request for some experimental film on 35-mm base. In February, 1947, the first samples of this film were received and tests were started with a Brush head. These first tests indicated that the general idea of 35-mm magnetic film was

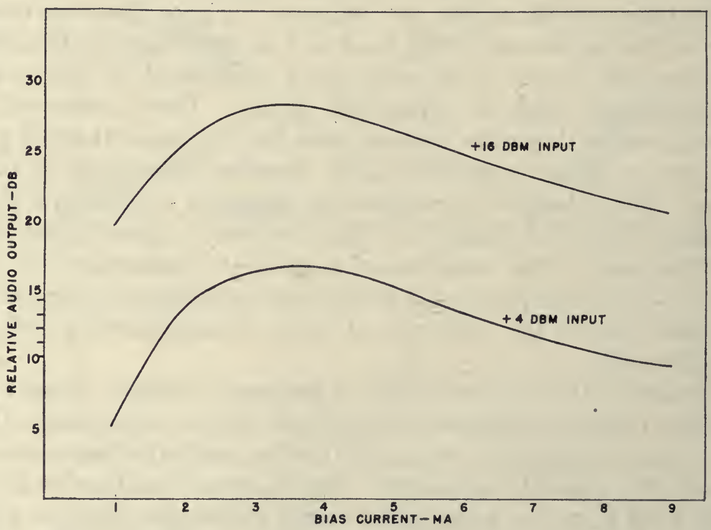

Fig. 5—Bias input versus audio output.

practical and construction on RCA heads was started by our development-engineering group in Camden. These new heads were then mounted on a PB-36 soundhead with some of the same features it was intended to incorporate in the final design. During this time, other film manufacturers were becoming interested in this field and the original maker was constantly improving his samples. It is not the intent of this paper to make comparisons between films made by different manufacturers. However, it is difficult to avoid distinguishing between films, because of the difference in equalization required. Complete tests have been made on only duPont and

Minnesota Mining films, both of which could be used for recording. For the purpose of demonstrating the capabilities of this system, all the data in this paper were made on duPont SW4 film.

BIAS INPUT VERSUS OUTPUT

A good starting place for film tests appears to be a curve of bias input versus audio output (Fig. 5) shown here for two input levels. As mentioned earlier, the bias current has the effect of straightening the transfer characteristic of the film, thereby decreasing distortion.

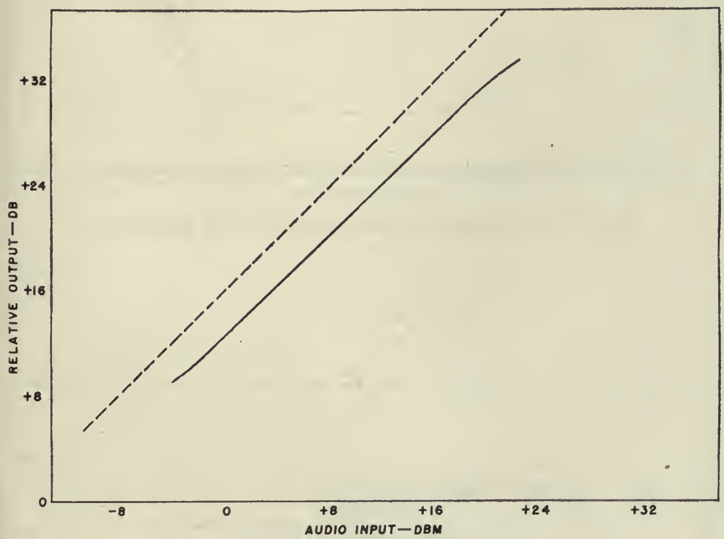

Fig. 6—Audio input versus audio output.

Output is increased with increasing bias current up to a certain point, after which output decreases with increasing bias current. Some investigators think of this decrease as being caused by the bias current being high enough to erase the audio signal.

AUDIO INPUT VERSUS OUTPUT

Now that the optimum bias current has been chosen, a curve is plotted of audio input versus output (Fig. 6) using this bias current. Linearity is very good up to the overload point of the film. This overload is gradual, being somewhat similar to the characteristic of

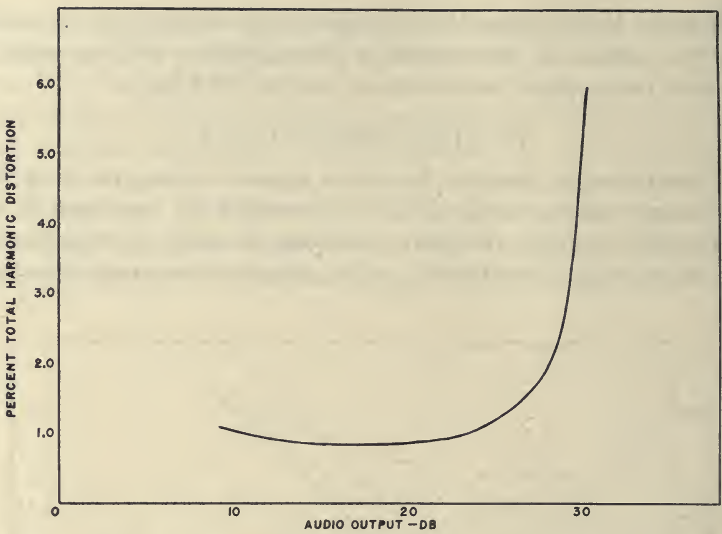

Fig. 7—Audio output versus total harmonic distortion.

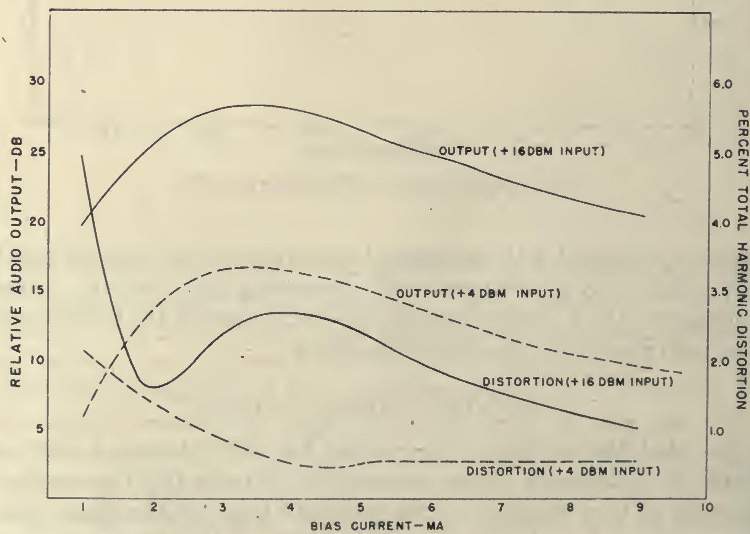

Fig. 8—Bias input versus total harmonic distortion.

variable-density recording and the 100 per cent track level is determined by the maximum allowable distortion.

DISTORTION

Most of our tests have been made with harmonic-distortion equipment. Fig. 7 shows the effect of varying the audio level on distortion. In this case, distortion is plotted against audio output. The optimum bias was used here.

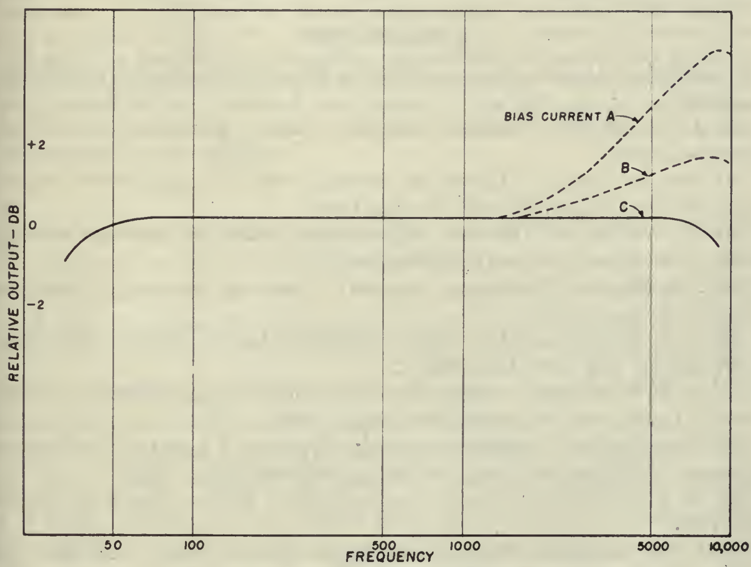

Fig. 9—Frequency response.

Fig. 8 shows curves of distortion versus bias for two audio inputs. The two upper curves are output curves and the lower ones are corresponding distortion curves.

FREQUENCY RESPONSE

Using the optimum bias current and an audio input which is safely below the film-overload point for the high frequencies, we obtain the frequency-response curve of Fig. 9. Since our equipment was designed especially for motion picture use, the upper frequency limit was set at 8000 cycles. However, we know from experiments that it can be held flat to 10,000. The dashed curves show the frequency response which would be possible if a lower bias current had been used. Had a lower current been used, however, the distortion would have gone up.

NOISE

In order to make accurate statements concerning signal-to-noise ratio for magnetic recording, it is necessary to specify not only the maximum harmonic distortion, but also the permissible frequency limits and the characteristics of the measuring channel.

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35-Mm Magnetic Recording System*

By EARL MASTERSON

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Summary—**An idea was conceived of designing and building a number of kits to add magnetic sound-recording facilities to a standard photographic recorder. It is believed that by starting magnetic recording in this manner it will enable the studios to obtain some practical experience without the expense of a complete film-handling mechanism and yet will not interfere with photographic sound-recording production work. The construction of the mechanical and electrical components of the kit and the operational features are discussed as well as the performance characteristics that can be expected of this system.**

Although magnetic recording is one of the oldest recording methods known, it was only during the last war that this form of recording came into its own. In more recent years the high fidelity obtainable by properly designed recording and reproducing equipment, together with improved recording media, made magnetic recording actually a competitor in several sound-recording fields. Demonstrations of the quality of performance of a laboratory 35-mm recorder were given to several groups of Hollywood people in Camden, New Jersey. It was felt that the quality of reproduction might be of great interest to the studios, although it appeared that considerable experience would be necessary to determine how successfully this entirely new medium could be fitted into the operations. It was also decided that the best method of gaining this experience would be to design a conversion kit for a standard photographic sound recorder, so that either photographic or magnetic recordings could be made on the same machine. In this way operational experience could be gained without seriously interfering with regular production work. The design and features of a magnetic conversion kit to adapt a well-known 35-mm sound recorder for magnetic recording will be described.

Although almost all of the early work in magnetic recording had been with solid wire or solid tape, it was found during the war, both in this country and especially in Germany, that a better recording

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

medium could be made in the form of a magnetic coating on a non-magnetic support or base such as paper or plastic. This form of magnetic-recording medium shows several advantages over the solid type. The two major requirements of a solid recording medium are that it be both ductile and a permanent magnet. These requirements are not normally compatible. As a result of considerable work on the part of wire manufacturers, a satisfactory wire has been developed for the average quality requirements of sound recording. One

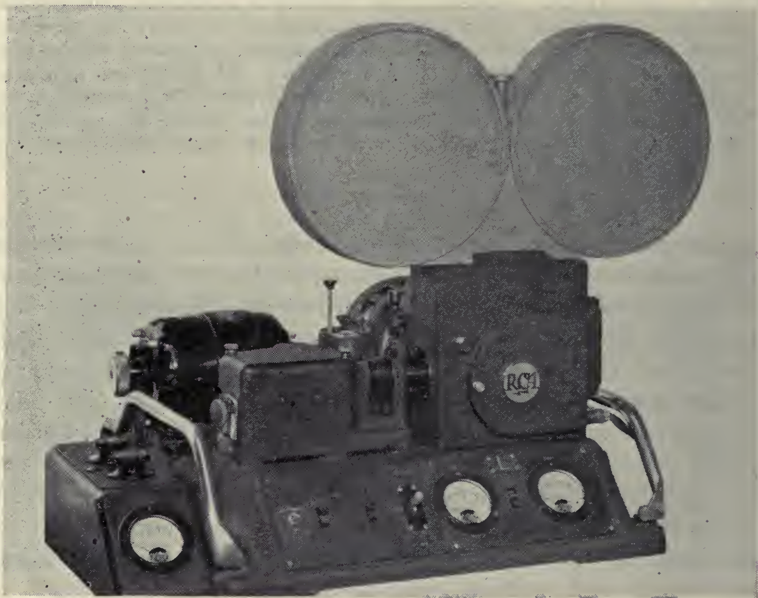

Fig. 1—Magnetic conversion kit in PR-23 recorder.

company has solved the problem of incompatibility by using a brass wire which has excellent drawing properties and plating a magnetic coating upon this wire which has the proper recording properties. This still does not meet the requirements of the strictly high-quality sound-recording field.

By suspending a magnetic oxide in a binder and coating this mixture on a film-support base, it is possible to combine both the correct magnetic qualities and a support having desirable mechanical qualities. Since the magnetic particles of a coated tape can be extremely fine and also well distributed and suspended in a binder, it is possible to record and reproduce wavelengths of much smaller physical length than that possible on solid wire or tape, the factor being something like 3 to 1. This means that a magnetic track at the standard 35-mm recording speed of 90 feet per minute is capable of producing excellent frequency response.

Hollywood, unlike other sound-recording industries, is quite fortunate in having had years of experience in the handling of long tapes or films. This makes the conversion from present recording methods to magnetic recording a relatively simple one, so simple, in fact, that a conversion kit appears to be a very good answer to the immediate

Fig. 2—Electrical units of magnetic conversion kit.

problem of introducing magnetic recording to Hollywood. In order to make the kit available to most studios, it was decided that it should be designed to fit the widely used RCA PR-23 sound recorder.

Fig. 1 shows the installation of the complete mechanical conversion kit. In applying this kit to the PR-23, a minimum of work is required. Several roller studs are pressed out of the frame, and some new studs, supplied with the kit, are pressed in, to secure the head and idler mounting plate. This conversion mechanism, includes a tight-loop sprung idler film filter system and the magnetic-recording and -reproducing heads complete with all adjustments. A nonmagnetic sound drum and shaft is also supplied. Electrical connections for the heads are made to small Cannon sockets in the side of the new film-compartment housing.

It is assumed that most users will erase the film as a separate operation not connected with recording. However, if it is desired, an erasing head can be furnished as a separate kit. This head is pivoted on its own mounting plate and rides on the film on the top of the sound drum. The sound drum is relieved in the area under the head to prevent its bounding or hammering.

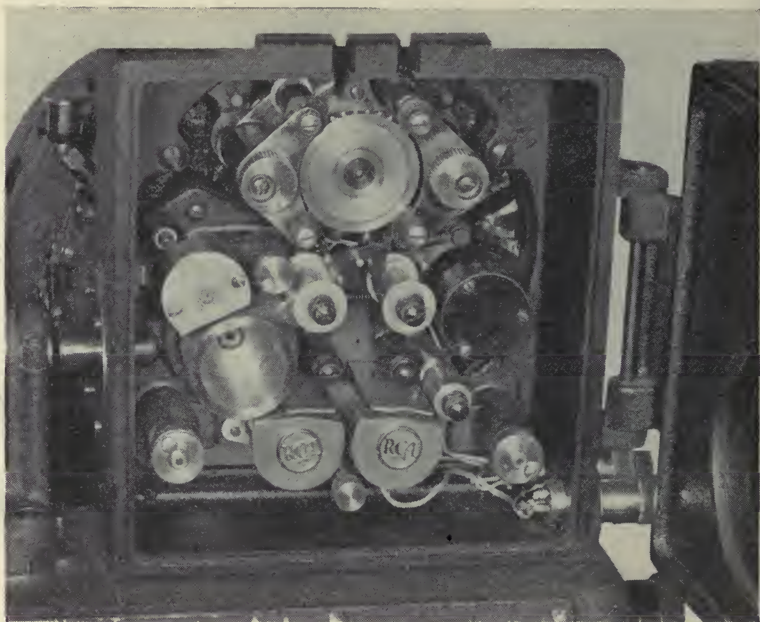

Fig. 3—Film path and magnetic heads.

In order to make the electrical kit as flexible as possible for various installation requirements, it was decided to use individual plug-in chassis which could be mounted either on a single shelf in a rack or in two boxes as shown in Fig. 2. By means of adjustable brackets furnished with the kit, it is possible to mount these boxes on a wall, on a table, or underneath a table. A door is provided in the end of the box so that the chassis may be readily removed for servicing. One box contains a single chassis which provides an oscillator with its own power supply for high-frequency bias and erasing currents. This chassis also contains the necessary recording equalization circuits. A meter on the front panel enables an operator to measure bias current. The other box contains two preamplifiers and a chassis for the playback equalization network.

Fig. 3 shows the film path with the kit mounted on the PR-23 recorder. A drawing of the new film path and the mounting arrangement for the recording and reproducing heads is shown in Fig. 4. As the film enters the compartment from the magazine, it passes the sprocket in the usual manner and then passes around a sprung idler which acts both as a filter and as a film guide for the photographic-track placement. After the film passes around the sound drum, it

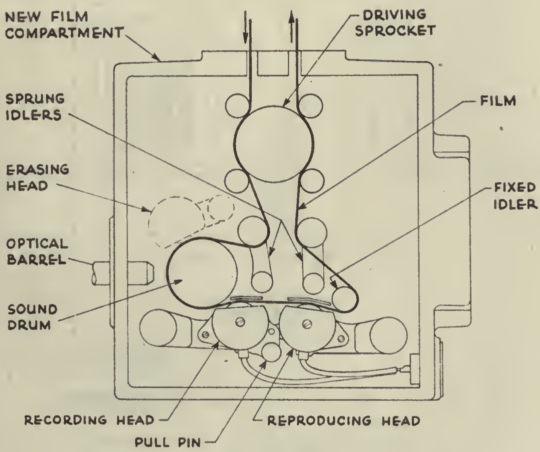

Fig. 4—Film path showing tight-loop system and magnetic heads in position.

then goes immediately over the magnetic-recording head and then over the magnetic-reproducing head. These heads are arranged on movable arms and are linked together. By means of a pull pin, such as is sometimes used on pad rollers, it is possible to drop or retract the two heads for threading. The heads also remain in the retracted position during photographic recordings. The film then passes around a fixed idler and then to a second sprung idler which completes the tight-loop filtering system, then around the second side of the driving sprocket into the film magazine. The spacing of the recording and reproducing heads is such that for monitoring purposes the reproduced signal will lag the actual signal by approximately $^1/_{15}$ of a second. The azimuth of each head is independently adjustable by means of a setscrew. By loosening a screw in the center of the head, it is possible to rotate head for best contact between gap and film.

The magnetic-track placement can then be adjusted by means of adjusting nuts on the end of the studs around which the head-mounting arms pivot. Since no standard has been established on the placement of a magnetic track, it was decided to utilize the equivalent print dimensions of the photographic wide-track push-pull system. Therefore, the centerline of the magnetic track is identical with that of the

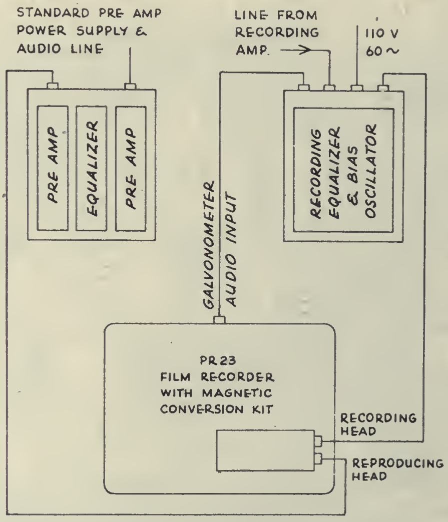

Fig. 5—Block diagram of electrical units.

double-width photographic track. The recording-head width is 184 mils and the reproducing head is 176 mils. In order to maintain a balanced support of the film over the two heads, a skid the diameter of the head laminations is provided near the back side of the film so that the support is symmetrical. Fig. 5 is a block diagram of the electrical part of the kit as the units are arranged with the recorder. The line from the recording amplifier which normally plugs into the rear of the recorder is now removed and plugged into the rear of the recording chassis box. A new cable then goes from this box to the recorder to provide connections for photographic recordings. A switch is provided on the front of the recording box to select either photographic or magnetic recording. If it is desired to make magnetic recordings, the audio signal is equalized and then mixed with the proper amount of high-frequency bias and goes to the rerecording head. For playback, either as monitoring or as a film phonograph, the output of the playback head is connected to the left-hand box by means of another cable and enters the first preamplifier. The output of this amplifier is then equalized and passes to the second preamplifier, the output of which is at mixer level. The preamplifiers are powered, and the audio is returned by the standard preamplifier connecting cable.

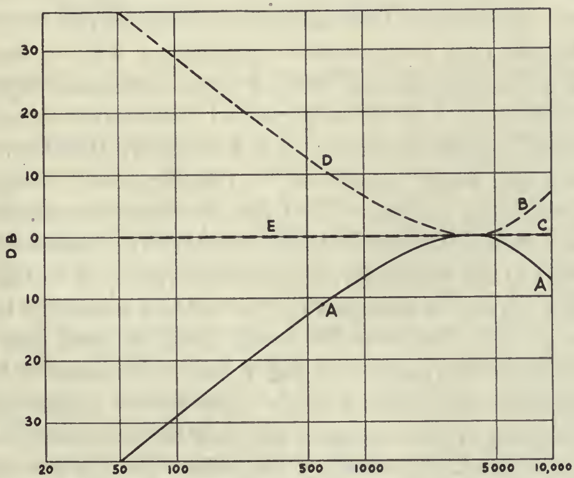

Fig. 6—Response curve of normal system and equalization required.

The solid curve A in Fig. 6 is the uncompensated response of a typical magnetic film at 90 feet per minute. If constant current is maintained in the recording head at all frequencies, substantially constant magnetization of the tape will result at all frequencies, but this does not mean that a film so recorded will produce a flat response when reproduced. Two major effects prevent the response from being at all flat. The first is that a magnetic-reproducing head is a "rate-of-change" device which means that the voltage output is proportional to the rate of change of the flux rather than to the amplitude of the flux. This effect accounts for the 6-decibel-per-octave rise starting at the low-frequency end and, at this film speed, extending up to about 4000 cycles. The second effect which causes the output above 4000 cycles to fall is due to several factors, one being the inability of any magnetic material to maintain extremely short, closely spaced magnets. This is called self-demagnetization and would, perhaps, be equivalent to loss of resolution in a photographic film. Another cause of this high-frequency loss is again equivalent to a photographic system and that is slit loss or, in this case, gap loss. The magnetic gap is and should be smaller than the photographic slit and consequently, is of less importance in regard to the high-frequency loss. A third effect contributing to high-frequency drop is the eddy-current loss in the iron in the heads, although this is of minor importance, especially if thin laminations of good iron are used.

It is obvious that considerable equalization will be necessary to obtain a flat over-all response, but the uncompensated response is not greatly unlike that of an uncompensated disk-record reproducer and can be treated in a like manner. It is well known that the energies of actual voice and music sounds in the high-frequency range are well down in output as compared to their low-frequency output. This fact allows a certain amount of high-frequency pre-emphasis. If constant current in the recording head produces curve *A* in Fig. 6, and if the constant current is obtained by the use of a relatively high resistance in series with the recording head, it can be seen that a recording-current curve like curve *B* in Fig. 6 can be obtained by by-passing the constant-current resistor with capacitor of proper size. The amount of tip-up or pre-emphasis and how far it is extended is determined by the intended frequency response. In this case the specifications were for flat response to 8000 cycles. Curve *C* is then the sum of recording pre-emphasis added to the normal playback response.

Since voice and music energies are at their maximum at low frequency, it is not possible to use pre-emphasis over this range, so this correction must be made during playback. Somewhere in the playback system a characteristic similar to curve *D* must be inserted. Since considerable amplifier gain must be used during playback, this equalizer may be used not only to obtain proper response, but also to reduce greatly first-tube hiss and noise. This means that this equalizer should be used after the first tube or tubes of the playback system. In the conversion kit the equalizer is arranged in the circuit to follow the first two-stage amplifier. When the response of this equalizer is added to the normal response, a flat curve will result, as shown by curve *E*.

Optimum High-Frequency Bias in Magnetic Recording*

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Summary—An experimental study was made of magnetic tapes and films produced by several manufacturers. The effects of bias current upon the frequency characteristic, the reproducing level, and the harmonic distortion are shown. Conclusions are drawn as to the best method of testing a given tape for the optimum value of high-frequency bias.

A high-frequency bias for magnetic recording was first used by W. L. Carlson and G. W. Carpenter in 1921. Since that time there have been differences of opinion regarding the exact cause of the improved linearity and lower distortion produced by this type of bias. Many people subscribe to the theory that the action of the high-frequency magnetic field is to keep the molecules in a constant state of agitation and thus make them more responsive to the lower frequencies required for the recording of speech and music. Others believe that the improved results can be accounted for by the action of the combined high- and low-frequency magnetic fields upon the normal magnetic characteristics of the material in question. Toomin and Wildfeuer[1] attempted to explain the action of a high-frequency bias upon a sound-recording system using a recording medium having permanent-magnet characteristics. Later, Holmes and Clark[2] gave a different explanation of the same phenomena and showed how a magnetic-recording system is analogous in some respects to a push-pull amplifier. The writers of the present paper are of the opinion that the theory advanced by Holmes and Clark adequately explains the observed performance of a magnetic-recording system when various amounts of high-frequency bias are used. The purpose of this paper is to review briefly the above-mentioned theory and to show the effects of high-frequency bias upon the total harmonic distortion, the frequency response, and the output level for four coated magnetic tapes.

Fig. 1 is a simplified diagram showing how the high-frequency bias acts to reduce distortion and noise reproduced from a

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

permanent-magnet recording medium. The dotted line K shows one half of one of the major hysteresis loops for the magnetic material. The complete loop is symmetrical about the point O. The solid lines OF and OG represent the virgin characteristics of the material plotted in both the positive and negative directions from the magnetically neutral point O. The curves F and G are the ones with which we are most concerned, since the material does not pass through a major loop during the recording process. A high-frequency sine wave L of amplitude S has superimposed upon it lower-frequency waves E and D which are identical and which represent the speech or music being recorded. It is assumed that the magnetic material on which a record is to be made is in a magnetically neutral state before it comes under the influence of the recording head. As a particular point on the magnetic tape approaches the recording air gap, it is magnetized along a series of minor loops which occur at the frequency of the bias. These loops start at point O and progress up curve F. The amplitude of the minor loops increases until the point on the tape reaches the entering edge of the recording gap. The minor loops remain constant in amplitude during the passage across the recording air gap, but they may vary in position if the amplitude of the low-frequency recorded signal varies appreciably during the time the point on the tape is passing across the gap. When the point leaves the gap, the amplitide of the minor loops starts decreasing and finally reaches zero. If the amplitude of the recorded signal was of such value as to cause the ends of the minor loops to reach position a (Fig. 1) when the point on the tape reached the exit edge of the gap, the loops would then decrease in amplitude and recede down curve a-b until point b is reached. This is the residual induction left in the tape at the particular point in question after it has passed over the recording head.

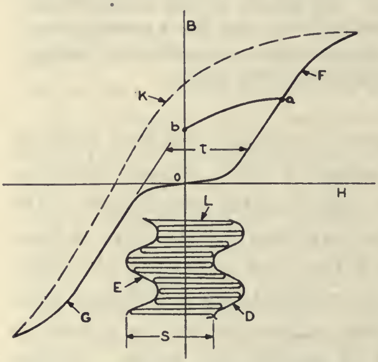

Fig. 1—Diagram showing how virgin-tape characteristic is modulated.

From Fig. 1 it can be seen that one of the functions of the high-frequency bias is to eliminate the effect of the "kink" in the normal characteristics of a permanent-magnet material. This can be done if

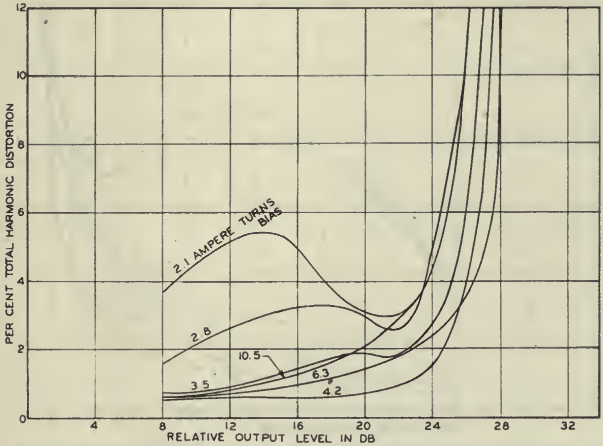

Fig. 2—Distortion-versus-reproducing-level, German Type C tape.

the amplitude S of the high-frequency bias is about equal to the distance t between the straight portions of the curves F and G. Another very important function of the high-frequency bias is to reduce noise from the reproduced signal. It is well known that the amount of noise reproduced from a magnetic-recording medium increases with the residual induction left on the medium after recording. This

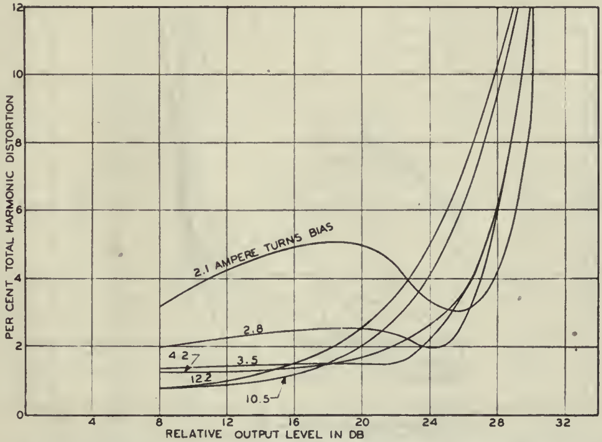

Fig. 3—Distortion-versus-reproducing-level, duPont SW4 tape.

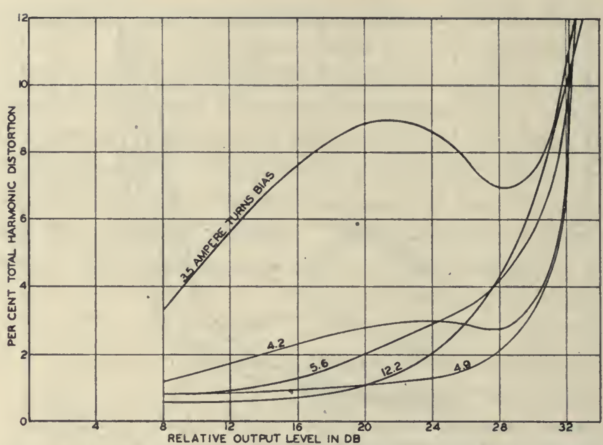

Fig. 4—Distortion-versus-reproducing-level, Minnesota Mining black-oxide plastic tape.

noise is of a random nature and sounds to the ear very much like thermal noise from a resistor, or like "shot effect" from an amplifier tube or phototube. The ear is very sensitive to this type of noise when there are no other reproduced signals to mask it. The high-frequency bias, therefore, serves the important purpose of keeping the recording medium in a magnetically neutral state when no signal is recorded.

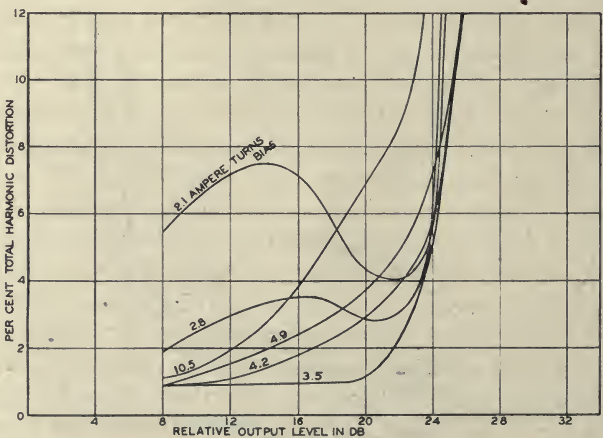

Fig. 5—Distortion-versus-reproducing-level, Minnesota Mining Type RR tape.

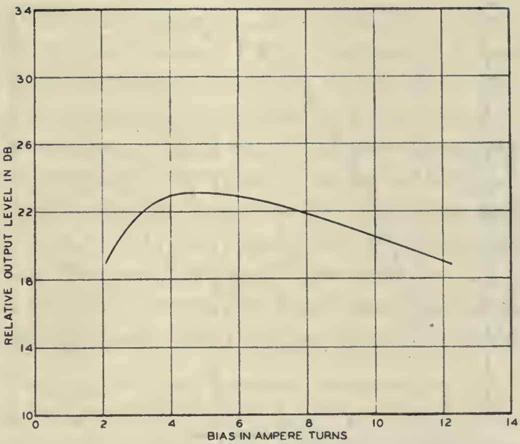

Fig. 6—Output-level-versus-bias, German Type C tape.

In order to determine experimentally the effect of high-frequency bias upon distortion and output level, a $^1/_4$-inch tape recorder and reproducer was so arranged that many of its characteristics could be held constant throughout the tests. The tape speed was set at 15 inches per second, and the over-all frequency characteristic was adjusted to be flat within 1 decibel from 50 cycles per second to 10,000 cycles per second when using German Type C tape with the bias set

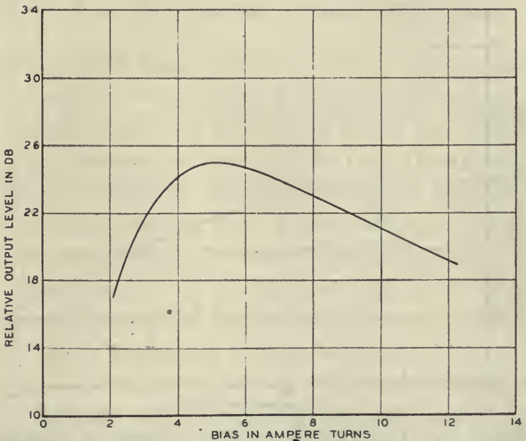

Fig. 7—Output-level-versus-bias, duPont SW4 tape.

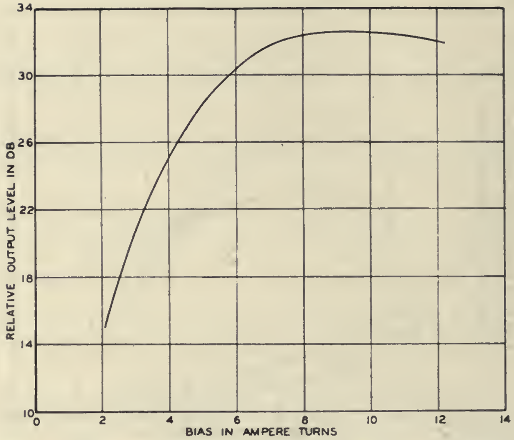

Fig. 8—Output-level-versus-bias, Minnesota Mining black-oxide plastic tape.

at its optimum value. The frequency of the bias was 100 kilocycles. The recording characteristic was flat from 50 to 3000 cycles per second and rose 10 decibels between 3000 and 10,000 cycles per second. Three-foot loops of each of the tapes were used for the tests, and the recorded material was continuously erased before new material was recorded. The erasing frequency was also 100 kilocycles. Ring-type heads of RCA design were used for recording, reproducing, and erasing. The recording gap was 0.001 inch while the reproducing gap was

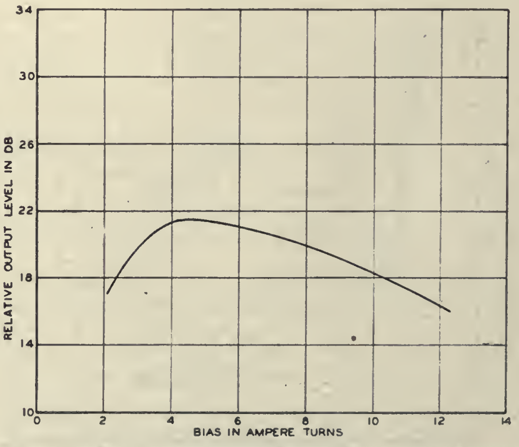

Fig. 9—Output-level-versus-bias, Minnesota Mining Type RR tape.

0.0005 inch. The total distortion introduced by the recording and reproducing amplifiers was about 0.25 per cent. A General Radio Type 732-A total-harmonic-distortion meter was used, and the distortion and output-level measurements were made at a frequency of 400 cycles per second. The gain of the reproducing amplifiers was held constant throughout the tests, in order to have a direct comparison between the output levels for the four tapes tested. These were German Type C, duPont Type SW4, Minnesota Mining black plastic tape, and Minnesota Mining Type RR tape.

Fig. 2 shows a family of curves in which the total harmonic distortion in per cent is plotted against output level in decibels for various

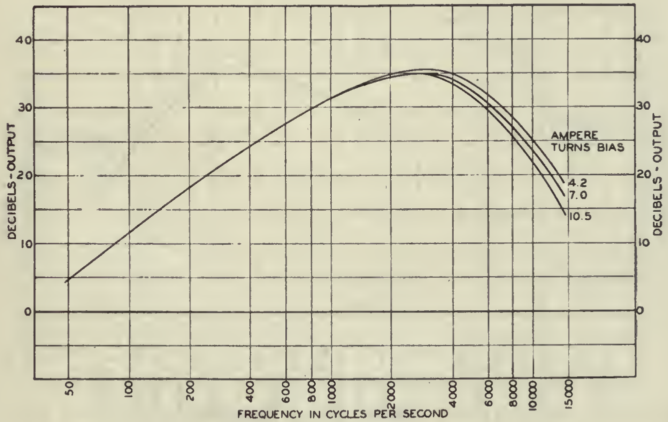

Fig. 10—Frequency response, German Type C tape.

values of high-frequency bias. This family of curves was made with German Type C tape under the test conditions described above. A range of bias values extending above and below the optimum value was chosen. It is quite apparent that the curve made with a bias of 4.2-ampere turns will result in the greatest output with the least distortion. The distortion is less than 1 per cent for output levels below 22.5 decibels, after which the curve breaks sharply. For higher or lower bias values, the distortion is greater for a given output level.

In view of the explanation of the recording process based upon Fig. 1, it seems reasonable to expect the distortion curves to be as they are shown in Fig. 2. For low values of bias we should expect the distortion to be relatively low for small recorded-signal amplitudes. This is because the curve *GOF* (Fig. 1) is relatively straight where it passes through the point O. When the signal is increased until the peaks extend beyond the toe portions of curves G and F, the distortion will reach a maximum value. For still greater values of recorded signal the distortion will decrease because the distortion effect of the "kink" in the curve GOF will become a smaller percentage of the total signal. For even greater values of recorded signal, the distortion will rise again because the peaks of the waves will begin to occupy the "knee" portions of curves G and F.

It is assumed that the best value of bias is the one which just eliminates the "kink" in the over-all characteristic and results in a constant slope through the origin O. Any further increase in bias re-

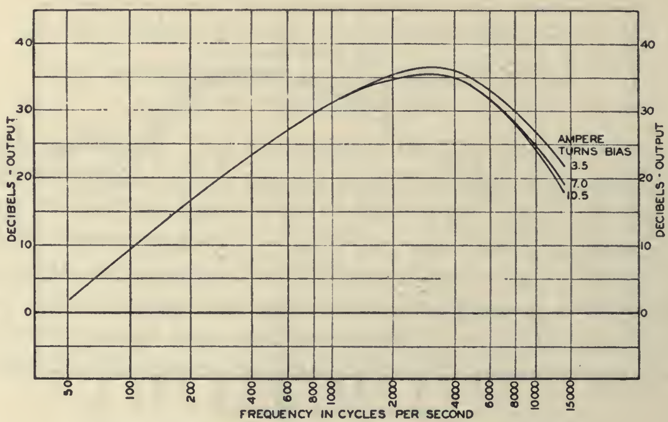

Fig. 11—Frequency response, duPont SW4 tape.

sults in the slope being greater near the origin, and it also results in a reduction in the total effective length of the characteristic curve, due to partial erasing. These two effects account for the fact that for high values of bias the distortion is increased and the overload level is decreased.

It should be pointed out here that the absolute values of the output levels and bias values shown in Figs. 2 to 9 have no significance. A bias of 1.0-ampere turn used with a recording head of one design would not necessarily produce the same effect as the same bias value used with a recording head of another design. Since in this case the same recording head was used throughout the tests, the numerical values of bias are necessary in order to compare one tape with another. The gain of the reproducing amplifiers was held constant throughout the tests in order to make it possible to compare output levels for different tapes.

Fig. 3 shows a family of output-versus-distortion curves for duPont SW4 tape. It may be seen that the best bias value is 3.5-ampere turns. Comparing Fig. 3 with Fig. 2, it will be observed that the overload levels (for optimum bias) are about the same for German Type C and duPont SW4 tape. The distortion values below overload are, however, appreciably higher for the duPont tape.

Fig. 4 shows a family of output-versus-distortion curves for Minnesota Mining black plastic-base tape. It will be observed that the

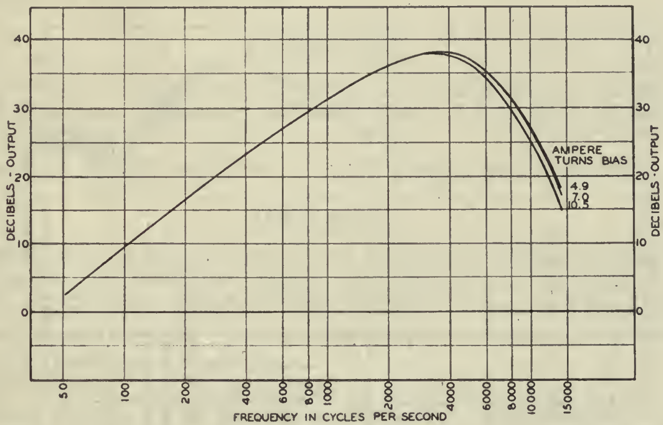

Fig. 12—Frequency response, Minnesota Mining black-oxide plastic tape.

best bias value is 4.9-ampere turns, which is somewhat higher than for the other two tapes. If we arbitrarily assume the overload point to occur at 3 per cent distortion, the overload level (for optimum bias) of Minnesota Mining black tape is 4 decibels higher than for German Type C tape. It will be noticed that the curve for 5.6-ampere turns is much poorer than for 4.9-ampere turns. At 12.2-ampere turns, the curve gets better again but not so good as for the optimum bias. The overload point drops $3^1/_2$ decibels when the higher bias value is used, but this level is still higher than for the German tape.

Fig. 5 shows a family of output-versus-distortion curves for Minnesota Mining Type RR tape. The best bias value occurs at 3.5-ampere turns, which is the same as for duPont SW4 tape. The overload level (for 3 per cent distortion) is 3 decibels lower than for

German Type C tape and 7 decibels lower than for the Minnesota Mining black plastic-base tape. The Type RR tape has compensating advantages over the black type in that it is much easier to erase, requires a lower bias value, and has a lower noise level.

The effect of bias current upon output level for four different tapes is shown in Figs. 6 to 9, inclusive. These curves were made with a constant recording level, and the output level is plotted as a function of bias in ampere turns. The recording level was set to give an output level of 23 decibels for German Type C tape, 23 decibels for duPont SW4, 28 decibels for Minnesota Mining black tape, and 21

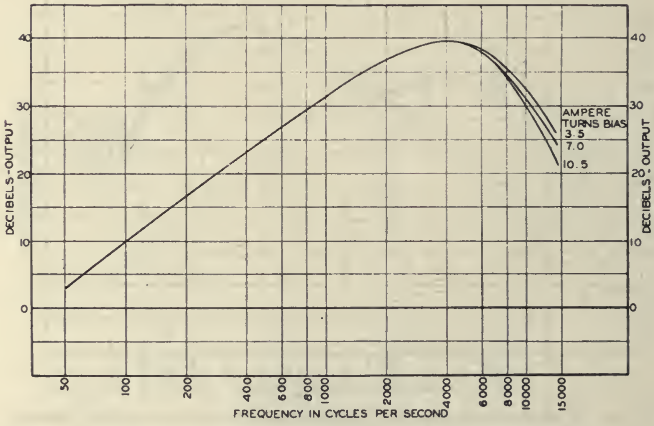

Fig. 13—Frequency response, Minnesota Mining Type RR tape.

decibels for Minnesota Mining Type RR tape. By comparing values on Figs. 2 and 6, it can be seen that for German Type C tape the bias value required for lowest distortion is the same value required for maximum output level. This is a very desirable condition because it means that slight variations in bias about its optimum value will not cause corresponding variations in the output level. For duPont SW4 and Minnesota Mining Type RR tapes (Figs. 7 and 9) the bias required for least distortion occurs slightly below the point of maximum output level. For Minnesota Mining black plastic-base tape, the bias which gives the maximum output is nearly twice the value which is optimum from the standpoint of distortion.

The effect of bias upon frequency characteristic for four tapes is shown in Figs. 10 to 13, inclusive. The purpose of these curves is to show that the bias current produces some erasing of the signal and this effect is greatest at the highest signal frequencies. It will be observed that Minnesota Mining black tape is less affected by bias than the other red-oxide tapes. This is probably because the coercive force for this tape is higher and the effect of demagnetization at high frequencies is less. All three of the American-made tapes have better high-frequency response than the German Type C tape. The curves shown in Figs. 10 to 13 were made without compensatión and represent the variation in output voltage of the reproducing head with recorded frequency. The current in the recording head was held constant at all frequencies.

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(2) Lynn C. Holmes and Donald L. Clark, *Electronics*, July, 1945.

DISCUSSION

CHAIRMAN JOHN G. FRAYNE: Mr. Pettus, is the performance of the film drive from the standpoint of velocity or speed variation as good for the position occupied by the magnetic-recording head which is not on the recording drum as compared to the speed variation or flutter which exists in optical recording in which the point of translation is on the drum?

MR. J. L. PETTUS: Are you referring to the recorded reproduction?

CHAIRMAN FRAYNE: I am referring to the position of the record head. How does the speed-recording variation compare to the speed for normal optical film?

MR. PETTUS: Tests of flutter made by optical recording have indicated this drive to be considerably improved over the former machines. With the recording reproducing head in place, which would be adding to the film, our measurements show no serious difficulty in that respect. In brief, we believe that the drag of the recording reproduction head offers nothing objectionable.

CHAIRMAN FRAYNE: Do you have any factual data?

MR. PETTUS: Not at this time.

MR. CRONIN: Mr. Dimmick, in connection with the curves in which you described the percentage of distortion of total distortion versus ampere turns—is it not a problem to know the volume of material that is being magnetized; for example, was there any difference in the thickness of the magnetic film or the pigment? I presume the width of the regions of influence were the same. Could not that be normalized to some quantity stated to unit volume, for example?

MR. G. L. DIMMICK: We have no data on the exact thickness of the four films presented. I believe that the German film is thicker than the films used in the American-manufactured films, but I am not certain. To get that data, we should have to go to the manufacturers of the film itself.

MR. C. R. KEITH: Do you have any particular reason for choosing the position of the sound track that was mentioned in the paper? It appeared that the sound track is placed in exactly the same position as the 200-mil photographic sound track. That is quite possible, but it seemed to me there would be some advantage in having the magnetic track farther away from the sprocket holes.

MR. DIMMICK: That is a very good question, and one for which we probably do not have a complete answer, but one on which the various committees are working. All other things being equal, it would seem best to have the track location in the same place as formerly used for wide-track photographic recording. One might think that it would be best to put the track down the center. I think there is no doubt that you would be freer from the effect of the sprocket holes if you did this; however, you do sacrifice the ability to turn the film around and put two tracks on. I think that there will have to be much work done on this before the final standardization is given for the location of magnetic track.

CHAIRMAN FRAYNE: Have you done any work on $17^1/_2$-mm film?

MR. DIMMICK: No.

MR. L. D. GRIGNON: Do you have any information comparing the impregnated tapes versus the coated tapes that you have shown here today?

MR. DIMMICK: Are you thinking of tape like the German tape? No, we have not, and I think the reason for that is that the Germans themselves became discouraged by the results they obtained from the Type L. The reason for that was that the print-through was too great. You would have one layer against the other, and you get printing too high to tolerate.

MR. GEORGE LEWIN: Is there any optimum value for the width of the track? It would seem to me the wider you make it, the better the signal-to-noise ratio.

MR. DIMMICK: Yes, the same consideration holds for magnetic recording and variable-density recording.

MR. LEWIN: Why did you use only 180 or so? Why not the full width?

MR. DIMMICK: Once again, we did take exactly the same dimensions as had previously been standardized for photographic recording. There is a recording head over the same area formerly covered by the recording light beam, and the reproducing head is the same width as the reproducing light beam.

QUESTION: Do you feel then that if you went to full width that the amount of gain is not sufficient to justify it?

MR. DIMMICK: There are two factors. We believe that the signal-to-noise ratio obtainable from the present width of track is so much greater than formerly available in photographic recording that it is not necessary to go to wider tracks, and tolerance on angle of both recording and reproducing heads gets much worse as the width of the track goes up in width.

MR. LAW: Will the bonding agent in the tape, when used, say in 16-mm work, stand developing without any signal loss?

MR. DIMMICK: I cannot answer that specifically, but I am of the opinion that developing will not harm the tapes. I believe there are in the audience representatives from the tape manufacturers. Possibly they could answer that better.

MR. R. R. HERR: I cannot speak from experience, but certainly nothing that I know of has much effect. There is a plastic oxide binder in which the magnetic oxide is placed, and I am quite sure it will have no effect on the oxide itself which is impregnated in that binder.

Variable-Area Recording with the Light Valve*

By JOHN G. FRAYNE

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Summary—**Various types of variable-area track, including standard and push-pull, may be obtained by various arrangements of the light-valve ribbons. A mathematical analysis is made of the effect of various light-valve constants on the magnitude of the resonance-peak and frequency-response measurements of an improved light valve with high magnetic damping are given. A theoretical study of the effect of azimuth deviation on unilateral, dulateral, and bilateral tracks is included in the paper and is illustrated with graphical charts of the distortion produced by various amounts of azimuth deviation for these types of tracks.**

Introduction

The new Western Electric variable-area light valve recently introduced to the motion picture industry is based on a design initiated by Wente and Biddulph[1] of the Bell Telephone Laboratories in the application of the light valve to variable-area recording in connection with the development of a stereophonic sound-film system. While the light valve has been ordinarily associated with the variable-density type of sound track it is only necessary to rotate the valve through an angle of 90 degrees to obtain the variable-width type of modulation. While many more or less unsuccessful attempts have been made over a period of years to adapt the light valve to variable-area recording its successful application in this type of recording has only been made possible by improvements in light-valve design and in the development of a suitable anamorphote optical system to magnify the relatively small movements of the ribbons into full sound-track-width modulations.

A cross section of the Wente-Biddulph valve is shown in Fig. 1. The outer shell forms the permanent-magnet structure of the valve while the permandur pole pieces form a sealed structure when the assembly is magnetized. A condenser lens is mounted in one pole piece while an objective lens is mounted in the other pole piece.

* Presented May 17, 1948, at the SMPE Convention in Santa Monica.

The ribbon-support structure is carried by one of the pole pieces. An optical schematic of the associated variable-area light-valve modulator is shown in Fig. 2. It will be noted that in addition to the spherical objective lens L_1 mounted in the valve, a cylinder lens L_2 is mounted near the film plane. The former serves to magnify the ribbon movement so that the desired track width is obtained for 100 per cent modulation while the latter serves to reduce the height of the slit S to a suitable value at the film plane.

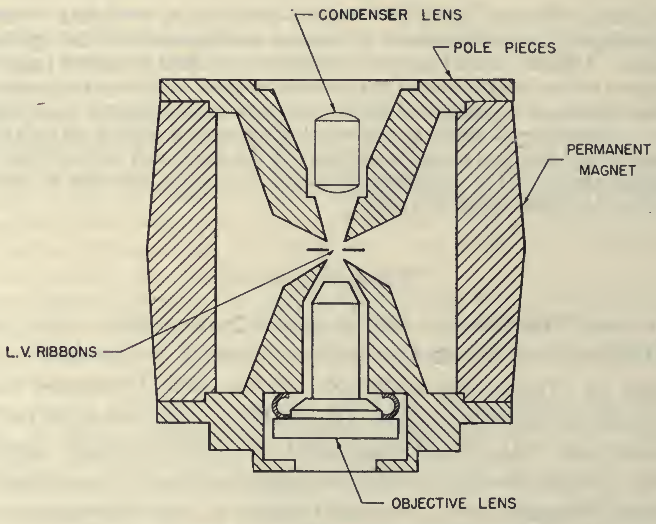

Fig. 1—Cross-section Wente variable-area valve.

The new variable-area light valve which is described in another paper[2] follows the general basic design of the Wente valve and all details of slit height, lens magnification, and ribbon arrangements are given in that paper.

Types of Tracks

(a) *Two-Ribbon Valve*

The various types of tracks that may be recorded by an area light valve depend on the number and disposition of the ribbons employed. The simplest valve employs only two ribbons; and, by reference to Fig. 3, three types, namely, (a) bilateral, (b) unilateral, and (c) push-pull, may be obtained by connecting the signal input circuits as shown in the figure. In these three applications only one bias line appears on the film with the application of noise-reduction bias current as indicated. In the bilateral method the noise-reduction currents are superimposed on the signal currents in both ribbons in a manner analogous to that used in the well-known double-ribbon variable-density light valve.[3] For a ten times magnification of the light-valve aperture a 0.2-mil biased spacing will produce a 2-mil bias line. Since a 3.8-mil spacing is indicated to produce a 38-mil "half" or unbiased track, the noise reduction for 2-mil bias line obtained is theoretically given by[4]

$$NR = 10 \log \frac{3.8}{0.2} = 12.8 \text{ db.}$$

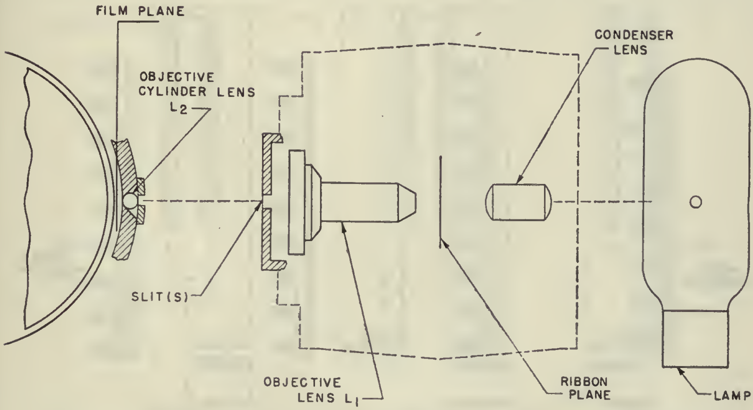

Fig. 2—Schematic for Wente variable-area light-valve modulator.

In the unilateral method the signal is applied to one ribbon only while noise reduction is applied to the second ribbon. This requires double the movement of the signal ribbon obtaining in the bilateral connection, the effect of which will be discussed below.

Class A push-pull operation is obtained by the connections shown in Fig. 3(c). The signal currents flow in the same direction in each ribbon causing them to move in the same direction due to the reaction of these currents to the magnetic field. On the other hand, the noise-reduction currents, flowing in series through the ribbons, produce the normal biasing action.

Reproduction of the three types of tracks resulting from the above three methods of connecting the ribbons to the signal and bias circuits is shown in Fig. 4(a). These are all based on a 76-mil maximum modulation the half-track width being 38 mils for the duplex and unilateral tracks. In order to permit a 6-mil septum on the push-pull track, a "half" track of 41 mils, with modulation limited to 94 per cent of the ribbon aperture, is employed. In all cases the maximum track width is limited only by the modulation of the light-valve ribbons.

In addition to the above types of track that may be laid down by the two-ribbon light valve it is possible to produce a double-bilateral or a double-unilateral track by means of an image doubler. This is readily accomplished by inserting an optical biplate in the objective lens of the light-valve modulator in a manner described in another

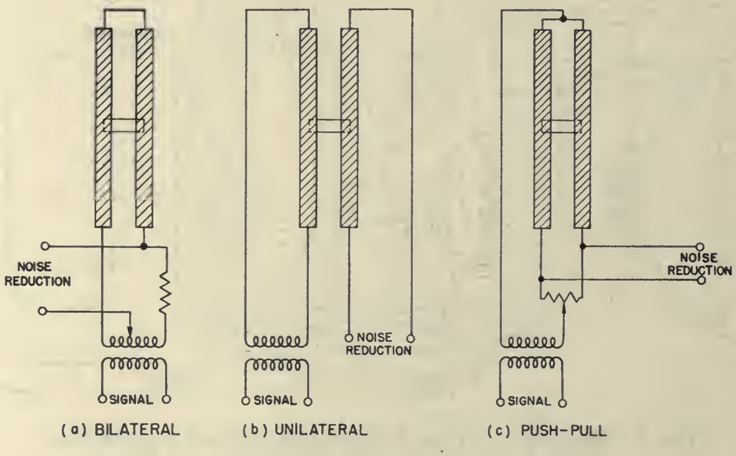

Fig. 3—Connections for two-ribbon variable-area valve.

paper.[2] The use of either of these types of track obviates the difficulty encountered from reproducing either the bilateral or unilateral tracks in reproducers equipped with push-pull reproducing optics, since the septum in these optics may result in severe distortion in low-level signals. The double-unilateral track, known as dulateral track, and shown in Fig. 4(b), is produced by the same type of valve as that used for obtaining the unilateral track, the only physical difference being in the spacing of the ribbons which is reduced by one half. This valve has the advantage over the double-bilateral type of separating noise reduction and signal circuits and offering greater damping by reducing the over-all resistance of the light-valve signal circuit.

(b) Three-Ribbon Valve

While a push-pull track may be recorded by a two-ribbon valve a preferred method employs a three-ribbon valve, the circuit connections of which are shown in Fig. 5. In this case the speech currents are confined to the center ribbon while the noise-reduction currents are confined to the outer two ribbons. This provides complete separation of the two circuits which previously[5] has been shown to be desirable for stable operating conditions. A sample negative track laid down by this valve is shown in Fig. 6. In this case the clear central area of modulation is caused by the movement of the image of the central speech ribbon while the dark portions are produced by the varying spacing between the noise-reduction ribbons and the

(a) BILATERAL (b) UNILATERAL (c) PUSH-PULL

Fig. 4(a)

Fig. 4(b)—Dulateral track.

central ribbon in accordance with the impressed signal modulation and noise-reduction bias currents. If a 76-mil push-pull track with a 5-mil septum is required a 4.0-mil wide ribbon with ten times magnification is provided. On the other hand if a double-width track is required the width of the ribbon must be increased proportionately. In practice, a 10-mil ribbon is required for a double-width track in order to preserve the centerline separation of each component track previously established for 200-mil push-pull density[6] sound tracks.

The three-ribbon structure may also be employed to obtain Class B type push-pull operation. This is shown schematically in Fig. 7. In this case the signal currents flow in the same direction in the outer ribbons while the return current flows in the opposite direction in the center ribbon. In this valve ribbons 1 and 3 must not be coplanar with ribbon 2 in order to permit passage behind the latter. If the three ribbons are adjusted so that no light is transmitted through the aperture between them for the condition of zero input, then ribbons 1 and 3 on moving to the right under an impressed signal will permit a half wave of exposure to be transmitted between 2 and 3. Vice versa, the other half wave will be transmitted between 1 and 2 when the ribbons 1 and 3 move to the left of the normal position. Thus a Class B track may be laid down with this valve. A Class A-B track may be recorded by permitting some exposure between the ribbons for the unmodulated condition. Since noise reduction is automatically obtained with either Class B or A-B push-pull no provision for bias currents is required with this valve.

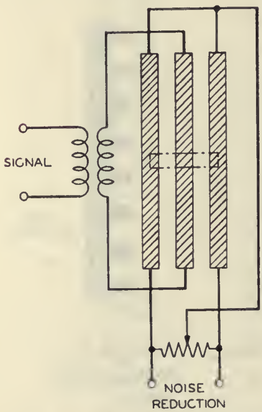

Fig. 5—Connections for three-ribbon Class A push-pull variable-area valve.

Fig. 6—Double-width class A push-pull.

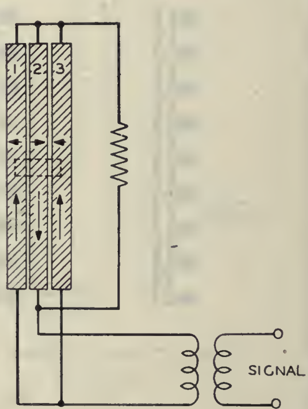

Fig. 7—Connection for three-ribbon Class B variable-area valve.

Frequency Characteristic of Light Valve

(a) *Theoretical*

The maintenance of precise sound-track and bias-line dimensions depend on a high order of stability of ribbon position and sensitivity. This called for the elimination of the high resonance peak which had been found to cause considerable instability in the earlier type of light valves.[7]

While this peak may be eliminated by the use of feedback,[8] in the design of a modern variable-area valve a high magnetic-flux density in the air gap is relied on mainly to provide efficiency electromagnetic damping of the ribbons at resonance. In order to evaluate the factors which control the frequency response of a light valve the following mathematical analysis is employed.

The velocity v of the ribbon at any instant when subject to a force F is given by

$$v = \frac{F}{R_m + j(\omega M - (1/\omega C_m))} = \frac{F}{Z_m}. \tag{1}$$

where

R_m = mechanical resistance
M = mass
C_m = compliance
ω = $2\pi \times$ frequency
Z_m = mechanical impedance.

The force on the ribbon is given by

$$F = Bli \tag{2}$$

where

B = magnetic flux in the air gap
l = length of the ribbons
i = the current in the ribbons.

Now the counter electromotive force generated by the ribbon motion in the magnetic field is Blv. Hence

$$E = Blv + R_0 i \tag{3}$$

where

E = the voltage applied to the ribbon
R_0 = electrical resistance.

Substituting (1) and (2) in (3), we obtain

$$i = \frac{E}{R_0 + (B^2l^2/Z_m)}. \tag{4}$$

From (2)

$$F = \frac{BlE}{R_0 + (B^2l^2/Z_m)}. \tag{5}$$

Therefore, from (1)

$$V = \frac{(BlE/R_0)}{(B^2l^2/R_0) + Z_m}$$

$$= \frac{(BlE/R_0)}{R_m + (B^2l^2/R_0) + j(\omega M - (1/\omega C_m))}. \tag{6}$$

The two real terms in the denominator constitute the effective mechanical resistance. The first term which is mainly due to windage resistance may be neglected in valves where the magnetic flux B is large as in the case of the modern permanent-magnet light valve.

The displacement is given by integrating (6)

$$d = \frac{(-jBlE/R_0)}{(\omega B^2l^2/R_c) + j(\omega^2M - (1/C_m))}. \tag{7}$$

The displacement at zero frequency is given by

$$d_0 = \frac{BlEC_m}{R_0}. \tag{8}$$

Equation (7) may therefore be rewritten in terms of d_0 as

$$\frac{d}{d_0} = \frac{-j/C_m}{(\omega B^2l^2/R_0) + j(\omega^2M - (1/C_m))}. \tag{9}$$

Expressed in terms of Q which is defined as $(M\omega_r/R)$ where ω_r is defined as $1/\sqrt{MC_m}$

$$\frac{d}{d_0} = \left|\frac{-jQ}{\omega/\omega_r + jQ((\omega/\omega_r)^2 - 1)}\right|. \tag{10}$$

The valve frequency-response characteristic for a constant-current input can therefore be computed from (10) simply by inserting assigned values of ω/ω_r and Q. The latter may be determined experimentally by comparing the sensitivity (displacement) at the mechanical resonance frequency to that at zero frequency or direct current as indicated by (10) which reduces to

$$\left|\frac{d_r}{d_0}\right| = Q \text{ for } \frac{\omega}{\omega_r} = 1. \tag{11}$$

Now from (7)

$$d_r = \frac{jE}{\omega_r Bl}. \tag{12}$$

Hence

$$Q = \left|\frac{d_r}{d_0}\right| = \frac{R_0M\omega_r}{B^2l^2}. \tag{13}$$

Since it is customary to express frequency response in terms of decibels, (10) may be written

$$\text{db} = 20 \log \frac{d}{d_0} = 20 \log X \left|\frac{-jQ}{\omega/\omega_r + jQ((\omega/\omega_r)^2 - 1)}\right|. \tag{14}$$

A series of characteristic curves based on (14) are shown in Fig. 8

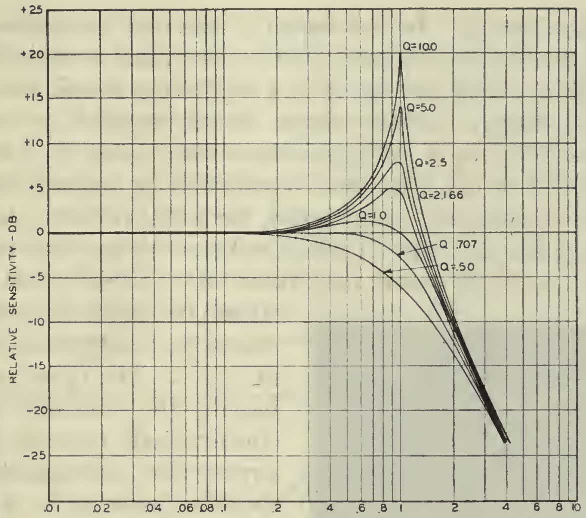

Fig. 8—Light-valve theoretical response for various values of Q.

for values of Q ranging from 10 to 0.5. The latter curve which shows a loss of 6 decibels at resonance corresponds to the critical damping condition.

(*b*) *Experimental Characteristic*

It will be noted that the Q of the light valve varies inversely as the square of the flux density in the air gap and directly as the resistance

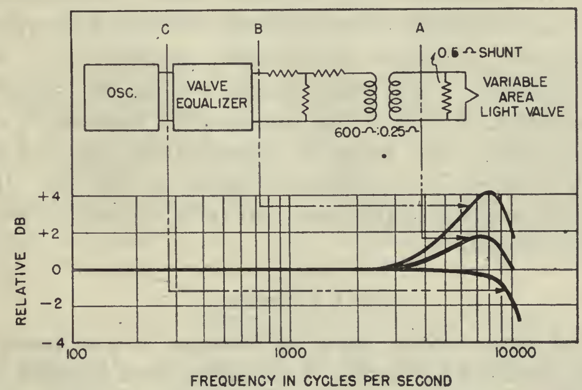

Fig. 9—Actual response of variable-area light valve.

of the valve circuit. In the design of the new variable-area light valve, the flux density has been built up to a value in excess of 30,000 gauss. By applying the signal to a single ribbon and avoiding the additional resistance of the simple circuit required in two-ribbon valves the resistance of the light-valve circuit is kept to a minimum. The resistance of the light-valve circuit may be reduced further by placing a low-resistance shunt across the signal ribbon. As a result of increased flux and reduced circuit resistance it has been possible to design the new variable-area light valve with a circuit Q less than 2.0.

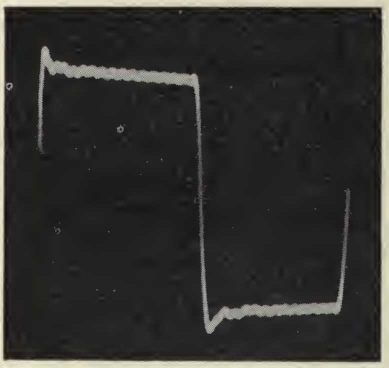

Fig. 10—Square-wave response of area light valve plus equalizer.

Actual frequency-response curves of a modern light valve are shown in Fig. 9. The upper curve represents the response for constant-voltage input at A in the circuit and corresponds to the condition existing in a zero-impedance generator. The actual resonance peak is somewhat less than 2 decibels, corresponding to a Q of 1.26. When measured for a constant input voltage in the 600-ohm circuit at B the peak is increased to slightly over 4 decibels, since in this case the voltage across the ribbon is not constant but rises with the impedance of the valve near resonance frequency. This peak is eliminated in practice by the insertion of an equalizer with a transmission characteristic which is roughly complementary to that of the valve. The resulting frequency-response characteristic measured at C in Fig. 9 shows the actual recording characteristic for constant input voltage into the recording channel. The square-wave response of a typical valve with 0.5-ohm shunt across the signal ribbon and with the complementary equalizer in the circuit is shown in Fig. 10. It will be noted that the response approaches that to be expected from a critically damped device.

Peak Chopper

As pointed out in another paper by Browder,[2] it is necessary to have the ribbons mounted accurately in the same plane in order to secure sharp definition of the images of the ribbon edges at the film plane.

Since physical clashing of the ribbons at overload should be avoided, it has been found desirable to limit the modulation by a chopping circuit. The use of a conventional limiter in addition to the noise-reduction circuit has not proved to be completely satisfactory as the combination gives a pumping quality which is not noticeable when either is used alone. Instead the use of a driving amplifier with an abrupt overload characteristic has been found quite satisfactory. The load characteristic of this amplifier is shown in Fig. 11. It will be noted that at the overload output of +28.5 decibels, peak chopping begins and no further increase in output results. The harmonic content of this amplifier is 0.5 per cent at 2 decibels below the peak-

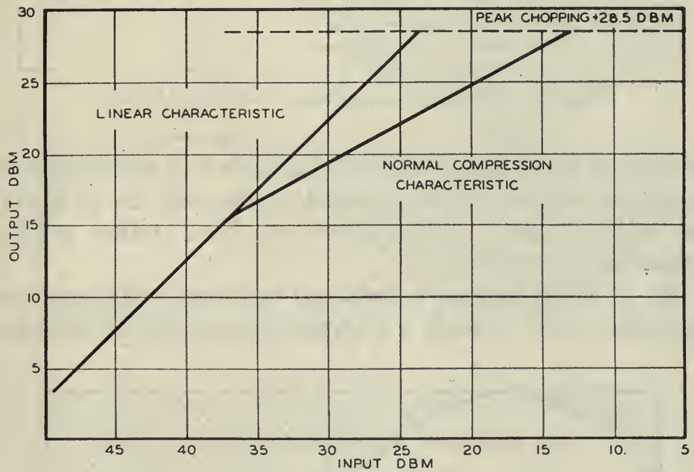

Fig. 11—Load characteristic of main amplifier.

chopping level which should be set just below the overload point of the light valve. Listening tests have confirmed that the distortion resulting from overload of the amplifier is quite similar to that associated with clipping of the signal peaks in an overmodulated track by the reproducer scanning slit. It is preferable to clashing the ribbons at overload, since in this case a transient is induced because the valve is not completely critically damped.

EFFECT OF AZIMUTH DEVIATION ON TRACKS

In evaluating the performance of the various types of variable-area tracks laid down by the light valve, the rigorous mathematical

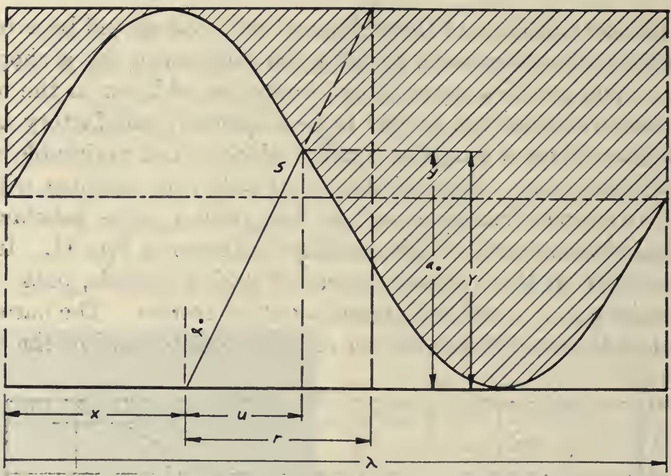

Fig. 12—Off-azimuth scanning of unilateral track.

analysis given in the Appendix has been made to determine the effect of azimuthal deviation of the reproducer scanning slit on distortion in the various types. This problem has been studied previously by Cooke[9] and Foster.[10]

In Fig. 12, there is shown a unilateral-type track with amplitude a_0 scanned by a slit $\dot{S}$ at angle α with the true azimuth of the scanning

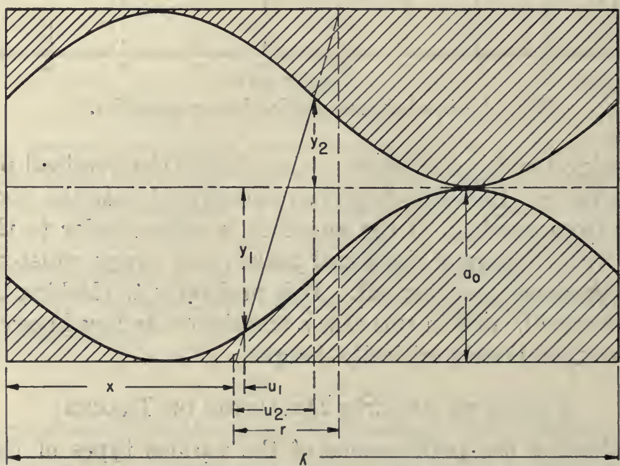

Fig. 13—Off-azimuth scanning for bilateral track.

beam. The instantaneous amplitude of the unilateral track so scanned is

$$Y = a_0 + a_0 \sin \frac{2\pi}{\lambda} (x + u) \tag{15}$$

where

a_0 = the amplitude of the wave
x = the distance from the origin
λ = the wavelength of the sound, and
u = the reflection of the scanning line S along the x axis.

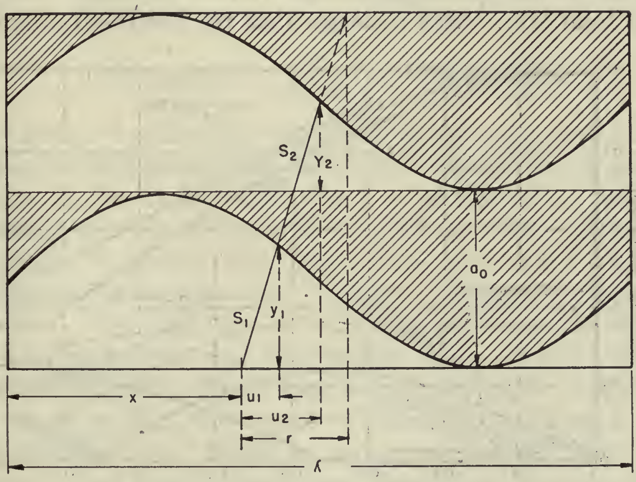

Fig. 14—Off-azimuth scanning of dulateral track.

In the Appendix it is shown that as a result of scanning this wave form with the off-azimuth slit the resultant wave form is given by

$$S = a_0 \sec \alpha \left[1 + \frac{2}{(\pi r/\lambda)} \sum_{1}^{\infty} \frac{1}{n} J_n \left(\frac{n\pi r}{\lambda} \right) \sin \frac{n\pi r}{\lambda} \left(\lambda + \frac{r}{2} \right) \right] \tag{16}$$

where

r = the deviation of the scanning beam.

The expression within the brackets on the right-hand side represents an infinite series of harmonic components resulting from scanning a sinusoidal wave form by a slit with a deviation r over the normal track width.

The coefficients of the first three components are as below:

$$\text{fundamental} = \frac{2}{(\pi r/\lambda)} J_1\left(\frac{\pi r}{\lambda}\right); \tag{17}$$

$$\text{second harmonic} = \frac{1}{(\pi r/\lambda)} J_2\left(\frac{2\pi r}{\lambda}\right); \text{ and} \tag{18}$$

$$\text{third harmonic} = \frac{2}{(3\pi r/\lambda)} J_3\left(\frac{3\pi r}{\lambda}\right); \tag{19}$$

where the J's are the well-known Bessel coefficients.

It will be noted that the term r/λ appears in the expression for the amplitude of the fundamental and various harmonic components derived from (16). This indicates that the distortion produced by

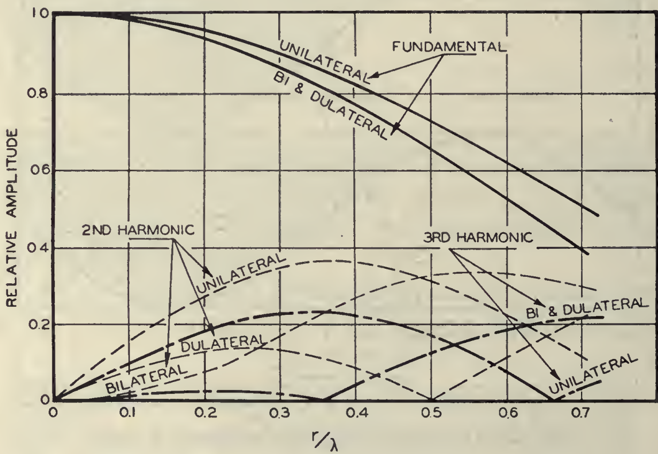

Fig. 15—Effect of azimuth on fundamental and harmonics in various tracks.

aperture misalignments is a function only of this ratio. This means that as frequencies on the sound track increase, that is, as λ decreases, the deviation r decreases proportionately for constant harmonic distortion. In other words, aperture misalignment is a more serious source of distortion in the high-frequency end of the sound spectrum.

A similar analysis of the duplex- or bilateral-type track based on the construction shown in Fig. 13 indicates that the effect of aperture misalignment in this case also produces an infinite series of harmonics, the values of the first three terms of the series being

$$\text{fundamental} = \frac{2}{(\pi r/2\lambda)} J_1\left(\frac{\pi r}{2\lambda}\right) \cos\left(\frac{\pi r}{2\lambda}\right); \tag{20}$$

$$\text{second harmonic} = \frac{1}{(\pi r/2\lambda)} J_2\left(\frac{\pi r}{\lambda}\right) \sin\left(\frac{\pi r}{\lambda}\right); \text{ and} \tag{21}$$

$$\text{third harmonic} = \frac{2}{(3\pi r/2\lambda)} J_3\left(\frac{3\pi r}{2\lambda}\right) \cos\left(\frac{3\pi r}{2\lambda}\right). \tag{22}$$

The analysis of the dulateral track based on the sketch of Fig. 14 similarly shows that the values of the first three terms of the series are given as follows:

$$\text{fundamental} = \frac{2}{(\pi r/2\lambda)} J_1\left(\frac{\pi r}{2\lambda}\right) \cos\left(\frac{\pi r}{2\lambda}\right); \tag{23}$$

$$\text{second harmonic} = \frac{1}{(\pi r/2\lambda)} J_2\left(\frac{\pi r}{\lambda}\right) \cos\left(\frac{\pi r}{\lambda}\right); \text{ and} \tag{24}$$

$$\text{third harmonic} = \frac{2}{(3\pi r/2\lambda)} J_3\left(\frac{3\pi r}{2\lambda}\right) \cos\left(\frac{3\pi r}{2\lambda}\right). \tag{25}$$

The relative amplitudes of the fundamental and second and third harmonics have been computed for the three cases analyzed above and are shown in Fig. 15 for values of r/λ up to 0.7. This latter value corresponds to a slit deviation of 1.4 mils for 9000 cycles or 2-mil wavelength. In practice a deviation of the order of 0.2 mil is about the maximum to be tolerated. This gives a value of r/λ of 0.1 at 9000 cycles. For this value of r/λ the second-harmonic content is about 2.5, 6, and 15 per cent, respectively, for the bilateral, dulateral, and unilateral tracks. For a very severe misalignment resulting in values of $r/\lambda > 0.25$, the second harmonic of the bilateral exceeds that of the dulateral. It will be noted that the amplitudes of the fundamental and third harmonic are identical for both the bilateral and dulateral tracks.

From the equations derived for the amplitude of the fundamental and second and third harmonics, these values may be determined as a function of frequency for any assigned value of azimuth deviation. Thus, assuming an angular deviation of 0.25 degree, the curves of Fig. 16 show the reproduced characteristic for a unilateral track while Fig. 17 shows the same characteristics for the bilateral and dulateral tracks. All of these curves are based on 100 per cent modulation.

CONCLUSION

The light valve which has long been used to produce the variable-density type of track lends itself readily to the variable-width type of modulation. Increase in magnetic flux in the air gap adds to the

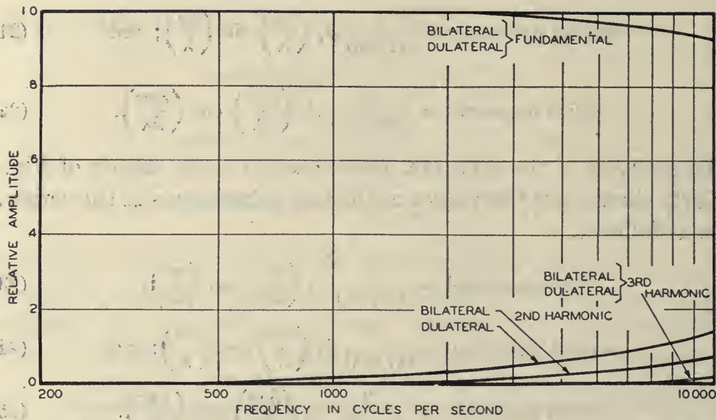

Fig. 16—Frequency and harmonic response for bilateral and dulateral tracks.

stability of the valve, making possible the maintenance of accurately located bias and track centerlines. A variety of single tracks as well as a Class A push-pull track can be laid down by a two-ribbon-type valve while both Class A and Class B push-pull readily can be recorded by a three-ribbon structure. Both double-bilateral and double-unilateral (dulateral) can be obtained from the single tracks by image doubling. An analysis of the effect of azimuth deviation on distortion indicates the dulateral track to be superior to the unilateral for all azimuthal deviations and superior to the bilateral for large values of the deviation.

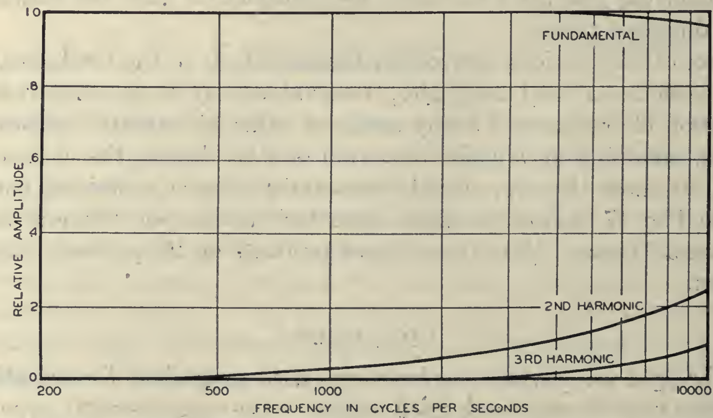

Fig. 17—Unilateral track, frequency and distortion characteristics.

ACKNOWLEDGMENTS

The writer wishes to express his appreciation to Dr. V. Pagliarulo for his assistance in obtaining the analytic solution for distortion induced by azimuth deviation of the scanning beam, and to Mr. L. B. Browder for his invaluable help in obtaining basic information used in many of the figures.

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APPENDIX

Referring to Fig. 12 for the off-azimuth scanning of the unilateral sound track, the instantaneous amplitude of the light transmitted by the unilateral modulation as scanned in the figure is given by

$$Y = a_0 + a_0 \sin \frac{2\pi}{\lambda} (x + u) \tag{26}$$

where

a_0 = the amplitude of the wave
x = the distance from the origin
λ = the wavelength of the sound wave
u = the reflection of the scanning line S along the x axis, and
r = the deviation of the scanning beam.

The voltage developed across the track in the phototube is proportional to the length S uncovered in the clear area of the track. The shaded area is considered sufficiently opaque to contribute no voltage.

Now

$$S = Y \sec \alpha \tag{27}$$

where

$$\begin{aligned} S &= \text{the length of the scanning line} \\ \alpha &= \text{the azimuthal deviation of } S\text{, and} \\ u &= S \sin \alpha \end{aligned} \tag{28}$$

so that

$$S = a_0 \sec \alpha \left(1 + \sin \frac{2\pi}{\lambda} (x + S \sin \alpha)\right). \tag{29}$$

Multiplying each side by $\sin \alpha$, and adding x to each side

$$x + S \sin \alpha = x + a_0 \tan \alpha + a_0 \tan \alpha \sin \frac{2\pi}{\lambda} (x + S \sin \alpha). \tag{30}$$

Let

$$\begin{aligned} y &= \frac{2\pi}{\lambda} (x + S \sin \alpha) \\ z &= \frac{2\pi}{\lambda} (x + a_0 \tan \alpha) \\ \beta &= \frac{2\pi a_0}{\lambda} \tan \alpha. \end{aligned} \tag{31}$$

Then (30) becomes

$$\frac{\lambda}{2\pi} y = \frac{\lambda}{2\pi} z + \frac{\lambda}{2\pi} \beta \sin y \tag{32}$$

or

$$y = z + \beta \sin y.$$

This simplified form is identical with that previously developed[7] for the exposure of a variable-density sound track with a two-ribbon light valve and the solution takes the same form. Thus, $y - z$ can be expanded into a Fourier series of z having sine terms only.

Thus,

$$y - z = \sum_{1}^{\infty} \alpha_n \sin nz. \tag{33}$$

Hence,

$$A_n = \frac{2}{\pi}\int_0^{\pi} (y - z) \sin nz \, dz. \qquad (34)$$

Integrating by parts,

$$A_n = \frac{2}{n\pi}\left[- (y - z) \cos nz \Big|_0^{\pi} + \int_0^{\pi} \cos nz \; d(y - z)\right]. \qquad (35)$$

The integrated term disappears since $y = z$ for the limiting values of 0 and π as is evident from (31). Also $\int_0^{\pi} \cos ny \, dy = 0$.

Hence, on substituting

$$y - \beta \sin y = z$$

$$A_n = \frac{2}{n\pi}\int_0^{\pi} \cos n \, (y - \beta \sin y) dy \qquad (36)$$

$$= \frac{2}{n} J_n \, (n\alpha) \qquad (37)$$

by the Bessel integral. The solution thus becomes

$$y - z = \frac{2}{n}\sum_1^{\infty} \frac{1}{n} J_n(n\beta) \sin nz. \qquad (38)$$

Substituting from (31)

$$\frac{2\pi}{\lambda}(x + S \sin \alpha) = \frac{2\pi}{\lambda}(x + a_0 \tan \alpha) + \frac{2}{n}\sum_1^{\infty}\frac{1}{n} Jn\left(\frac{n2\pi a_0}{\lambda} - \tan \alpha\right)$$
$$\sin \frac{n2\pi}{\lambda}(x + a_0 \tan \alpha). \qquad (39)$$

Since $\tan \alpha = \dfrac{r}{2a_1}$

$$S = a_0 \sec \alpha \left[1 + \frac{2}{(\pi r/\lambda)}\sum_1^{\infty}\frac{1}{n} J_n\left(\frac{n\pi r}{\lambda}\right) \sin \frac{n\pi r}{\lambda}\left(\lambda + \frac{r}{2}\right)\right]. \qquad (40)$$

From this equation the coefficients of fundamental, second, third, etc., harmonics may be computed for assigned values of r/λ and known values of J_n.

Solutions for the bilateral and dulateral cases may be obtained in an analogous manner.

DISCUSSION

MR. C. R. SKINNER: The Skinner Company has been manufacturing a unit like that since 1928. There is one slight difference. To get the slit effect, a double slit was used instead of a separate slit for the purpose. Other than that, it is identical to the machine that has been on the market since 1928.

Mr. P. E. Brigandi: Many times I have heard Dr. Frayne repeat at meetings that variable area has a certain characteristic noise that identifies it, and that it is difficult to project because of its susceptibility to uneven slit elimination. Is the Western Electric type of variable area less susceptible to those noises and problems, and does the hush-hush he mentioned indicate that density is a less desirable medium for recording than area?

Dr. J. G. Frayne: The answer to the first part of Mr. Brigandi's question should be referred to Eastman and duPont for an answer.

With regard to hush-hush, twenty years ago that was a big problem, when we had very coarse-grained films. As you know, the noise on a variable-density track is primarily grain noise. The noise on variable-area track, on the other hand, if it is processed correctly, is not grain noise, but noise contributed by scratches and dirt which increase with running. The higher grain noise on film shows up in hush-hush or breathing in variable density much more than it does on variable area.

To offset that, the wider track was brought in several years ago, so that on originals that has not been particularly bothersome, because of the increase on the wider track. On density release, the problem still remains to a certain extent, although with the finer-grain films made by the film industry the problem is no longer serious for variable density. That, I think, is borne out by the large number of Academy Sound Awards won by variable-density films.

Variable-Area Light-Valve Modulator*

By LEWIS B. BROWDER

Western Electric Company, Hollywood, California

Summary—A variable-area modulator is described which employs a ribbon light valve as the basic modulating element. Double-width push-pull, variable-area sound track or standard width dulateral sound track may be recorded at will by inserting the appropriate light valve into the modulator. The light valve is registered in place in the modulator by indexing dowels and securely locked by means of lever-controlled clamping springs.

The light-valve ribbons are oriented so as to be parallel to the direction of motion of the film. The ribbon edges are projected at ten times magnification onto the film to define the amplitude co-ordinate of the recording image while the image height is determined by a narrow rectangular stop which is imaged onto the film at a 70:1 reduction in height by a cylindrical lens system.

The modulator is a completely self-contained unit embodying the basic components for the recording optical system, an optical system for rear projecting an enlarged image of the ribbon aperture onto a viewing screen, a photoelectric monitoring system, and an exposure meter.

Introduction

The Western Electric variable-area sound-on-film recorder to be described represents a reduction to motion picture studio practice of the recording apparatus employed in the stereophonic-sound-film system demonstrated by the Bell Telephone Laboratories before the Society in 1941.[1] In particular, the ribbon or light-valve type of modulator and the basic recording optical arrangement as used in that system have been carried over into the new recorder.

As used in the variable-area modulator, the light-valve ribbons are supported so that their edges are parallel to the direction of motion of the film. The ribbons thus serve to define the vertical edges of an illuminated aperture, an enlarged image of which is projected onto the sensitive surface of the film. These aperture edges move toward and away from each other in response to speech and noise-reduction currents to vary the lateral extent of the illuminated image on the film. The height of the recording image in the direction of film travel is fixed, being defined by a horizontal slit located on the

* Presented May 17, 1948, at the SMPE Convention in Santa Monica.

film side of the above lens system. The aperture enclosed by the horizontal slit edges is imaged on the film by a cylindrical lens system whose axis is parallel to that of the horizontal slit. This lens system is located adjacent to the film so that the height of the recording image is greatly reduced from the actual spacing of the horizontal slit.

The two optical systems involved, that for defining the amplitude co-ordinate of the recording image and that for defining the recording image height are completely independent, since the cylinder lens does not participate in the magnification of the vertical ribbon edges and the slit defining the image height is located on the image side of the lens system employed in projecting the ribbon edges. This optical system permits the recording of a considerable variety of variable-area sound tracks, the electrical connections and the arrangement of ribbons to secure the various types of sound tracks being described in another paper.[2]

Two of the variations have been developed for use with this film recorder. The first of these employs three ribbons with speech current applied to the central one of the three and noise-reduction current applied to the outer two ribbons. Such a valve when used with this recorder will lay down a double-width push-pull, variable-area sound track. The other light valve employs but two ribbons with speech current impressed upon one and noise-reduction current on the other. An image-doubling device incorporated within the magnifying objective lens forms two images of the aperture defined by the light-valve ribbons. These images are formed side by side giving a sound track consisting of two, inphase unilateral, variable-area sound tracks with a total width at full modulation of 76 mils. This track will be referred to as a "dulateral" type of variable-area track. Such a sound track has been shown to be adequately free of the type of distortion introduced by scanning with a reproducing optical system improperly adjusted for azimuth.[2]

General Design of the Variable-Area Light Valve

The ribbons used in the variable-area light valves are sheared from 0.0005-inch thick duraluminum sheets. They are suspended between pairs of clamp carriages which are mounted so as to insulate each ribbon electrically from the case of the valve and from the other ribbons. These carriages provide a means for achieving an accurately coplanar setting of the several light-valve ribbons so that they will all be in sharp focus at the film, and also allow of adjustment during the assembly of the light valve of the spacing between the ribbons and of the tension to which they are stretched. The carriages are shown assembled on the light-valve pole piece in Fig. 1. The magnetomotive force is supplied by an Alnico V magnet which forms the case of the valve. The magnetic flux is concentrated at the ribbon gap by means of permandur pole pieces which also constitute the ends of the light valve as shown in the cross-sectional view of Fig. 2. It is possible with such a structure to achieve flux densities in the ribbon gap of the order of 30,000 gauss. The mechanical force developed between the two pole pieces after the valve is magnetized is adequate

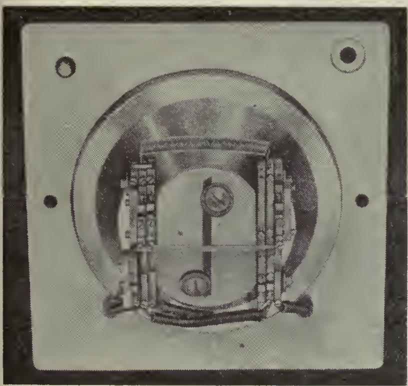


Fig. 1—Area light-valve pole piece showing arrangement of ribbon carriages.

Fig. 3—Assembled area light valve.

to hold the poles and the magnet together without resort to conventional fastening devices. The ribbon carriages and the magnetic circuit employed in the variable-area light valves are identical to those developed for use with the new Western Electric variable-density light valves and have been fully described elsewhere.[3]

The aperture between the light-valve ribbons is projected on the film at a magnification of ten times by the light-valve objective lens. The necessity always present in variable-area recording for obtaining sharp photographic boundaries between the exposed and unexposed portions of the sound track imposes a rather severe requirement on the degree of resolution expected of this lens system. Fortunately it has been possible to arrange the optical working distances so that a high-quality standard microscope objective lens can be employed in this application. A ten-power apochromatic lens is used because of the completeness of the correction for spherical aberration with this type of lens in the neighborhood of 4200 angstroms at which the film is most sensitive. The lens system is mounted within the structure of the light valve which enables the light valve to be removed from the modulator and reinstalled or replaced without the necessity for refocusing or readjustment of sound-track position. A plane-glass window is employed at the light-source end of the light valve

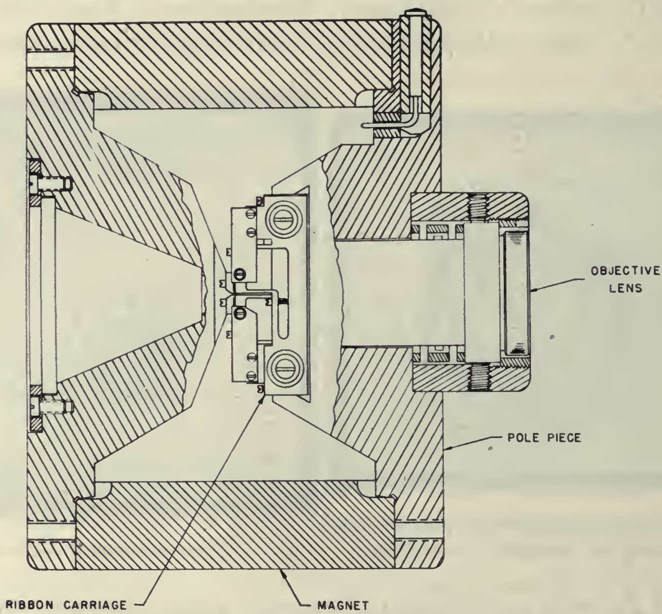


Fig. 2—Cross-section view of area light valve.

so that, it, the objective lens, the pole pieces, and the magnet structure provide complete sealing of the ribbon gap against the entrance of moisture or magnetic particles. Fig. 3 shows the completely assembled variable-area light valve.

The RA-1247, or push-pull, light valve employs three ribbons which are directly imaged onto the film by means of the objective lens. The RA-1405 dulateral light valve employs an image doubler, the functioning of which is depicted schematically in Fig. 4. The light flux emerging from the ribbon aperture is divided by a biplate image doubler which consists of two plane-parallel glass slabs inclined in opposite senses on the two sides of the optical axis and so arranged that each section intercepts half of the light flux and laterally displaces the image of the ribbon aperture formed by the first two lens elements. The third lens element thus sees two images of the ribbon aperture which it projects onto the film. The amount of deviation is such that at full modulation the two images completely fill the 76-mil

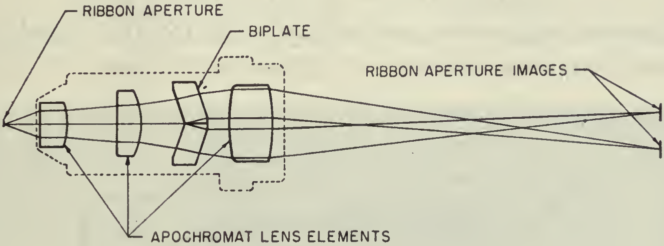
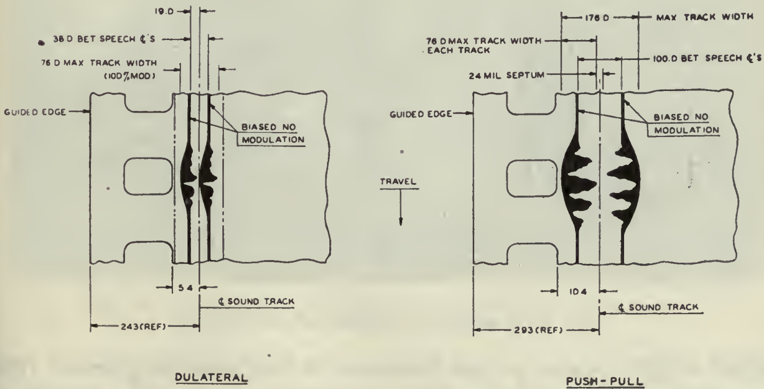


Fig. 4—Action of biplate in forming dulateral recording image.



A B

Fig. 5—Dulateral and double-width push-pull sound tracks.

wide sound track. At low levels of modulation the two unilateral sections of the track are symmetrically related to the sound-track centerline so that the sound track may be played on reproducers with push-pull optics without danger of distortion occurring when low-level modulation crosses the centerline due to misalignment of the reproducer or weaving of the film. Any interference with a septum in the reproducer will occur only at full modulation where the effect is not so serious. In this respect the dulateral sound track is similar to the duplex bilateral type of variable-area sound track except that the two halves of the sound track are identical rather than being mirror images as in the case of the duplex bilateral. The dulateral-type sound track is shown in Fig. 5A while Fig. 5B shows the push-pull sound track obtained with the RA-1247 light valve.

General Design of the Modulator

The various components associated with the RA-1243 variable-area modulator are all mounted on a cast-aluminum plate which is in-

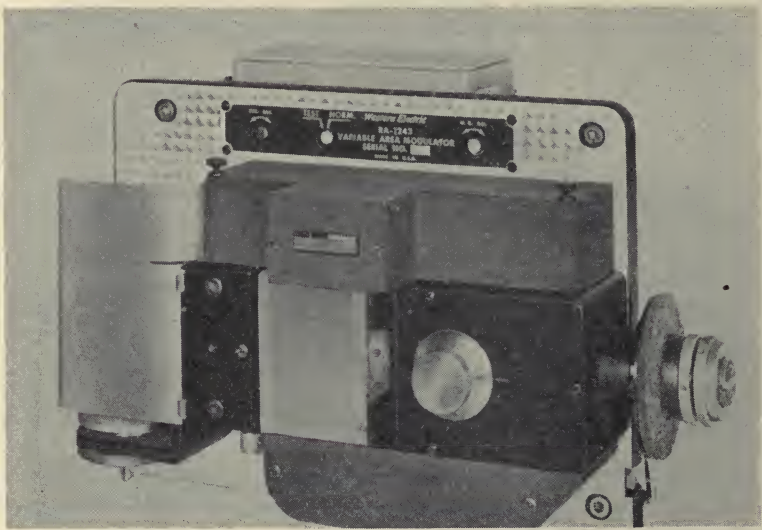


Fig. 6—Assembled variable-area modulator.

stalled in the recorder proper by means of four mounting bolts. The general arrangement as seen from the operating side of the modulator is shown in Fig. 6 while Fig. 7 shows the complete recorder. Provision has been made for easy removal of the light valve which slides into an opening in the center of the modulator and indexes by means of dowel pins. The condenser lens as seen in Fig. 6 is located in the housing immediately to the left of the light valve, while the recording lamp is mounted on a bracket at the extreme left of the modulator. An exposure meter is incorporated into the modulator structure and is located below the light-valve opening. The visual monitor optical system is located immediately above the light-valve opening. The monitoring phototube is located in an assembly on the rear face of the modulator mounting plate. The modulator is thus completely self-contained and may be removed easily from the film recorder and interchanged with the Western Electric variable-density modulator.[3]

A double-width push-pull sound track or a standard 76-mil wide sound track is recorded with this modulator depending on whether an RA-1247 or an RA-1405 light valve, respectively, is installed into the light-valve compartment. The change in light valves is accomplished simply and quickly without the use of tools. The difference in sound-track position between the push-pull sound track

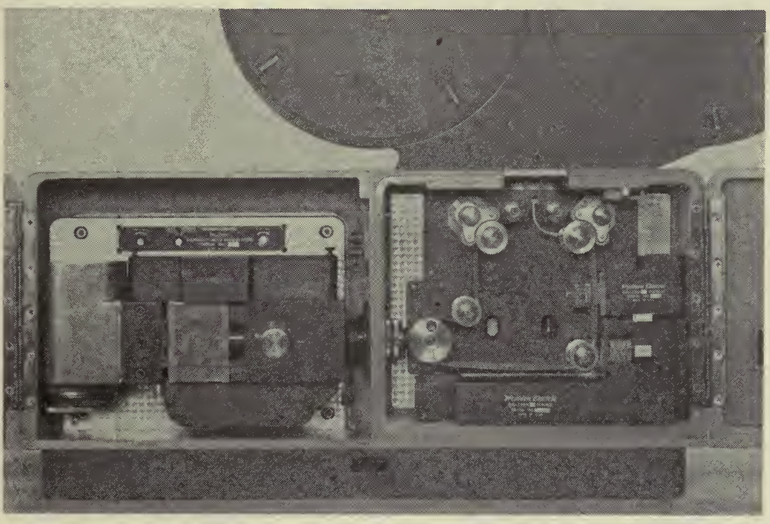


Fig. 7—Variable-area modulator as installed in film recorder.

and the standard sound track is taken care of in the optical adjustment of the light valve. Thus the push-pull light valve is arranged to record a track symmetrical about the optical centerline of the modulator, while the centerline of the standard sound track is displaced optically by adjustment of the light-valve objective lens to the standard position for release sound track. This adjustment is made at the time the light valves are assembled. The circuit connections to the light valves are taken care of in the contact arrangement at the edge of the valve, while the optical offset automatically takes care of the change from push-pull to standard operation in the photoelectric-monitoring system.

Optical System

The recording optical system is shown schematically in Fig. 8. The recording light source is a 7.8-ampere, 10.5-volt curved-filament lamp equipped with a prefocused-type base. The lamp works into an aspheric surfaced anamorphic condenser-lens system, which images the height of the filament at the plane of the light-valve ribbons and the length of the filament between the ribbon plane and the light-valve objective lens. Such an arrangement has proved quite effective in obtaining uniform exposure across the width of the sound track

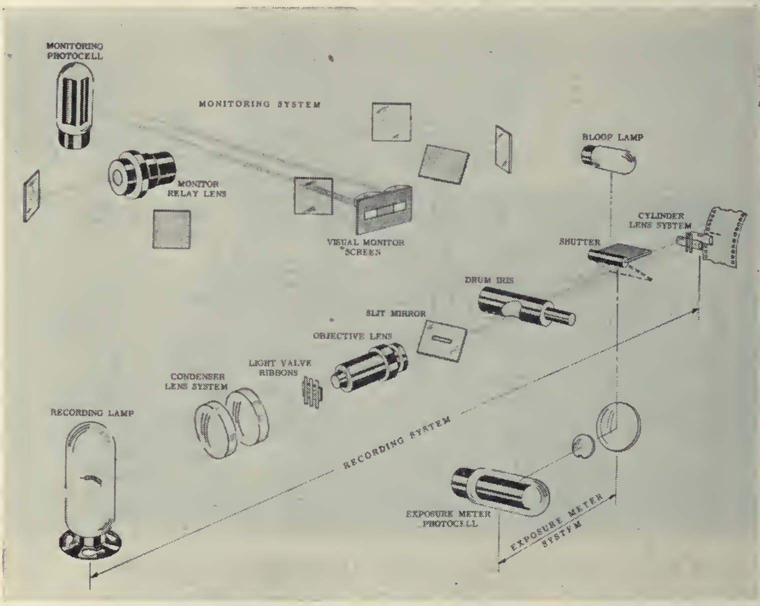


Fig. 8—Optical schematic of area modulator.

despite the inherently discontinuous structure of the filament image. A mask is located between the ribbons and the valve objective lens which is so proportioned that light leakage does not occur around the outer edge of the light-valve ribbons at the extreme of their inward excursion. The objective lens, as mentioned previously, is a 10-power apochromatic microscope objective especially mounted and coded for this application. The focusing and adjustment of this lens is carried out in a fixture designed to simulate a nominal installation in the modulator. The horizontal slit which defines the height of the recording image is located immediately to the right of the light-valve opening and is integrally mounted with the modulator structure. The slit is a clear ruled section in an aluminized mirror surface. The mirror is inclined so as to direct upward to the visual monitoring and the photoelectric-monitoring facilities the excess of the light over that passing through the recording slit. The cylindrical lens, which images the ruled slit on the film, is a two-element system designed to minimize spherical aberration when working at an aperture of approximately $f/1.7$. The azimuth of the recording image is adjusted by rotation of the cell in which the cylindrical lenses are mounted, while focus of the recording slit onto the film is achieved by axial movement of this cell by means of a threaded focusing ring.

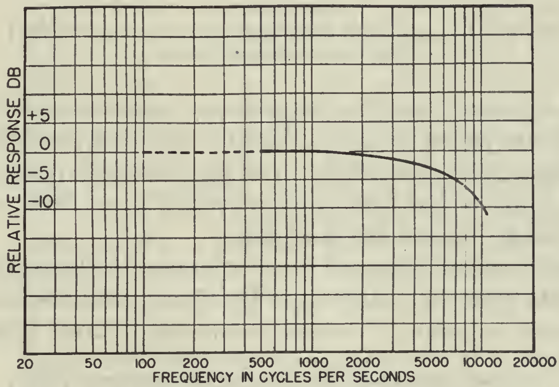


Fig. 9—Experimental film-frequency characteristics.

The light projected upwards by the slit mirror is directed into the visual-monitor compartment directly above the light valve where the beam is folded for the sake of mechanical compactness. The spatial image of the ribbons formed by the light-valve objective lens is picked up by a 6-power achromatic relay lens, further folded and projected upon a ground-glass screen located so as to be visible through a corresponding opening in the door of the modulator compartment of the recorder. The image formed at the screen is erect, i.e., with the light-valve ribbon edges vertical. Its height is made greater than the opening for the visual-monitor screen so that the excess is intercepted by a reflecting-lens system and projected rearward through the modulator-mounting plate to the plates of the monitoring phototube. The separation of the two halves of the push-pull monitor image is effected by dividing the above-mentioned reflecting lens into two

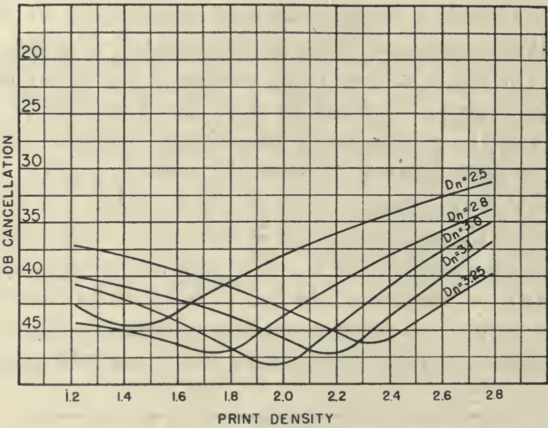


Fig. 10—Experimental cross-modulation curves obtained with push-pull light valve.

sections so arranged that the two parts of the image are directed to the appropriate plates of the RCA-920 monitoring phototube. The reflecting separator lenses project upon the phototube plates an image of the exit pupil of the light-valve objective lens which produces a variable-intensity spot at the phototube.

An exposure-meter photocell is incorporated in the modulator for measuring the light flux delivered to the film. This meter is brought into operation by means of a solenoid-operated mirror which swings

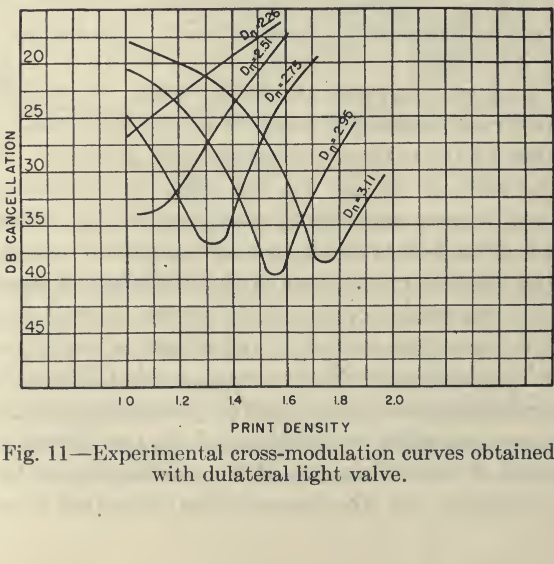


Fig. 11—Experimental cross-modulation curves obtained with dulateral light valve.

into place to deflect the recording light beam down and to the exposure-meter cell. A blue filter is used in this optical train in order to complement the spectral response of the RCA-929 phototube to match that of the film so that exact correlation between exposure-meter reading and density of the sound track is obtained. This exposure-meter facility is also available for setting up noise reduction on an exposure basis although the graduated scale of the visual monitor screen is ordinarily used for setting up noise reduction on the basis of width of the bias line. The graduations on this scale are 0.030 inch apart and represent 0.005-inch intervals at the film so that

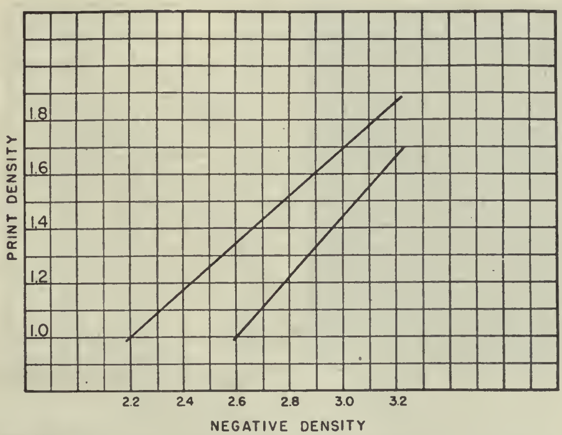


Fig. 12—Experimental processing tolerances for dulateral sound track based on minimum of 30-decibel cancellation.

2-mil bias lines may be estimated easily. A glow-discharge type of bloop lamp is located so that the light therefrom is directed off the surface of the solenoid-operated mirror onto the film.

OPERATING CHARACTERISTICS

The height of the recording image is such as to record a sound track on a variable-area negative emulsion such as EK-1372 or duPont 226, which will require a print density of 1.4 to 1.5 on release stock such as EK-1302 or duPont 225 to give maximum cross modulation cancellation.[4] The frequency characteristic of such a film recorded at constant-amplitude modulation of the light valve is depicted in Fig. 9. Typical cross-modulation curves obtained with high-gamma negative developer and normal release-print developer are shown in Fig. 10 for the push-pull sound track and in Fig. 11 for the dulateral release sound track. Corresponding processing tolerances for a minimum of 30 decibels cancellation with the dulateral sound track are shown in Fig. 12.

The RA-1247 push-pull light valve requires a level of +21 dbm* for 100 per cent modulation, while the noise-reduction ribbons require 300 milliamperes for complete closure. The level into the speech ribbon includes that absorbed by a shunt connected across the ribbon. The use of this shunt adds to the effectiveness of the damping besides simplifying the design of the light-valve equalizer. With the shunt, the resonant rise of the light valve as seen

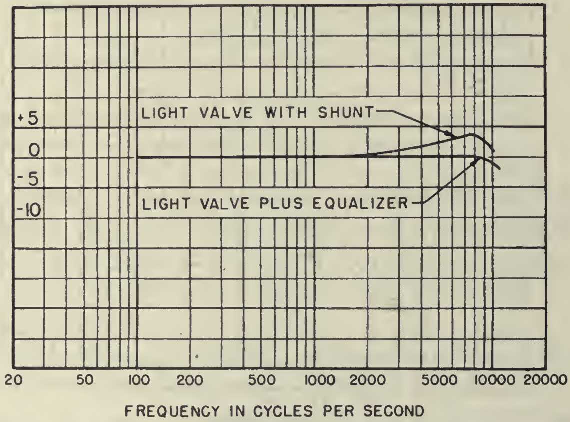


Fig. 13—Frequency response of area light valve with and without light-valve equalizer.

by a 600-ohm generator looking into the primary of the light-valve matching coil is as shown in Fig. 13. An equalizer, coded RA-1275, has been developed for use with this and the RA-1405 release light valve, which gives an over-all response as shown in the second curve of Fig. 13. A photograph of the cathode-ray trace of the monitoring-phototube output as the light valve is driven with a square-wave generator is shown in Fig. 14. The relationship between the magnetic-flux density, the input voltage, and the ribbon dynamics has been fully developed in another paper.[2]

The RA-1405 standard light valve requires for operation of its speech circuit a level of approximately +14.0 dbm,* while noise-reduction ribbon closure is obtained with a current of 200 milliamperes. The frequency characteristics and the square-wave

* Decibels with respect to 0.001 watt.

response are identical to those shown for the RA-1247 on Fig. 13. In the case of the RA-1405 a shunt is used across both the speech and noise-reduction ribbons, that across the noise-reduction ribbon is employed in order to limit and damp out the transient excursions of this ribbon due to any accidental mechanical shock excitation.

The original model of this modulator has been used in making original production and release recordings at Twentieth Century-Fox Studios since August, 1947. The recordings made with this machine exhibit a degree of cleanness and naturalness which has seldom, if ever, been attained in sound-on-film recordings.

CONCLUSION

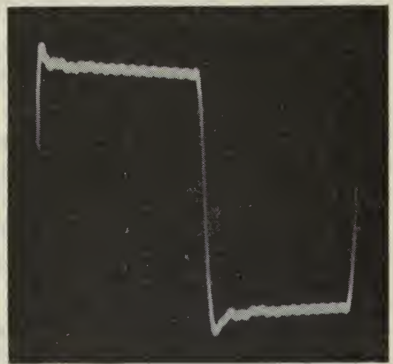


Fig. 14—Cathode-ray oscillogram of area light-valve square-wave response with equalizer.

The modulator described in this paper adapts the ribbon light valve to the recording of variable-area sound track. By incorporating the light-valve ribbons, the magnetic structure, and the light-valve objective lens into an integral, easily replaced unit, an extremely flexible design of modulator has been obtained. The possibilities of the light valve in producing distortion-free recordings having been demonstrated in the stereophonic system, the basic philosophy governing the design of the new variable-area modulator has been convenience of operation. Toward this end, the modulator is arranged so that it can be set up for either push-pull or single operation in a matter of seconds by merely interchanging light valves.

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(1) H. Fletcher, "The stereophonic sound-film system," *J. Soc. Mot. Pict. Eng.*, vol. 37, pp. 331–353; October, 1941.

(2) J. G. Frayne, "Variable-area recording with the light valve," *J. Soc. Mot. Pict. Eng.*, this issue, pp. 501–521.

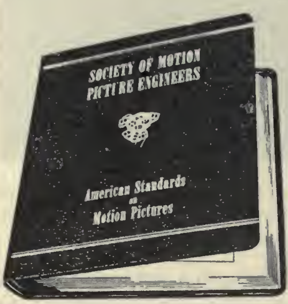
(3) J. G. Frayne, T. B. Cunningham, and V. Pagliarulo, "An improved 200-mil push-pull density modulator," *J. Soc. Mot. Pict. Eng.*, vol. 47, pp. 494–519; December, 1946.

(4) J. O. Baker and D. H. Robinson, "Modulated high frequency recording as a means of determining conditions for optimal processing," *J. Soc. Mot. Pict. Eng.*, vol. 30, pp. 3–18; January, 1938.

Nine Recent American Standards

NINE ADDITIONAL American Standards on Motion Pictures appear in the following pages, bringing to 49 the number of new and revised standards made available to the motion picture industry since January, 1946. With the help of many SMPE and Motion Picture Research Council committees, the ASA at that time embarked on an expanded standards program calling for a review of all motion picture standards approved prior to the recent war and reappraisal of all temporary war standards developed for the use of the military services during the intervening years.

All 49 of the standards have appeared in issues of the SMPE Journal for April and September, 1946, August and December, 1947, March, 1948, and the current issue. A complete subject index to these standards has been printed in $8\frac{1}{2}$- $\times$ 11-inch size and copies were mailed to all who purchased the SMPE Standards Binder shown here. If you have the Binder and your loose-leaf index has not been received, you either are not listed or are incorrectly listed on our records. If that is the case, please send your correct address marked "for the Standards Binder mailing list" to BOYCE NEMEC, *Executive Secretary*. A few complete sets of all standards approved to date, with binders, are still available from the Society office for $8.50, postpaid, when mailed to an address within the United States or $9.00 in U. S. funds when mailed to a foreign country. The nine new standards which appear on the following pages may be purchased, as a group, from the SMPE for $1.00. Individual copies of the standards, however, must be bought directly from the American Standards Association, 70 East 45th Street, New York 17, N. Y. The ASA will also furnish a catalog of American Standards in all industrial fields upon request and without charge.



(*continued on page 540*)

American Standard Dimensions for

Theatre Projection Screens

ASA
Reg. U. S. Pat. Off.
Z22.29-1948
Revision of
Z22.29-1946
*UDC 778.55

1. Scope and Purpose

1.1 This standard specifies dimensions for projection screens used for viewing motion pictures.

2. Screen Size

2.1 Sizes of screens shall be in accordance with the table below.

2.2 The over-all size shall be measured from the outer edge of border to the outer edge of opposite border. The ratio of the over-all width to over-all height shall be 4 to 3.

3. Border

3.1 A fabric reinforcing border shall surround the screen. The width of this border shall be from 2.5 to 3 inches.

4. Grommets

4.1 Metal mounting grommets, size No. 3 or No. 4, shall be securely fastened through the fabric border.

4.2 Grommets shall be spaced on 6-inch centers, starting from grommets located at the centers of the four sides of the screen, except that there shall also be a grommet in each corner of the screen. Grommets shall be set in a line parallel to the edge of the screen, with their centers from 1.0 to 1.31 inches inside the outer edge of the border.

5. Selection of Screen Size

5.1 The width of the screen should be not less than 1/6 of the distance from the center of the screen to the most remote seat.

5.2 The distance between the screen and the front row of seats should be not less than 0.87 foot for each foot of screen width.

American Standard Dimensions for

Theatre Projection Screens

ASA
Reg. U. S. Pat. Off.
Z22.29-1948
Revision of
Z22.29-1946

Size No. of Screen	Over-all Width (feet)	Over-all Height (feet)	Minimum Effective Picture Size (feet)	
8	8.00	6.00	7.50	5.50
9	9.00	6.75	8.50	6.25
10	10.00	7.50	9.50	7.00
11	11.00	8.25	10.50	7.75
12	12.00	9.00	11.50	8.50
13	13.00	9.75	12.50	9.25
14	14.00	10.50	13.50	10.00
15	15.00	11.25	14.50	10.75
16	16.00	12.00	15.50	11.50
17	17.00	12.75	16.50	12.25
18	18.00	13.50	17.50	13.00
19	19.00	14.25	18.50	13.75
20	20.00	15.00	19.50	14.50
21	21.00	15.75	20.50	15.25
22	22.00	16.50	21.50	16.00
23	23.00	17.25	22.50	16.75
24	24.00	18.00	23.50	17.50
25	25.00	18.75	24.50	18.25
26	26.00	19.50	25.50	19.00
27	27.00	20.25	26.50	19.75
28	28.00	21.00	27.50	20.50
29	29.00	21.75	28.50	21.25
30	30.00	22.50	29.50	22.00

NOTES:

1. Masking on each of the four sides of the screen is recommended as follows:

   1 inch of masking within the projected picture area on each of the four sides of the picture for every 12 feet of picture width, with a minimum of 1 inch for pictures less than 12 feet in width.

2. Screens larger than Size No. 30 are not specified as such screens are usually custom built or not in 4 by 3 ratio due to projection angle.

American Standard Specification for

Buzz-Track Test Film

for 16-Millimeter Motion Picture Sound Reproducers

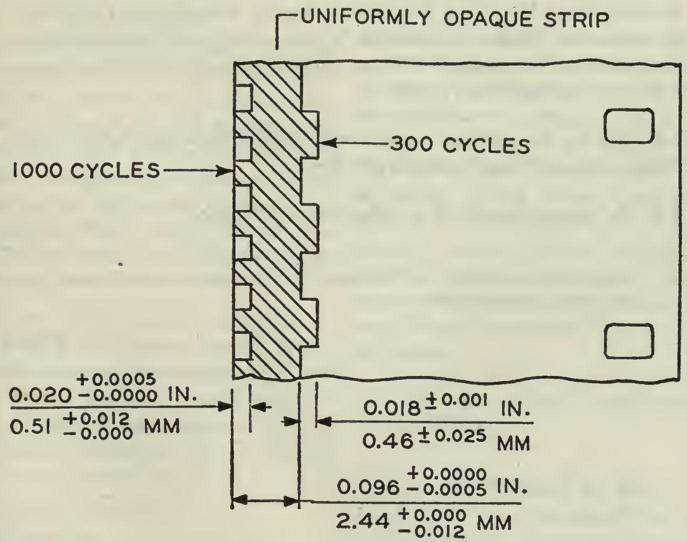
ASA
Reg. U. S. Pat. Off.
Z22.57-1947

1. Scope and Purpose

1.1 This specification describes a buzz-track test film used for checking the position of the sound scanning beam in 16-mm motion picture sound reproducers.

2. Test Film

2.1 The test film shall have originally recorded 300-cycle and 1000-cycle signal tracks on either side of the central exposed strip as shown in Fig. 1. The position of the tracks, weave in running film on the recorder included, shall be in accordance with Fig. 1.



2.2. The central exposed strip and the exposed portions of the two signal tracks shall have a density of 1.6 + 0.4.

2.3 Film Stock. The film stock used for the test film shall be cut and perforated in accordance with the American Standard Cutting and Perforating Dimensions for 16-Millimeter Sound Motion Picture Negative and Positive Raw Stock, Z22.12-1947 (Revision of Z22.12-1941), or the latest edition thereof approved by the American Standards Association.

American Standard Specification for

Buzz-Track Test Film

for 16-Millimeter Motion Picture Sound Reproducers

ASA
Reg. U. S. Pat. Off.
Z22.57-1947

2.3.1 Resistance to Shrinkage. The film stock used for the test film shall have a maximum lengthwise shrinkage of 0.50 percent when tested as follows: At least 20 strips of film approximately 31 inches in length shall be cut for measurement of shrinkage. After normal development and drying [not over +80 F (+26.7 C)], the strips shall be placed at least ¼ inch apart in racks and kept for 7 days in an oven maintained at +120 F (+49 C) and a relative humidity of 20 percent. The strips shall then be removed, reconditioned thoroughly to 50 percent relative humidity at +70 F (+21.1 C), and the shrinkage measured by an adaptation of the pin-gage method outlined in Research Paper RP-1051 of the National Bureau of Standards. The percent shrinkage shall then be calculated on the basis of deviation from the nominal dimension for the length of 100 consecutive perforation intervals given in American Standard Z22.12-1947.

2.4 Each test film shall be provided with suitable leader and trailer, and a title or other markings to identify the film.

2.5 The standard length of test film shall be 100 feet.

NOTE:
A test film in accordance with this standard is available from the Society of Motion Picture Engineers.

American Standard

Theatre Sound Test Film for 35-Millimeter Motion Picture Sound Reproducing Systems

ASA
Reg. U. S. Pat. Off.
Z22.60-1948

*UDC 778.5

1. Scope and Purpose

1.1 This standard describes a film for qualitatively checking and adjusting 35-millimeter motion picture sound reproducers and for judging the acoustical properties of the auditorium in which the sound is reproduced.

2. Test Film

2.1 The film shall have a sound track and accompanying picture. The sound track shall comply with American Standard Sound Record and Scanned Area, Z22.40-1946, and the film stock used shall be cut and perforated in accordance with American Standard Cutting and Perforating Dimensions for 35-Millimeter Motion Picture Positive Raw Stock, Z22.36-1947, or any subsequent revisions thereof.

2.2 The test film shall contain samples selected from studio feature pictures by an appropriate engineering committee of the Motion Picture Research Council and the Society of Motion Picture Engineers. The following sound samples are typical of those which may be included:

(a) Main title music
(*b*) Dialogue
(c) Piano
(*d*) Orchestral music
(e) Vocal music

2.3 The assembled film shall include appropriate samples of typical release-print material intended to provide a qualitative check of such reproducing system characteristics as:

(a) Frequency response
(*b*) Volume range
(c) System noise
(*d*) Power-handling capacity
(e) Flutter

2.4 Each film shall be provided with head and tail leaders as specified in American Standard Specifications for 35-Millimeter Sound Motion Picture Release Prints, Z22.55-1947, or any subsequent revision thereof. The main title shall include the issue number of the film so that revised versions, which may be issued periodically to conform to changing studio practices, may be easily identified. Subtitles superimposed over each sample shall indicate the particular sound characteristic demonstrated by that portion of the film.

2.5 The length of the film shall be approximately 500 feet.

3. Method of Use

3.1 From a typical location in the auditorium the observer should determine whether or not the frequency-response characteristics of the complete reproducing system are normal by listening to the sound reproduced from the test film at normal sound level.

NOTE: A test film in accordance with this standard is available from the Motion Picture Research Council or the Society of Motion Picture Engineers.

(*continued from page 534*)

THEATER PROJECTION SCREENS, Z22.29-1948

This 1948 revision of the theater-screen standard establishes over-all screen dimensions in addition to minimum effective picture size and includes border dimensions with more specific location of grommets. Screens wider than thirty feet have not been included since they are made to order, and because of keystoning do not usually have the standard height-to-width ratio of 3 to 4.

16-MM BUZZ-TRACK TEST FILM, Z22.57-1947

Critical dimensions of this new standard remain exactly the same as the previous American War Standard Z52.10-1944. Performance of the film has been improved by making both the 1000-cycle and 300-cycle buzz signals an integral part of the center opaque strip. They had each been separated from the center strip by a clear area 0.002 inch wide, but films made that way give a somewhat less critical indication of lateral placement of the reproducer scanning slit.

35-MM THEATER SOUND TEST FILM, Z22.60-1948

The familiar Academy Test Reel is described in a general way without specifying detailed requirements, either qualitative or quantitative. This is an apparent departure from accepted standardization practice but is very practical because it includes a statement of this film's purpose and a description of the several types of typical release-print sound samples that are included.

35-MM SOUND FOCUSING TEST FILM (9000-CYCLE), Z22.62-1948

This 9000-cycle film is an original recording intended for use by 35-mm reproducer manufacturers or theater equipment maintenance shops for focusing sound optical systems. It provides a critical test in these applications but is not recommended for use in theaters because theater amplifiers normally have low-pass filters that cut off somewhat below 9000 cycles.

35-MM SCANNING-BEAM TEST FILM (SERVICE TYPE), Z22.65-1948

The familiar continuous "snake track" used in the theater for checking the uniformity of illumination across the width of the 35-mm reproducer scanning beam is described. In service it is used as a loop, joined preferably with a butt splice held together with scotch

(*continued on page 546*)

American Standard

Sound Focusing Test Film for 5-Millimeter Motion Picture Sound Reproducers (Laboratory Type)

ASA
Reg. U. S. Pat. Off.
Z22.62-1948

*UDC 778.5

1. Scope and Purpose

1.1 This standard describes a film which may be used for precise focusing of the optical systems in 35-millimeter motion picture sound reproducers. The recorded frequency shall be suitable for use in laboratories and factories.

2. Test Film

2.1 The film shall be a print from an original negative and shall contain a 9000-cycle, sinusoidal, variable-area track recorded at 1 decibel below 100-percent modulation. The variation in power output level from the film shall be not more than ±0.25 decibel.

2.2 The sound track shall comply with American Standard Sound Record and Scanned Area, Z22.40-1946, and the film stock used shall be cut and perforated in accordance with American Standard Cutting and Perforating Dimensions for 35-Millimeter Motion Picture Positive Raw Stock, Z22.36-1947, or any subsequent revisions thereof.

NOTE 1: This test film is not recommended for theater use because the reproducing amplifiers ordinarily installed in theaters normally have low-pass filters which cut off below 9000 cycles.

NOTE 2: A test film in accordance with this standard is available from the Motion Picture Research Council or the Society of Motion Picture Engineers.

American Standard

Scanning-Beam Uniformity Test Film for 35-Millimeter Motion Picture Sound Reproducers (Service Type)

ASA
Reg. U. S. Pat. Off.
Z22.65-1948
*UDC 778.5

1. Scope and Purpose

1.1 This standard describes a film which may be used for determining the uniformity of scanning-beam illumination in 35-millimeter motion picture sound reproducers. The recorded sound track shall be suitable for use in the routine maintenance and servicing of the equipment.

2. Test Film

2.1 The film shall be a print from an original negative. It shall consist of a 1000-cycle, variable-area recording at full modulation of the 0.007-inch width and shall be approximately sinusoidal. The track shall move uniformly 0.077 inch from one edge of the scanned area to the other as shown in Fig. 1.

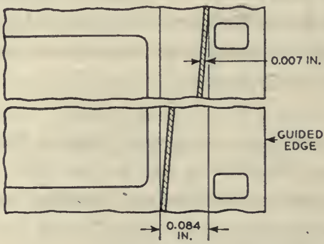


FIG. 1

2.2 The scanned area shall comply with American Standard Sound Record and Scanned Area, Z22.40-1946, and the film stock used shall be cut and perforated in accordance wtih American Standard Cutting and Perforating Dimensions for 35-Millimeter Motion Picture Positive Raw Stock, Z22.36-1947, or any subsequent revisions thereof.

2.3 The length of this film shall be approximately 8 feet.

NOTE: A test film in accordance with this standard is available from the Motion Picture Research Council or the Society of Motion Picture Engineers.

American Standard

Scanning-Beam Uniformity Test Film for -Millimeter Motion Picture Sound Reproducers (Laboratory Type)

ASA
Reg. U. S. Pat. Off.
Z22.66-1948

*UDC 778.5

1. Scope and Purpose

1.1 This standard describes a test film which may be used for determining the uniformity of scanning-beam illumination in 35-millimeter motion picture sound reproducers. The recorded sound tracks shall be suitable for use in laboratories and factories.

2. Test Film

2.1 The test film shall contain a number of 1000-cycle, variable-area tracks of narrow width, recorded at 100-percent modulation.

2.2 The test film shall contain 17 individual sound tracks, each with the same amplitude of approximately 0.007 inch. These tracks shall appear on the film in succession, the first so placed that its center line shall be not more than 0.197 inch from the guided edge of the film, and the seventeenth so placed that its center line shall be not less than 0.292 inch from the guided edge of the film. The intermediate tracks shall be spaced at equal intervals between the first and seventeenth tracks, similar to that shown in Fig. 1.

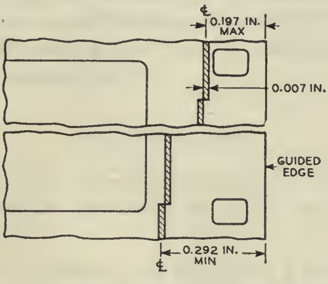


FIG. 1

2.3 The film stock used shall be cut and perforated in accordance with American Standard Cutting and Perforating Dimensions for 35-Millimeter Motion Picture Positive Raw Stock, Z22.36-1947, or any subsequent revisions thereof.

2.4 Each test film shall be provided with a suitable head leader identifying the film.

American Standard

Scanning-Beam Uniformity Test Film for 35-Millimeter Motion Picture Sound Reproducers (Laboratory Type)

ASA
Reg. U. S. Pat. Off.
Z22.66-1948

UDC 778.5

2.5 The length of this test film shall be approximately 230 feet.

2.6 Each of the 17 tracks shall be identified by an appropriate spoken announcement. The track modulated by the voice shall be limited to the same track width as a single 1000-cycle test signal.

2.7 Each film shall be accompanied by a calibration sheet showing the center-line position of each of the 17 tracks measured from the guided edge. The accuracy of these dimensions shall be within 0.002 inch.

NOTE: A test film in accordance with this standard is available from the Motion Picture Research Council or the Society of Motion Picture Engineers.

American Standard

1000-Cycle Balancing Test Film for -Millimeter Motion Picture Sound Reproducers

ASA
Reg. U. S. Pat. Off.
Z22.67-1948

*UDC 778.5

1. Scope and Purpose

1.1 This standard describes a film which may be used for balancing the respective power-level output from two or more 35-millimeter motion picture sound reproducers.

2. Test Film

2.1 The film shall be a print from an original negative containing a 1000-cycle, variable-area track recorded at 50-percent modulation. It shall be accompanied by a statement of the percent modulation of the incident light in the reproducer. The accuracy of calibration shall be within ± 1 decibel.

2.2 The harmonic distortion of the recorded 1000-cycle note shall not exceed 2 percent.

2.3 The sound track shall comply with American Standard Sound Record and Scanned Area, Z22.40-1946, and the film stock used shall be cut and perforated in accordance with American Standard Cutting and Perforating Dimensions for 35-Millimeter Motion Picture Positive Raw Stock, Z22.36-1947, or any subsequent revisions thereof.

3. Instructions

3.1 An instruction sheet, describing the manner in which this film is to be used in various types of reproducing equipment, shall be provided with each film.

NOTE: A test film in accordance with this standard is available from the Motion Picture Research Council or the Society of Motion Picture Engineers.

(*continued from page 540*)

tape. An 0.007-inch wide, 1000-cycle track moves across the 0.084-inch standard scanned area in 8 feet of film or approximately $5^1/_2$ seconds. Any nonuniformity of illumination will appear as cyclic variations of output power level.

35-MM SCANNING-BEAM TEST FILM (LABORATORY TYPE) Z22.66-1948

This laboratory type of scanning-beam film is a more precise measuring tool than the "snake track" and is used by manufacturers of theater and studio sound reproducers for adjusting new equipment or as a final check of new sound installations. It has seventeen successive individual 1000-cycle sound tracks each 0.007 inch wide and about 12 feet long, equally spaced across an area slightly wider than the standard sound-track scanned area covered in American Standard Z22.40-1946, SMPE JOURNAL for April, 1946, page 292.

35-MM BALANCING FILM (1000-CYCLE), Z22.67-1948

The output power level from all soundheads in any theater must be balanced so that normal release prints will reproduce at proper volume with a single fader setting. This film provides a standard reference signal required for balancing power-level output from standard sound reproducers but is not intended for use in balancing the outputs from the two halves of push-pull reproducer systems.

DOUBLE-WIDTH PUSH-PULL SOUND TRACK, Z22.69-1948 AND Z22.70-1948

Double-width push-pull sound tracks, sometimes called "200-mil push-pull," that are now in commercial use follow two "standards." One is the Normal Centerline Type, Z22.69, wherein the half of the track nearest the perforations will play back on a reproducer intended for track in the normal 35-mm release-print position (American Standard Z22.40-1946, SMPE JOURNAL for April, 1946, page 292). The other is the Offset Centerline Type, Z22.70, which has its centerline 0.021 inch nearer the center of the film and will not play back on conventional theater equipment. These double-width tracks are now used only in studio production prior to re-recording the final release negative.

●

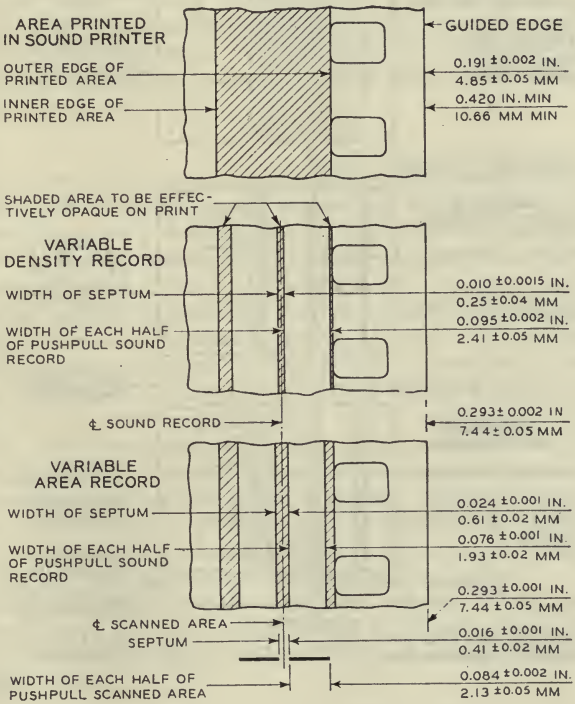
Motion Picture engineers who have been following the standards programs of the Society, the Motion Picture Research Council, and the American Standards Association will be interested in the reference to the Universal Decimal Classification System recently adopted by the ASA, which appears on page 552 of this issue.—Editor

American Standard

Sound Records and Scanning Area of Double Width Push-Pull Sound Prints

Normal Centerline Type

ASA
Reg. U. S. Pat. Off
Z22.69-1948
•UDC 778.534.4

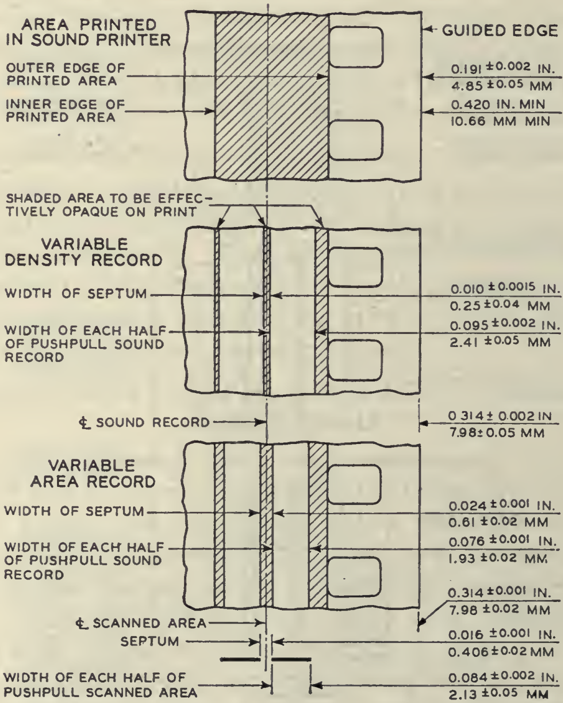


American Standard

Sound Records and Scanning Area of Double Width Push-Pull Sound Prints

Offset Centerline Type

ASA
Reg. U. S. Pat. Off.
Z22.70-1948
*UDC 778.534.4



Section Meetings

Atlantic Coast

On September 22, 1948, the Atlantic Coast Section of the SMPE held its first of the regular fall series of meetings. Two papers were presented before a group estimated at 300 people in Studio 3-A of the National Broadcasting Company.

The first paper by Robert M. Fraser of the Development Engineering Group of the National Broadcasting Company was titled "Recording Television Programs of Motion Picture Films." The paper dealt with the history and the growth of the methods used to record television images onto 16-mm film for subsequent reuse. Both the technical and the practical engineering aspects were covered by Mr. Fraser. A demonstration reel showing a comparison of early experimental work with the present stage of the art was well received by the audience.

The second paper, "Flicker in Motion Pictures," by Lorin D. Grignon, Sound Department of Twentieth Century-Fox Corporation, was presented for the third time to an SMPE audience. This was a timely review of the causes, methods of analysis, and suggested remedial steps concerned with various types of flicker in motion pictures.

Midwest

The September 16, 1948, meeting of the Midwest Section was held jointly with a group forming the Optical Society of Chicago in the auditorium of the Metallurgy and Chemical Engineering Building, Illinois Institute of Technology in Chicago.

Dr. Robert A. Woodson addressed the 125 members, guests, and those interested in forming the optical group who were in attendance.

First on the program was a 16-mm English Technicolor film titled "Colour" produced by the Imperial Chemical Industries. It dealt with color fundamentals and research in the development in coal-tar dyes. "Adopting Motion Picture Equipment to the Needs of Medical Teaching" by Mervin W. LaRue, Sr. covered the reasons for the great need of medical films to keep practicing physicians abreast of the latest techniques and practices as well as student teaching of medicine. Special apparatus for microcinematography and macroscopic work was described and the actual equipment was on display. This equipment is covered in a paper published in the JOURNAL for September, 1947. A reel of Kodachrome motion pictures of medical subjects made on the described equipment was projected, and appropriate comments were made by the author.

"Seeing Light and Color" by Ralph M. Evans in charge of Color Quality, Color Control Department, Eastman Kodak Company, Rochester, was accompanied by over two hundred color slides which prove beyond a doubt that you "only see what you think you see..."

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CAMERAMAN: Eight years' experience in 35- and 16-mm cinematography, color, black-and-white. Experienced in educational, documentary, training, advertising, and entertainment films—studio and location. References and complete record of experience available. Willing to relocate anywhere. Write air mail, Peter H. Swart, 28 Webber Road, Germiston, South Africa.

Book Reviews

The Diary and Sundry Observations of Thomas Alva Edison, Edited by Dagobert D. Runes

Published (1948) by the Philosophical Library, 15 E. 40 St., New York 16, N. Y. 244 pages + XII pages + 3-page index. 5 illustrations. 6 × 9 inches. Price, $4.75.

This volume is in all respects the most extraordinary of all the presentations in print pertaining to Mr. Edison. It is quite as remarkable and quite as interesting for what it is not as for what it is. It tells something about him, but with the quality of an image projected through a diffusing screen and picked up by a ground-glass mirror. There is enough of him there for the reader to be conscious of his presence but not convinced of his actuality and substance. To the researcher of tomorrow who would know about Edison, it is a document to be considered and read only after he has seen everything else that has been printed. In that respect, this book would have the same interest which it now has to those intimate with both the real and the traditional Edison and with a measure of his poignant realism and dynamic place in the industrial scene.

From the particularized and technological point of view of the readers of this journal, the specific attentions attributed to Mr. Edison pertaining to motion pictures are positively somewhat less than negligible. The document contains nothing informative pertaining to Mr. Edison's invention of and contribution to the motion picture which is not either in casual error, in casual misunderstanding, or, at best, susceptible of misinterpretation. For motion picture engineers, this book can be an object lesson in the perils of pseudo-literary adventure in the art of expression for persons who do not carry over into that art the skills and criteria that they bring to bear upon their science. For this peculiar state of affairs, there are two discernible reasons. The first of these pertains to the frequently nonchalant manner in which Mr. Edison discussed his works and his charming willingness to talk about anything which might be a passing topic of interest. Second is the fact that the volume appears to have been assembled and edited by Dr. Dagobert D. Runes, a writer of distinction about philosophical subjects, for his Philosophical Library, Inc. The approach is scholarly-mannered and with a brave effort at categoried analytical presentation of the omniferous miscellany of Mr. Edison's interests, all of them expressed in his declining years.

There is, unhappily because of that play upon the words "the diary," an early disappointment. The "diary" element hazily covers one week in 1885. Very little of the real Edison comes through, anywhere. We get no picture of that salty fellow, dynamic, belligerent, collarless, with tobacco stains on the bosom of his hard-boiled shirt, mildly profane and belligerently positive, talking behind that big roll-top desk at West Orange about what he really thought. We have here an Edison sandpapered, shellacked, and waxed. We do not have, in any part of the book, the "Old Man," ebullient, ironic, and vital.

For purposes of specification to this engineering audience, it is appropriate to cite a single but painfully indicative specimen of error occurring on page 77 of the volume, in which Mr. Edison is caused to say apparently that his Kinetoscope, the name of which, incidentally, is misspelled, "attracted quite a lot of attention at the World's Fair in Chicago in 1893." The date alleged and the facts pertaining to the Kinetoscope involved are all important to motion picture history. The Kinetoscope, as Mr. Edison had very decided reason to know, was under contract for exhibition at the World's Fair in Chicago in Edisonia Hall, and was in fact not delivered there, being unavailable until after the Fair closed. That was because the mechanic he had assigned to the building of the battery of mechanisms decided to spend most of his time at an adjacent West Orange tavern, playing dominoes or something. Edison cared very little. So, as has been competently recorded and is historically documented, his Kinetoscope made its first appearance to the public on the night of April 14, 1894, at 1155 Broadway.

The great Edison was great enough not to be deceived about himself and he took neither the motion picture nor Edison too seriously. This reviewer once took Mr. Edison to task because of a piece of Sunday-supplement journalism which had gone to extravagant lengths in a sort of interview indicating that the Wizard of West Orange was building a machine with which to communicate with the dead.

The "Old Man" looked puzzled a moment and then flung out with a defense. He said, "Don't be too hard about it. That reporter was a space writer. He came over here without any raincoat and there were holes in his shoes. He needed a story in the worst way and I gave him the best one I could think of."

You need a touch of that to understand this book.

Terry Ramsaye
Motion Picture Herald
New York 20, N. Y.

L'Annuaire du Cinema 1948 (Motion Picture Yearbook for 1948)

Published by Editions Bellefaye, 29 Rue Marsoulan, Paris (12ème), France. 1230 pages. $5^1/_2 \times 8^1/_2$ inches. Price, $6.00. United States Representative, André Harley, 15 E. 40 St., New York 16, N. Y.

This French yearbook on the film industry is the first revised and re-edited book of its kind to be published since the Liberation of France.

The book is divided into seventeen sections, subdivided as follows: Paris addresses, out-of-town addresses, general information on French film industry, list of motion picture theaters in Paris and environs with number of seats, manager's name and address, same list for out-of-town theaters, 16-mm section with names of all people interested (laboratories, distributors, synchronizers, and theater owners), films (information on 440 films presented in France between January, 1946, and June, 1947), producers, distributors for Paris, distributors for other regions, export, foreign countries, newspapers and magazines, technicians, artists, suppliers, studios, and laboratories.

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

29, 9, September, 1948

Television Camera Operation (p. 302) H. I. Smith

British Kinematography

13, 1, July, 1948

Colour Vision and the Film Industry (p. 1) W. D. Wright

13, 2, August, 1948

Reversal Processing (p. 37) Ir. H. Verkinderen

Set Construction Methods (p. 46) J. Gow

Light Efficiency of 16-Mm Projectors (p. 50) W. Buckstone

Electronics

21, 10, October, 1948

Television Transcriptions (p. 68) T. T. Goldsmith, Jr., and H. Milholland

International Photographer

20, 9, September, 1948

Motion Picture Industry in Sweden (p. 10) W. J. Barndale

International Projectionist

23, 9, September, 1948

Magnetic Recording Advances Promise Extensive Use for Film Work (p. 6)

Basis of the Schmidt Optical System (p. 8)

Television: How It Works (p. 17) W. Bouie

The Transistor: Amplifier-Oscillator May Supplant Vacuum Tube (p. 19)

Radio and Television News

40, 3, September, 1948

Something New in Color Television (p. 40) R. Crosman

The Recording and Reproduction of Sound. Pt. 19 (p. 48) O. Read

40, 4, October, 1948

The Recording and Reproduction of Sound. Pt. 20 (p. 56) O. Read

Tele-Tech

7, 9, September, 1948

New Design for Medium Definition TV Camera System (p. 52) J. B. Sherman

ASA Adopts Universal Decimal Classification System

The American Standards Association has decided to adopt the practice followed by other national standardizing bodies and to classify American Standards in accordance with the Universal Decimal Classification system. By means of this classification, American Standards can be easily incorporated into libraries and identified as part of the technical literature in all parts of the world. The UDC numbers, which are in Arabic and thus can be read without difficulty regardless of the language of the country, will appear on the front cover of all standards approved by the American Standards Association and distributed through the ASA office.

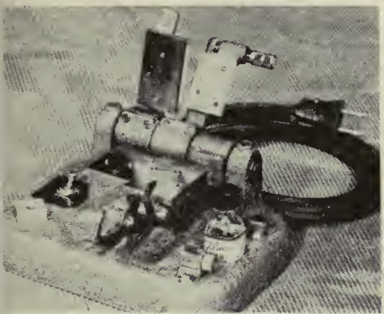
Reprinted by permission of the ASA from *Industrial Standardization*, for August, 1948.

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.

Heavy-Duty Splicer

A combination 8-mm and 16-mm semiprofessional splicer for heavy-duty use in schools, film libraries, and laboratories has been announced by **Bell and Howell Company,** 7100 McCormick Road, Chicago 45, Illinois.



In one operation, the new splicer shears both ends of the film diagonally and applies pressure to the film ends while they are being cemented. An electrical element in the base, operating on alternating current only, heats the shear blades, thus shortening cement-setting time.

In addition to the usual provision for scraping emulsion from the left-hand film end, the right-hand shear blade and arms of the new splicer are designed to permit scraping the emulsion from the right-hand film end, a process necessary for splicing certain types of prints and titles.

A gauge block on the splicer base simplifies setting the scraper blades at the proper working depth. Extra scraper blades may be stored in a covered receptacle on the right side of the base.

This splicer is $6^3/_4 \times 5^1/_2 \times 3^1/_2$ inches and weighs but three pounds. The base and three operating arms are made of cast aluminum; the four shear blades are hardened, ground, stainless steel.

The splicer base has been designed so that it may be screwed to a worktable; an accessory subbase has been designed to accommodate the splicer combined with a Filmotion Viewer and heavy-duty rewinds, to provide a complete heavy-duty editing outfit.

Synchronous Tape Recorder

The Hallen Development Company of Burbank, California, is reported to be manufacturing a magnetic tape, slit and perforated to 16-mm dimensions, and a gear-driven recorder which will stay in synchronization with any camera equipped with a synchronous drive.

Additional features include top-quality amplifiers, a recording capacity greater than sound film, and an immediate playback. It is adaptable to 16-mm and 35-mm commercial film production, as well as in television broadcasting.

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Journal of the Society of Motion Picture Engineers

VOLUME 51 DECEMBER 1948 NUMBER 6

PAGE

Subscription to nonmembers, $10.00 per annum; to members, $6.25 per annum, included in their annual membership dues; single copies, $1.25. Order from the Society's general office. A discount of ten per cent is allowed to accredited agencies on orders for subscriptions and single copies. Published monthly at Easton, Pa., by the Society of Motion Picture Engineers, Inc. Publication Office, 20th & Northampton Sts., Easton, Pa. General and Editorial Office, 342 Madison Ave., New York 17, N. Y. Entered as second-class matter January 15, 1930, at the Post Office at Easton, Pa., under the Act of March 3, 1879.

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Flicker in Motion Pictures: Further Studies*

By LORIN D. GRIGNON

Twentieth Century-Fox Films, Beverly Hills, California

Summary—**Flicker is defined for the general case and additional information on subjective effects and analysis presented. The subject is then restricted to those types of flicker which are the result of equipment deficiencies and quantitative methods for measuring such effects are described. The application of methods to specific equipments, the results obtained, and certain remedial measures are discussed. Finally, recommendations for future work in this field are submitted.**

Flicker in motion pictures is a visual, random, or periodic change in the brightness of a projected picture which is not deliberately introduced for its suggestive or dramatic effect. The periodic frame or shutter rates which are fundamental to the methods of motion pictures are included in the definition when these rates produce visual sensation. Such effects are, in general, sufficiently high in frequency to be detrimental only to the second order at presently used illumination levels. In the following material the subject matter will be restricted to flicker which is caused by periodic rates in addition to the basic frame or shutter frequency except in instances where remarks on the general subject are pertinent.

Several years ago a paper[1] was presented before the Society on this subject. Most of the data given were not quantitative due, principally, to lack of suitable apparatus and testing methods for such a complex problem. The purpose of the present paper is to review the basic problem of flicker, to describe methods of analysis applicable to the problem, present the results of the application of indicated methods to specific situations, to discuss the data, indicate certain remedial measures, and submit recommendations for future work.

Discussion

Even though some basic facts concerning flicker have been previously stated it seems expedient to restate the information and, perhaps, add thereto to further an understanding of the underlying problem.

* Presented May 17, 1948, at the SMPE Convention in Santa Monica.

Luckiesh and Moss[2] state Porter's law to the effect that the maximum observable frequency of an intermittent visual stimulus increases proportionately as the logarithm of the brightness but Hecht and Smith[3] show that this is only true below certain light levels and that above these levels no further increase in frequency is noted, as shown in Fig. 1. The discontinuity in the curves at low levels is caused by the transition from rod to cone vision. In considering

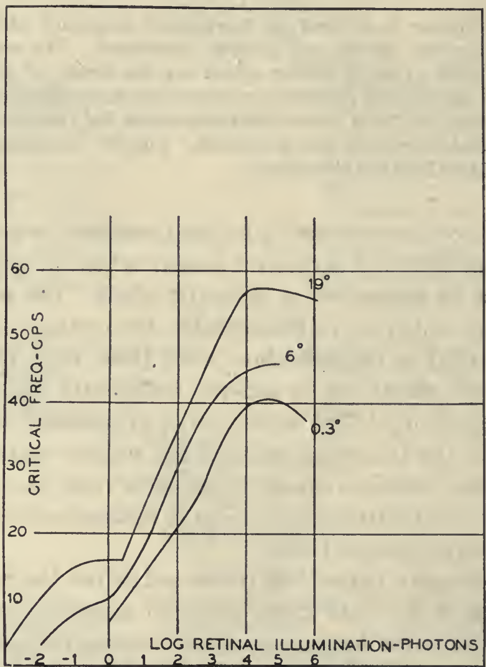

Fig. 1—Relations between perceptible frequency, illumination, and visible area.*

* Figures 1 and 2 reprinted from the *Journal of General Physiology*, July, 1937, with the permission of the copyright owners.

periodic flicker we are principally interested in perceptible brightness differences. We can get some idea of this matter from other data.

Luckiesh and Moss[2] also show a curve by Hecht of the minimum perceptible brightness difference as related to the logarithm of the incident brightness. This curve, Fig. 2, shows the minimum to be between 1 and 100 millilamberts which is within the range of present screen-brightness practice. The same authors present data concerning the relation between minimum perceptible brightness difference and the brightness ratio of a central area to its surroundings. As shown in Fig. 3, the minimum perceptible difference is less than 0.5 per cent for ratios greater than unity and to something above 10. Although we do not have data on periodic brightness differences it should be noted that projection practice has established conditions which are desirable for motion picture presentation but have made it manyfold easier to observe flicker.

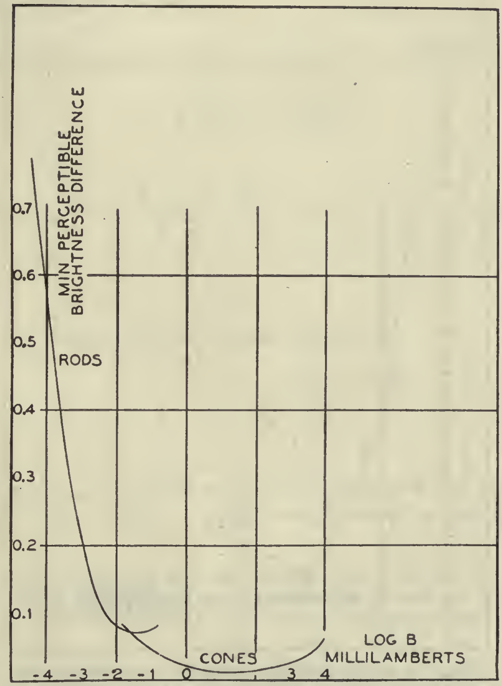

Fig. 2—Relationship between field brightness and minimum perceptible brightness difference.

The relations between modulating flicker frequency brightness and surrounding conditions are apparently complex. Broca and Sulzer[4] examined this subject indirectly by studying the growth and decay of visual sensation. They established that the apparent brightness of a periodic pulse of light grew from zero, went through a maximum, and then approached a constant value somewhat less than this maximum as the duration of the pulse was allowed to increase from zero. Their data were collected for various pulse intensities but at only one repetition rate.

None of the earlier studies mentioned considered the basic problem of a periodic amplitude modulation of an effectively steady light. Data corroborating that given in the original paper on this subject regarding perceptible flicker will be given later in this report.

It is interesting and instructive to consider mathematically flicker due to frame-by-frame differences caused by shutter action. Consider

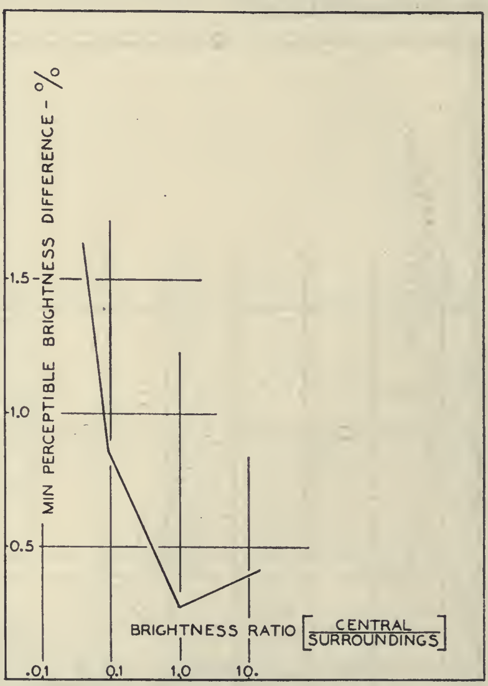

Fig. 3—Relationship between minimum perceptible brightness difference and the ratio of the brightness of the central visual field to the brightness of the surrounding field.*

* Reprinted from "Science of Seeing" by Luckiesh and Moss, © 1937, by D. Van Nostrand Company, Inc., with the permission of the copyright holders.

the case of a camera and assume the exposure to be the product of a constant light intensity and the open time of the shutter, the latter being a function of a constant angular velocity plus a superimposed sinusoidal disturbance in angular velocity. Also assume the amplitude of the modulating velocity small compared to the constant velocity and neglect the finite included angle of the picture frame and all second-order and frequency-modulation terms. With these assumptions, the shutter open time may be expressed as follows:

$$X = \frac{\phi}{a} - \left[\frac{2}{\omega}\left(\frac{b}{a}\right)\sin\left(\frac{\omega}{a}\right)\left(\frac{\phi}{2}\right)\right]\sin\left(\omega t + \frac{\omega\phi}{2a}\right).$$

where

X = open time of shutter
f = modulating frequency
a = constant angular shaft velocity
ϕ = shutter open angle
b/a = velocity modulation index
ω = $2\pi f$.

Note that the maximum flicker amplitude is represented by

$$F = \left[\frac{2}{\omega}\left(\frac{b}{a}\right)\sin\left(\frac{\omega\phi}{2a}\right)\right]$$

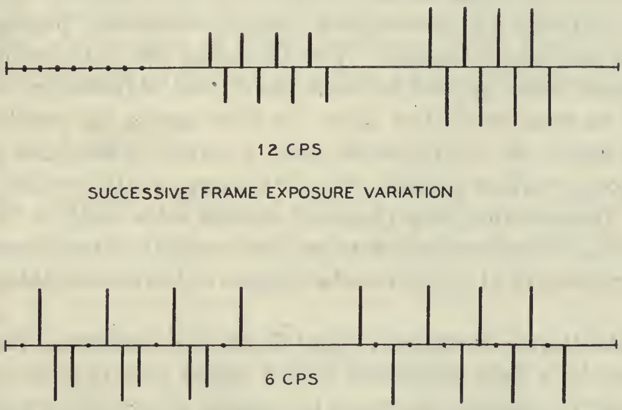

Fig. 4—Illustrating possible flicker due to frame-by-frame transmission differences for 12 cycles per second at 3 initial phase angles and 6 cycles per second at 2 phase angles.

which reveals the relations between flicker amplitude, the shutter opening, relative velocities, and corresponding initial amplitudes. If

$$\frac{\omega\phi}{2a} = n\pi \qquad (n \text{ is any integer})$$

then flicker does not exist even though nonuniform shutter velocity is in evidence.

The above equation represents a continuous periodic wave, whereas shutter operation is a sampling process. The use of this equation requires obtaining values when t is successively incremented by the frame period. Hence, it is obvious that the initial value of t determines the actual wave shape of the disturbance. This effect is shown in Fig. 4.

The analysis further states that shutter motion should not be investigated by other sampling schemes such as stroboscopes if accurate data are required, unless such tests include a number of different initial phase angles.

MEASURING METHODS

In the following discussion on measurements, it is sometimes convenient to use communication terms and in this sense the frame or shutter rate can be considered as the carrier frequency, periodic flicker as an amplitude-modulating frequency, and random variations as noise.

Required measuring techniques fall into three general classes, as follows: methods for determining angular velocities, photographic densities, and light intensities. The difficulties associated with any of these appear when applied to the measurement of flicker rates superimposed on frame or shutter rates. In other words, the problem is to measure signals 35 to 45 decibels below a carrier of 24 cycles per second, or some multiple of same, with the frequency ratio as small as two to one. Incidentally, with projector shutter rates of 48 or 72 cycles per second, the problem is somewhat ameliorated but the cross-modulation products of 24 cycles remain because of the initial taking frame rate.

Consider the measurement of light flicker in a projector. Basically, this must be a light-responsive device whose output must be integrated and/or recorded and must be capable of accurately indicating signals under the above-stated conditions. Such equipment is feasible provided the ratio of signal to noise is favorable which is hardly the case under the circumstances.

Densitometric measurements must be made frame by frame and be accurate and reproducible to density differences of 0.002. The variations due to exposure, dirt, and abrasions, analogously, constitute a serious noise problem and, further, the same area in each frame must be used. Manually, this is a very laborious and questionable process unless unusually large deviations exist. Suitable recording or automatic equipments to meet these requirements of analysis apparently do not exist.

Apparatus for angular-velocity measurement is more readily available than either of the aforementioned classes of equipments. The carrier frequency for the signal may be selected, means provided for generation, stable amplification applied, and the resultant rectified, filtered, and measured with common apparatus. A similar class of apparatus is represented by sound-equipment flutter-measurement devices. The carrier frequency may be generated by tone wheels on the shaft in question and suitable pickups or by stable oscillators exciting the fields of various types of velocity generators. The difficulties of velocity measurement reside in the necessary equipment precision and variations equivalent to noise.

Given apparatus to measure modulating signals, some method must be devised to introduce such signals under controlled and reproducible conditions to enable engineering analysis.

For the work at hand, efforts were concentrated on angular-velocity-measurement methods. Velocity generators of the drag-cup induction type were chosen as the translating device. Such units are available with very low moment of inertia, utilize a carrier frequency of 400 cycles per second, and produce an output which is linearly proportional

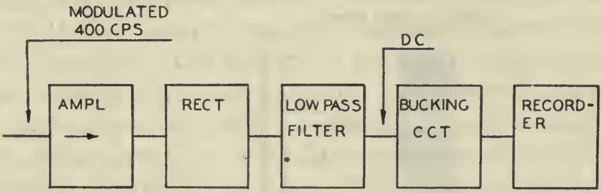

Fig. 5—Block schematic of velocity generator receiving circuits and recording device.

to instantaneous angular velocity over a considerable range. They have the disadvantage that mechanical coupling to the part to be measured must be devised and the signal-to-noise ratio is dependent upon velocity, the ratio being poorest at low velocities. The signal-to-noise ratio at 1440 revolutions per minute of commercially obtainable units is about 30 decibels, making it possible to measure modulating signals of 5 to 6 per cent only, unless the noise signal can be reduced. It is possible to reduce noise by 15 or 20 decibels by careful and judicious trimming of the drag cup and the electrical balance; hence, it is possible to measure modulating signals of 1 to $1^1/_2$ per cent of the carrier. Care must be exercised when coupling the device to any rotating member to consider relative moments of inertia, avoid frictional loading, and nonuniform velocity or play in the mechanical coupling. For hand-held contact coupling the most suitable method is to provide a collet-type member on the generator shaft fitted with a hemispherical rubber point of 60 to 70 Shore hardness. This contact should preferably mate with a 90-degree shaft center but the common shaft centers have been generally suitable.

The electronic apparatus (Fig. 5) consists of a stable 400-cycle oscillator and associated power amplifier for energizing the generator fields, an amplifier for the generator output, linear rectifier, carrier filter, and indicating or recording means.

To provide reproducible modulating signals, a magnetic brake was devised and arranged for attachment to various rotating parts. This brake is energized by a stable, very low-frequency oscillator, wave-shaping circuits, and power amplifier, as in Fig. 6.

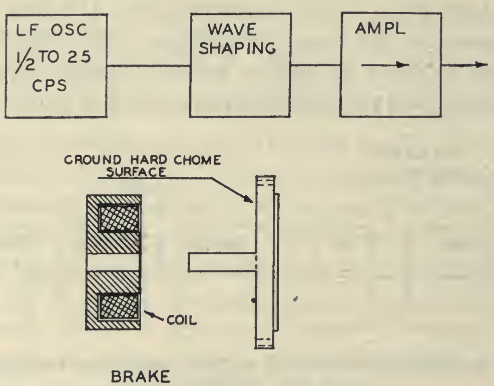

Fig. 6—Magnetic brake for test loadings and associated driving circuits.

For thorough analysis it was considered advisable to have three complete receiving systems available to provide simultaneous measurement at three points; and, further, permanent records were desirable. A multielement recording oscillograph provided the latter facility.

MEASUREMENTS AND RESULTS

Before proceeding with a program of tests, a flicker-free projector was needed to evaluate the flicker samples visually. Flicker in projectors is caused by (a) shutter rate, (b) nonuniform shutter velocity, (c) arc-supply ripple, and (d) arc-burning characteristics.

The effects of (a) are generally known. Most projectors are supplied with two-bladed shutters producing a 48-cycle shutter rate which is sufficiently high, at present illumination levels, to be of secondary importance. In studio review rooms a three-bladed shutter frequently is used. No studies were made of two- versus three-bladed shutters. One point concerning shutters should, however, be made. Any multibladed shutter must be symmetrical, otherwise the 24-cycle frame rate is reintroduced and frame flicker becomes apparent. Analytically, shutters can be expressed by a Fourier series and the effects on flicker rate of various designs studied very simply.

The shutter used for all visual work consisted of three 93-degree blades and three 27-degree openings. It is currently used in all studio review rooms at Twentieth Century-Fox.

Nonuniform shutter velocity can result from poor driving motor operation or excessive mechanical backlash between driving point and shutter shaft. Analogously, backlash can be considered as a complex nonlinear compliance which in concert with the masses involved can be resonant. Many cases of long gear trains with large backlash on currently used equipment have been noted with attendant flicker observable in the projected picture. In order to evaluate the seriousness of the shutter nonuniformity, a temporary filtered shutter was devised and applied. The design was not wholly satisfactory because of an insufficiently low cutoff frequency but it served to demonstrate that the higher-frequency flicker components could be noticeably attenuated. This part of the work has not progressed beyond this point. It is, however, clear that projector improvements either should include shortened gear trains with a minimum of backlash or some type of damped or filtered shutter.

Arc-supply ripple is the worst source of flicker. Any 60-cycle component greater than 0.15 per cent will cause a 12-cycle flicker resulting from beats between the 60 and the 48 cycles of a two-bladed or the 72 cycles of a three-bladed shutter. Supplies operating from 50-cycle sources do not produce the same result since the beat frequencies are 2 and 22 cycles, respectively. Unfortunately, it has generally been considered that three-phase rectifiers and motor-generator sets require filtering only for the theoretical higher frequencies prevalent and that any 60-cycle components are low enough to be neglected. This is not true. Consider the three-phase rectifier. Either unbalanced line voltages or differences in rectifier element voltage drops will introduce line-frequency components and these must be safeguarded against by some filtering which is effective at such frequencies. Motor-generator sets can also contain line-frequency components resulting from armature slots or rotational effects. Six-phase rectifiers are superior in this regard because they tend to contain less 60-cycle components. In view of the above remarks the cure is obvious but it is surprising to learn that single-phase rectifiers having insufficient filtering are used for arc supplies.

To eliminate the difficulties from 60-cycle ripple, all studio projectors employing three-phase rectifiers for arc supply are being equipped with additional series inductance. The increased series impedance offers a further advantage in that the arc stability is improved.

Independently, engineers involved in the frequency conversion to 60 cycles in the southern California area discovered the same trouble when flicker appeared in theaters after the 50- to 60-cycle change. The inductance design has been supplied them and, to date, five theaters have been equipped. Reported results state that the improvement amounts to 75 to 90 per cent elimination of visible flicker due to this source. Specifications for the inductance used for 50-ampere supplies are stated in the Appendix.

To forestall serious arc flicker, maintenance men have been supplied with a ripple meter which is arranged principally to measure 60-cycle components.

A good visual tool having been obtained, attention was next directed to flicker sources in motion picture production. These include (a) illumination, (b) camera, (c) film, (d) negative processing, (e) printing, and (f) positive processing. It was felt that processing was not a major factor at present, so no work has been done in this category. It has been demonstrated[1] that printers can introduce flicker but, again, the present investigation has not progressed to that point. Hence, there will be no further discussion of this element. It is also known that set-lighting generator outputs contain 60-cycle components but to date no evidence exists that illumination periodic flicker has been important. The remaining items, camera and film, have had further study, particularly the former, and now will be discussed.

Flicker has been isolated to film difficulties in a few cases in the past. The drying-rack effects are easy to determine but the rate here is so low that it is not significant as a flicker effect. Drying-rack rate is well known to the manufacturers and it is presumed that eventually this trouble will be corrected. The changes in film which cause periodic troublesome flicker are hard to separate from the other elements in the system. Assuming that processing is free from variation, flicker should be visually apparent if a length of film is uniformly exposed by some means whereby it is not subjected to the strains common to camera mechanisms, processed, and then projected. With careful handling it would be possible, though tedious, to measure and plot the density variations over a given section. To expose film in 50- or 100-foot lengths in this manner requires elaborate equipment but such lengths are necessary to permit good visual study or catch intermittent cases. Such equipment does not exist in Hollywood but several attempts were made to expose stock in this manner. The tests were made in a relatively crude manner and showed random variations but, to date, no serious periodic rates have been noted in the stocks tested. This statement does not imply that film is always free from the subject defects but is, at least momentarily, free from suspicion. For future investigation, or to isolate trouble, suitable apparatus to provide the uniform exposure is highly desirable.

Flicker introduced by or within the motion picture camera results from (a) nonuniform shutter motion, (b) changes in film sensitivity by certain film stresses, and probably (c) nonuniform register or film lay in the picture aperture. The last two have been given only a superficial examination in this work. The most promising approach to (c) appears to be the use of high-speed photography and has been contemplated but not yet performed.

Periodic nonuniform shutter velocity is certainly a source of flicker, being the basic element in determining exposure when frame speed and illumination are fixed.

The flicker equation given earlier in this paper was set up particularly for camera-shutter operation and the explanatory statements made then specifically apply here.

For further discussion of camera mechanisms, it is convenient to consider all elements in terms of electrical analogies. If damping is ignored the driving-motor system constitutes one oscillatory mesh and further, since cameras generally include compliances either in the form of flexible couplings or mechanical backlash, additional oscillatory modes exist. In the specific case under discussion two flexible couplings, other than motor system compliance, existed. These were introduced for mechanical reasons and to minimize noise, and for such purposes served very well. The only damping present in the system was provided by the frictional losses, loading, and a small inherent damping in the coupling material. The designers of sound-recording apparatus know the necessity of damping but these techniques have not been applied as yet to cameras. As a result, oscillatory conditions can exist when excited by a suitable signal.

To analyze the camera conditions, a velocity generator was properly connected directly to the shutter, a second unit was used to indicate motor-shaft velocity, and when necessary a third unit was used on the distributor of the driving interlock system. In this way simultaneous, instantaneous measurements of velocities were made for steady-state and deliberately introduced signals. A typical record, simplified for purposes of illustration, is shown in Fig. 7. The transient response due to sudden loading or unloading also is shown. Note that the distributor is not affected although it displays a small amount of periodic variation. By varying signal frequency and recording the amplitudes at all points the frequency characteristic may be obtained and the resonant frequencies determined. A typical record is shown in Fig. 8.

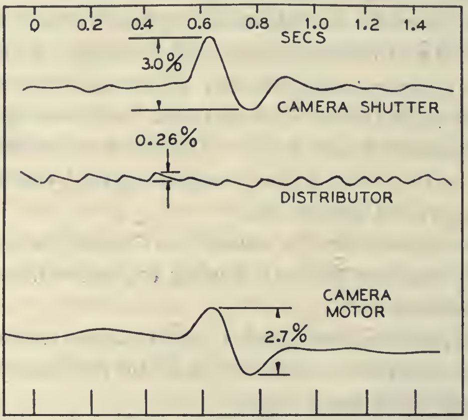

Fig. 7—Velocity changes at three points in camera system. Average velocity, 1440 revolutions per minute for each curve.

From data taken in the above manner, two significant results obtained. First, camera motors and associated systems have a resonant frequency between 3 and 6 cycles per second. This results from semistandardized dimensions of frames and armatures which determines the moment of inertia and the pull-out power requirements of camera motors which determines the stiffness. Note that all types of conventional speed-controlled camera motors will fit into this category because of prevalent motor sizes and power and, further, that the frequency of resonance is within the critical flicker region. To move the resonant frequency of motor systems to less critical regions would require at least a tenfold decrease in moment of inertia, a corresponding increase in stiffness, or a threefold change in both. This is a very impractical solution. The best answer to this situation would employ some form of damping or complete isolation of the shutter from probable disturbances from this source. In general, it may be said that the greater the power capability of a camera motor with respect to a given load, the less the possibility of flicker from various excitation signals. Second, one of the auxiliary couplings in the mechanism tested showed resonance at frequencies between 4 and 10 cycles, depending upon the material used, the amount of usage, temperature, and the preciseness of the various fits. As is obvious, these frequencies are also in the critical region of flicker. In such cases the moments of

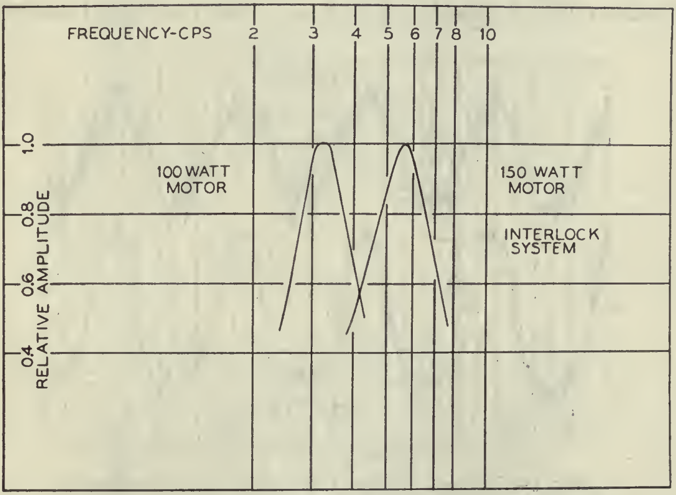

Fig. 8—Frequency characteristic for two motors having different power capability on same supply system.

inertia and stiffnesses must be suitably chosen to avoid trouble or, alternatively, damping applied.

In determining the data discussed so far sine-wave signals were used and applied to the camera motor shaft by means of the brake previously described.

Attention was next directed to the determination of the effect of periodic loadings when applied to various points in the camera mechanism. Only two such places were readily available; namely, the motor shaft and the film take-up. The results of motor-shaft loading have already been discussed except in the quantitative sense. With sine-wave signals, it was found possible to introduce easily shutter rates from $^1/_2$ to 12 cycles in magnitudes varying from 1 to 7 per cent. This magnitude is sufficient to cause noticeable flicker. Sine-wave signals applied to film take-up points did not appreciably disturb the shutter until the applied load was great enough to cause take-up clutch slippage. This latter result was not in keeping with simple exploratory tests made at this point by loads applied with the fingers. By trying signals of other shapes, it was found that impulsive waves of approximately the shape of the peak portions of sine waves would disturb the shutter sufficiently to cause flicker and still not be apparent visibly in the camera operation. A similar signal applied to the motor shaft also disturbed the shutter with a magnitude greater than ever achieved with sine-wave loading. The resulting instantaneous

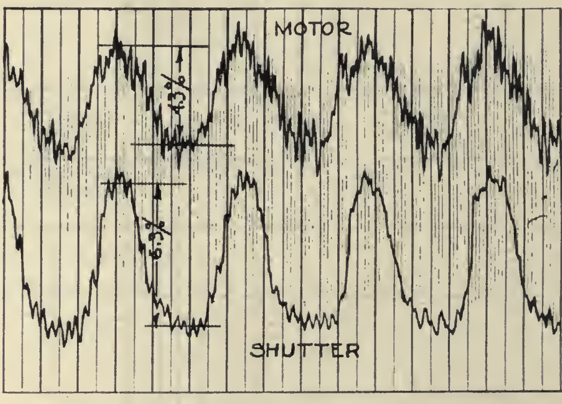

Fig. 9—Typical velocity differences in a camera when artificially loaded at 3 cycles per second. Average velocity is 1440 revolutions per minute.

velocities of one such test are shown in Fig. 9. The applied load was small enough so as not to be noticeable to operators of present equipments.

At this point it was decided to correlate the data obtained analytically by an attempt to introduce flicker into a photographic test. The exposure was made while applying periodic impulsive loads, of the type previously described, to the motor shaft and a record of the shaft velocity was taken simultaneously. The record is shown in Fig. 10, indicating peak-to-peak velocity differences as great as $7^1/_2$ per cent. The resulting picture contained flicker at the applied frequency and in greater magnitude than any previously obtained in production work. This result generally corroborates the data of the original paper which stated that 3 per cent variation was sufficient to cause perceptible flicker. If any revision is needed it would seem to be a downward one, perhaps to 2 per cent, especially when considering

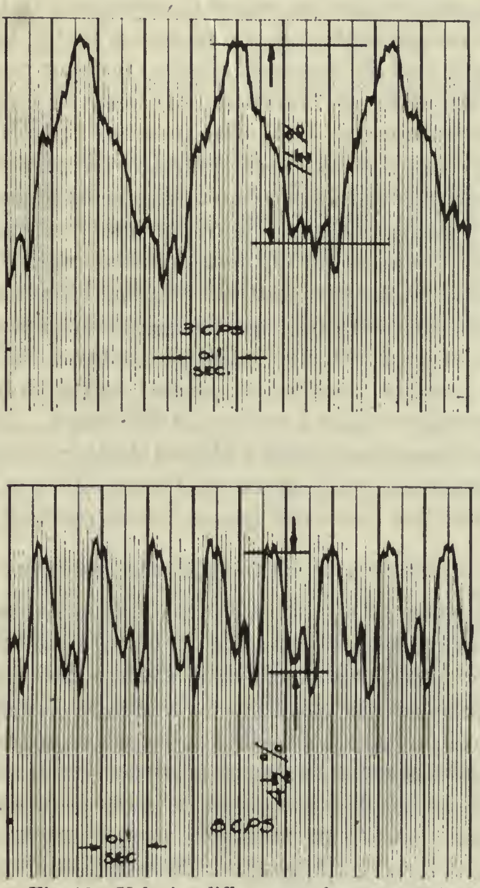

Fig. 10—Velocity differences of camera motor shaft which introduced excessive flicker in a photographic test. The 8-cycle-per-second result was visually much worse than the 3-cycle-per-second test.

negatives, because of the common usage of over-all gamma around 1.6. Definite correlation is thus obtained. Additional tests with spiked impulsive wave forms gave visual flicker effects generally corresponding to the applied wave shape but sine-wave signals did not produce as great a visual effect for a given load application as for the impulsive cases. This would indicate that periodic binding or tight spots in the camera mechanism can readily produce flicker if occurring at the proper rates.

The next question concerns remedial measures. Only four immediate remedies are available: (1) use motors with the best possible inherent damping and the greatest practical pull-out power, (2) reduce backlash to the absolute minimum, (3) keep all film propelling or handling mechanisms free of binding or other irregularities, and (4), where flexible couplings are used, redesign to include damping and constancy of characteristics or make the resonant frequency outside of the critical frequency region. Since the above methods are mostly precautionary, the best and ultimate solution resides in the use of a properly filtered or damped shutter. Again, this is analogous to the course followed successfully in sound-equipment design. It is probable that reduction of velocity variations in the 4- to 10-cycle region need be only to 0.5 per cent for the present, although future technical improvements may require a revision of this figure. To date no work has been done toward providing a filtered shutter for existing cameras but some thought has been given to the feasibility of such a design. It is hoped that this preferable course can be pursued in due time.

Conclusions and Recommendations

(1) Steady technical improvement in illumination level and theater presentation has reached the point where future attention must be directed toward improving mechanical motions and providing better auxiliary apparatus and materials to minimize flicker and/or allow greater latitude in usage before flicker becomes apparent. Nearly all elements in the basic technical motion picture production and exhibition system have insufficient margin for flicker-free operation.

(2) The sum total of all variations in the system which produce flicker should not exceed 2 per cent. However, 3 per cent variations may be temporarily acceptable.

(3) Analytic examination of film processing and incident or reflected light (with projector running) of a theater screen is involved and difficult. Mechanical motions can be best studied by measurement of instantaneous velocity.

(4) Symmetrical two-bladed projection shutters producing a 48-cycle rate are presently acceptable but may require revision if illumination is increased appreciably.

(5) Arc-supply apparatus should not contain more than 0.15 per cent of 60-cycle components for usual line-supply conditions and practical limits of equipment aging. Series inductance is desirable for filtering to meet these requirements and further stabilizes arc burning. Arc-supply ripple should be measured periodically to indicate proper operation and forestall serious flicker from this source.

(6) Film stock has introduced flicker but such cases are apparently random in nature.

(7) Nonuniform shutter velocities, either camera or projector, cause flicker. Variations up to 7 per cent, peak to peak, have been measured and reproduced for analysis. Shutters should be damped or filtered. Consequently, future work should be directed along this line.

(8) Conventionally controlled camera motors should be supplied for the greatest practical pull-out power. This includes synchronous motors controlled by line frequency.

(9) In so far as possible, flexible couplings having torsional compliance should be avoided but if this is impractical or impossible, suitable damping must be provided. Flexible couplings used for angled drives introduce nonuniform motion in the driven member. Therefore, this type of mechanism must be avoided.

(10) All film propelling or handling mechanisms must be kept free of small periodic bindings, tight spots, or other irregularities. This rigid requirement can be lessened if filtered shutters are provided.

(11) Work should be initiated to investigate the effects of periodic supply variation on photographic illuminants and the flicker resulting therefrom.

(12) A study should be made to provide accurate data on periodic perceptible brightness differences as a function of brightness, frequency, and surroundings. This could be done by a university or medical school, but since the information is peculiarly applicable to motion pictures, it may be that the Society should undertake to sponsor such a program.

Undoubtedly, in the foregoing material it has been noticed that many branches of this subject have not been explored and others only superficially examined. This is an indication of the amount of work still to be done and emphasizes the need for broadened and accelerated activity in this problem of motion picture production and presentation.

APPENDIX

Derivation of equation for exposure, or open shutter time, when the included angle of the picture aperture is small compared to the shutter opening.

Let X = exposure, or open shutter time
a = constant component of angular velocity of shutter shaft
b = peak velocity value of disturbing frequency
f = frequency of disturbance
b/a = modulation index of velocity
ϕ = angle of shutter opening
θ = angular displacement of shutter shaft.

Then, for sinusoidal disturbing frequencies, the shutter velocity is

$$\frac{d\theta}{dt} = a + b \sin \omega t = a \left(1 + \frac{b}{a} \sin \omega t\right). \tag{1}$$

Assume $b \ll a$, then

$$\frac{dt}{d\theta} = \frac{1}{a}\left(1 - \frac{b}{a} \sin \omega t\right). \tag{2}$$

Now, since $b \ll a$ and if second-order terms are neglected, $\theta \approx at$. Therefore,

$$\frac{dt}{d\theta} = \frac{1}{a}\left(1 - \frac{b}{a} \sin \frac{\omega\theta}{a}\right). \tag{3}$$

The exposure time, or open shutter time, X is

$$X = \frac{1}{a} \int^{\theta_0+\phi} \left[1 - \frac{b}{a} \sin \frac{\omega\theta}{a}\right] d\theta$$

where

θ_0 = angle at which shutter opens.

$$aX = \phi + \left[\frac{b}{\omega} \cos \frac{\omega}{a} (\theta_0 + \phi) - \frac{b}{\omega} \cos \frac{\omega\theta_0}{a}\right]$$

$$= \phi - \frac{b}{\omega}\left[2 \sin \frac{\omega}{2a} (2\theta_0 + \phi) \sin \frac{\omega\phi}{2a}\right]$$

$$= \phi - \frac{2b}{\omega} \sin \frac{\omega\phi}{2a} \sin \left(\frac{\omega\theta_0}{a} + \frac{\omega\phi}{2a}\right). \tag{4}$$

Now, (4) is a statement pertaining to single frames but we desire an expression for consecutive frames. This we obtain by incrementing θ_0 by 2π and writing the corresponding values of $X_1, X_2, X_3, \ldots X_n$. Further, having defined $b \ll a$ and $\theta \approx at$ we may write

$$X = \frac{\phi}{a} - \left[\frac{2}{\omega}\left(\frac{b}{a}\right) \sin \left(\frac{\omega}{a}\right)\frac{\phi}{2}\right] \sin \left(\omega t + \frac{\omega\phi}{2a}\right). \qquad (5)$$

It should be observed that (5) expresses a continuous periodic wave which is most suitable for analysis but to obtain data for each frame, t is successfully incremented by the frame time.

Filter Inductance

63 turns No. 7 twin square copper ($8^3/_4$ pounds)
Window area—$3^7/_{32} \times 1^1/_4$ inches
Tongue—2 inches
Build—$3^3/_8$ inches
Optimum gap (center leg only)—$^{11}/_{32}$ inch
Grade A transformer iron
Inductance at zero direct current—3.5 millihenries.

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Video Distribution Facilities for Television Transmission*

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Summary—This paper describes the Bell System's plans for furnishing network and local video facilities. The Telephone Company is now using broad-band coaxial cable and microwave radio systems to provide regular message telephone service on a number of principal intercity routes throughout the nation. These facilities can be used to provide television transmission channels when properly equipped. Video service between Washington, D. C., New York, and Boston over these two types of facilities has been demonstrated. New facilities are rapidly being extended. Local video channels for pickup and metropolitan-area networks are provided by ordinary paper-insulated cable pairs, special shielded polyethylene-insulated pairs, by microwave radio systems, or by combinations of these systems. Amplifier and equalizing arrangements for providing wide-band transmission over these facilities are described. Present Bell System views of the availability of microwave and coaxial cable facilities on the principal routes, types of circuits, bandwidths, bridging and terminating arrangements, and general information concerning the provision of television circuits are covered.

The phenomenal advance which has taken place in the field of television during the past few years has come in no small measure from many developments and contributions which have been furnished by the motion picture industry. As the industry develops further it appears that television will establish itself on a firm economic basis when the same programs are released to many audiences throughout the nation in a manner similar to that used so effectively in the motion picture field through extensive film-distribution organizations. With this focus we may examine the general types of facilities which are being provided by the Bell System for the transmission and distribution of television video signals on an area or nation-wide network basis.

Since the inception of network broadcasting 25 years ago, the Bell System has been furnishing program-transmission service to an ever-increasing number of stations. Today more than 1000 stations

* Presented May 17, 1948, at the SMPE Convention in Santa Monica; May 20, 1948, at the Second Annual Broadcast Engineering Conference of the National Association of Broadcasters in Los Angeles.

receive service over their lines and more than 150,000 miles of program circuits are in use.

Within the last few years audio program network channels have been provided in many instances by means of carrier systems operating over broad-band circuit facilities. These program-carrier systems are designed with phase and attenuation equalizers and provide high-quality channels. With about 600,000 miles of these broad-band systems in our plant, many of the future 8000- and 15,000-cycle program channels will be provided by this means.

Recently a 15,000-cycle network circuit using carrier terminal equipment was placed in service between Washington, D. C., and a suburb of New York City. By an extension of these same methods video circuits can also be provided.

In contrast to ordinary telephone-message circuits which require a bandwidth of about 3000 cycles, the video circuits require a band of frequencies several million cycles wide, depending upon the picture detail and definition which are desired. Such factors as echoes or ghosts, attenuation, phase distortion, noise, cross talk, and modulation products have an important bearing on the quality of picture images which are received. As in the case of message facilities, the necessary controls and protective measures are employed to maintain the quality of the picture transmission.

CHANNELS FOR TRANSMISSION OF LOCAL VIDEO SIGNALS

Local channels for television video pickup, distribution, and studio-transmitter connections are usually arranged for a bandwidth of about 4 megacycles. Because of the wide variety of locations at which these channels may terminate, advantage is often taken of the availability of ordinary paper-insulated cable pairs which can be used for video transmission. The transmission losses of these facilities in the video range are shown in Fig. 1.

Because of the relatively high losses which are involved, it is necessary to provide amplification on these circuits at intervals of from 0.6 to 1.5 miles depending upon the gauge of the conductors and physical layout of the cable.

These paper-insulated conductors are used most frequently where the loops are short or special low-loss pairs are not available. Their use entails the removal of bridge taps, or multiple conductors, to avoid echoes, and the pairs must be carefully selected to avoid interference.

The second type of facility for local service is a special 16-gauge, shielded, polyethylene-insulated, balanced pair. This structure has a low loss, is relatively free from interference and noise, and is very stable.

These polyethylene pairs are being provided over relatively short distances to many locations where it is expected that recurring or permanent television channels will be required. With a loss of about 18

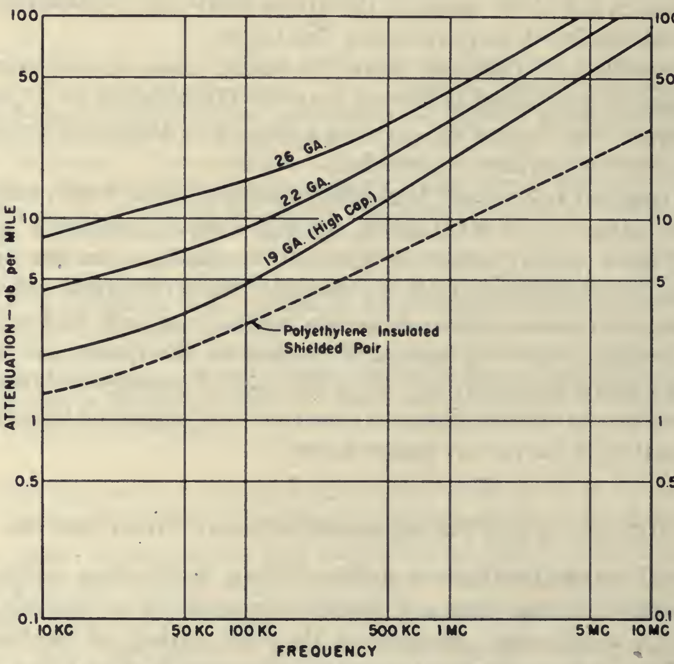

Fig. 1—Typical attenuation losses of facilities used for video transmission.
—— Regular telephone-cable pairs.
---- Polyethylene-insulated shielded pair.

decibels per mile at 4 megacycles, amplifiers can be spaced at intervals up to 3.5 miles in length. This wider spacing greatly reduces the requirement for locating video repeaters at locations outside of established telephone central offices.

Where long-range planning is possible, polyethylene pairs can be located to advantage in the same sheath with full-sized cables provided for telephone requirements with consequent economy of duct usage.

In addition to the channels which may be established by means of wire facilities, the telephone companies are utilizing microwave radio in many instances. The field of use for this latter facility is generally the longer loops which would otherwise require several wire sections in tandem.

As television programming develops further, it may be that microwave facilities will become economical to an even greater extent in furnishing the shorter temporary loops to points which may not normally be reached over the basic local wire networks.

Amplifier and equalizer arrangements for video channels are shown in Fig. 2. Transmitting and receiving amplifiers are available for

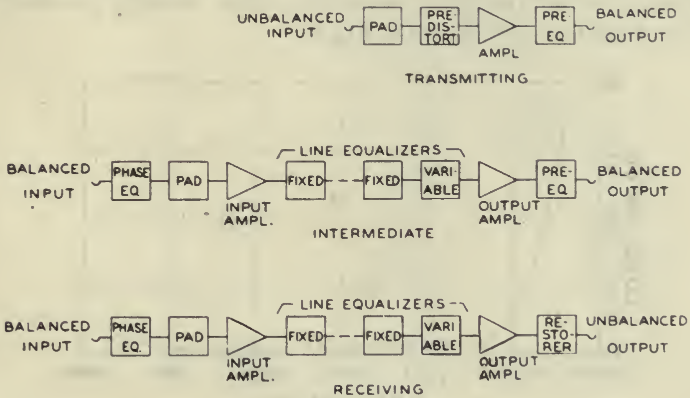

Fig. 2—Video amplifiers—block schematic.

use at the circuit terminals when required. Intermediate amplifiers are provided along the circuit route to make up for the attenuation losses. Predistorting and restoring networks are available for use to minimize the effects of high-frequency noise when required. The amplifiers are arranged for connection to 75-ohm unbalanced circuits such as are in common use at studio or pickup locations or for connection to 110-ohm balanced-cable pairs. Attenuation and phase equalization for the video cable circuits are provided at intermediate or receiving locations.

At transmitting terminals where amplification is not required, a repeating coil capable of passing video frequencies is connected between the 75-ohm output and 110-ohm balanced-cable circuit to effect the transition. A similar coil is used at the receiving end to make the transition from balanced-cable pair to unbalanced output.

Because of low-frequency transmission characteristics of these coils it is necessary to employ a clamper to reinsert the low-frequency information which has been removed in transmission. The transmission characteristics of the repeating coil, which has recently been made available, are shown in Fig. 3. An amplifier is associated with the clamper to assist in its operation and to increase the output signal to the desired level. In this case amplification and equalization for the balanced-loop facilities are provided at the intermediate central offices through which the circuit passes.

The application of the repeating coils and clamper circuit at the circuit terminals are shown in Figs. 4 and 5, respectively. Typical frequency characteristics of equalized video circuits provided by local cable facilities are shown in Fig. 6.

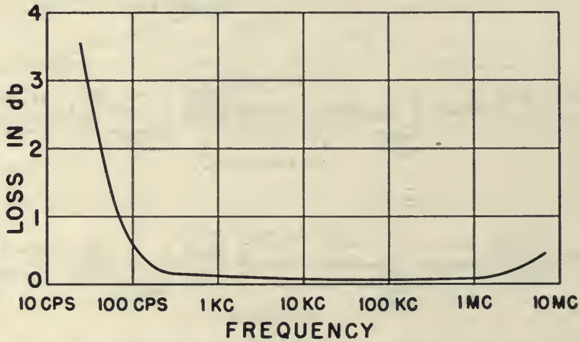

Fig. 3—Loss versus frequency characteristics of 197A video repeating coil.

Local distribution networks for transmitting video programs from one location to a number of other locations, such as chains of department stores or theaters, can be provided by using the same general circuit and equipment arrangements.

VIDEO INTERCITY NETWORK FACILITIES

As a consequence of the elaborate and costly arrangements which are required for producing television studio programs, it appears that there will be an even greater economic need for video network facilities than in sound broadcasting. As in the case of sound broadcasting, it is believed that the demand for network facilities will develop with the expansion of the television industry and that nation-wide networks will soon become a reality.

Present techniques for providing long-haul telephone circuits make use of broad-band facilities such as are provided by coaxial-cable or microwave-relay systems. At the present time there are about 7000 miles of these two types of facilities completed or under construction

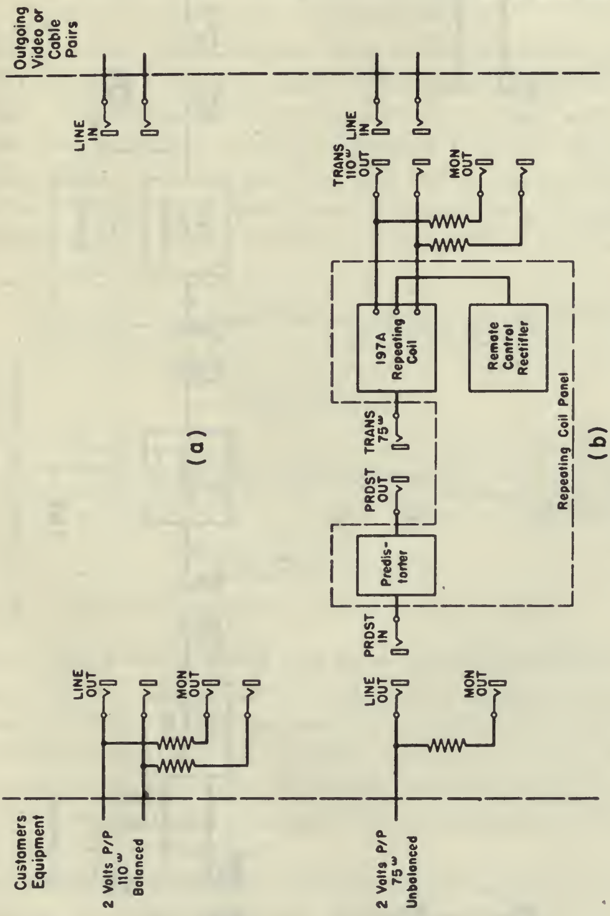

Fig. 4—Transmitting terminal.

and it is expected that this amount will be nearly doubled in the next few years. The same facilities that are used for deriving ordinary message circuits can also be used for providing audio program channels or for television video channels.

The requirements of the circuits, namely, ordinary message, audio program, or video program, determine the selection of the terminal

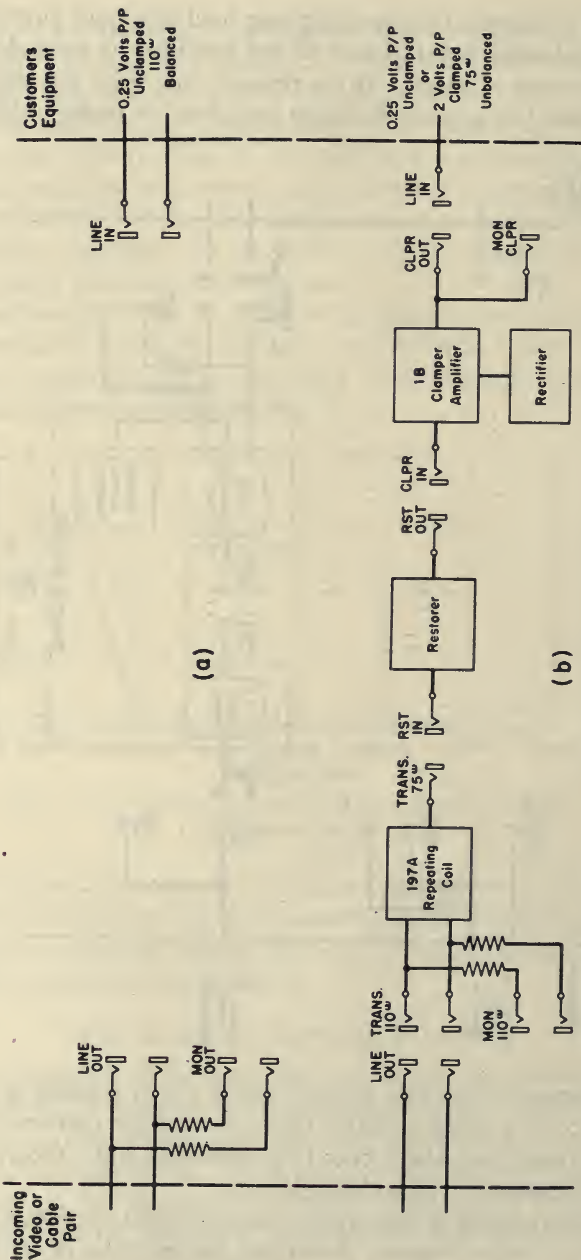

Fig. 5—Receiving terminal.

and intermediate apparatus to be applied to the broad-band system. While the basic techniques are relatively simple, considerable development work is required to provide the greater refinement and improvement which wide bandwidth and extreme length of circuit entail.

COAXIAL-CABLE SYSTEM

The layout and circuit details of the coaxial-cable system have been covered quite fully elsewhere so they will only be touched on briefly at this time. The coaxial conductor consists of a copper tube $^3/_8$ inch in diameter with a central conductor insulated from the outer tube by insulating disks. The bandwidth which can be transmitted over a conductor of this type depends upon the amplifier and equalizer arrangements which are used and the spacing at which they are placed.

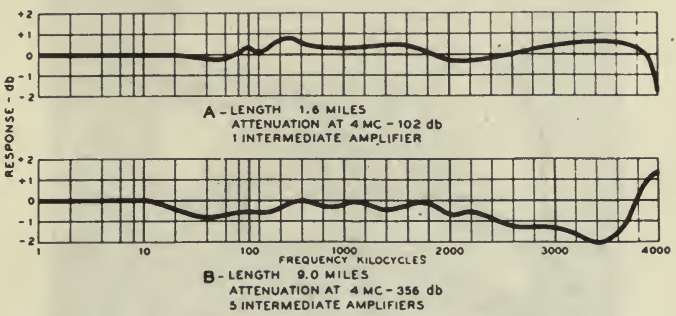

Fig. 6—Video circuits—frequency characteristics.

The amplifiers now in use have a gain of about 50 decibels at a frequency of about 3 megacycles and are used at 8-mile intervals. For telephone service, 600 message circuits are operated in the band between 68 and 2788 kilocycles. For television transmission, the signal is translated through a system of double modulation and transmitted as an upper sideband and a vestigial lower sideband on a carrier frequency of about 311 kilocycles.

The associated high-quality television audio channel is transmitted in the range below 200 kilocycles. This lower range is not used for video transmission because of the inadequacy of the shielding at low frequencies and the difficulty of equalizing a 3-megacycle band which includes these lower frequencies.

The present coaxial system provides a video band about 2.8 megacycles wide which can be used to transmit television pictures or as many as 600 message telephone circuits. Development work is being carried on for a system of the same general type which will have a useful bandwidth of about 7 megacycles and which will permit transmission of a 4-megacycle television channel as well as about 600 telephone circuits over two one-way coaxial tubes.

In order to insure high circuit stability and continuity of service in the coaxial system, many features have been provided to insure that incipient troubles are quickly corrected and that interruptions and variations are kept to a minimum. The underground type of construction employed reduces the likelihood of service interruption and greatly reduces the effect of temperature changes. Spare line facilities arranged for automatic switching in the event of cable trouble add to the reliability of the coaxial circuits.

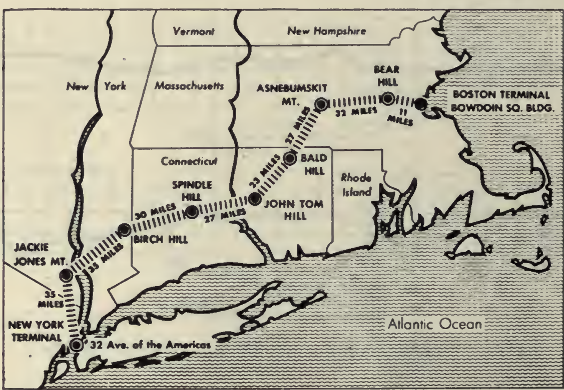

Fig. 7—Bell System radio-relay route between New York and Boston.

MICROWAVE-RELAY SYSTEMS

In order to determine the practicability of using microwave radio as a means of providing wide-band circuit facilities, a system of this type was constructed between New York and Boston. It was completed in November, 1947, and used to demonstrate the feasibility of this medium. The equipment operates in the 4000-megacycle range and requires line-of-sight transmission between relay points.

Following the customary wire-line technique of using repeaters at intervals along a circuit, seven intermediate radio repeaters or relays are employed as shown in Fig. 7. At each repeater location the incoming energy from each direction is converted to a frequency of 65 megacycles for amplification and then raised to the transmitting frequency. A typical microwave repeater station is shown in Fig. 8.

On the roof of each radio-relay station are four 10- by 10-foot horns each incorporating a shielded lens for focusing the radiation into a narrow beam, so sharp that it is 10,000 times more powerful than an unfocused signal. This increases the effective power very substantially and permits long-range transmission with very small radiated power. Two of the four horns face New York and two face Boston. This allows two-way operation, one antenna of each pair being used for transmitting and one for receiving.

Fig. 8—Birch Hill microwave repeater station.

These microwave radio-relay systems have been designed to afford a transmission band about 4.5 megacycles in width and provide an excellent means of producing high-quality television video circuits or

Fig. 9—Television stations and network routes.

hundreds of message-telephone circuits. The use of the New York-to-Boston system for television was demonstrated in November, 1947, and the results were very gratifying. By looping the two two-way circuits back and forth between New York and Boston, a circuit about 880 miles in length and having 32 repetitions was realized. Picture signals received back at New York were difficult to distinguish from the original material even on a direct comparison basis.

FUTURE PLANS

To provide additional capacity for television and telephone circuits, a wide-band New York-Chicago radio-relay system is planned for service late in 1949. The initial installation will care for one working channel and one stand-by channel in each direction and will be capable of extension to a substantially larger number of channels when required.

Early in 1949, the gap between the southern transcontinental coaxial cable and eastern coaxial network is scheduled to be closed by the completion of the St. Louis-Jackson (Mississippi) section. Although novel equalizing problems will be involved in equipping this length of cable for television, it is believed that transcontinental television can be provided about one year after completion of the cable if the demand justifies proceeding at once with this work. Fig. 9 indicates present and proposed television network routes.

Whether cable or radio-relay circuits will emerge as the better means for providing the various services in a particular area is still unknown. Present indications are that both systems will play their part and that the use of either or both will be determined by the particular needs and particular geographical conditions.

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Improved Optical Reduction Sound Printer*

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Summary—**An improved 35-mm to 16-mm optical reduction sound printer embodying improvements in image quality and film motion is described.**

I. Introduction

The optical reduction sound printer was developed for the industry because it afforded one of the most practical methods of producing 16-mm sound-track prints from original 35-mm sound negatives.[1] A number of these printers were produced by the Radio Corporation of America and have been successfully used by processing laboratories for the past twelve years. During this time a number of improvements in image quality and speed regulation have been reported before this Society by Drew and Sachtleben.[2] These and other features have now been incorporated into a new printer known as the RCA Type PB-177.

II. Description

As illustrated in Fig. 1, the mechanism consists essentially of a driving motor, mounted on the rear side, with associated enclosed gearing, 35-mm and 16-mm film paths appearing left to right, respectively, the optical system, and a control panel. The driving motor is specially designed for smooth starting, with torque reduced for the first half second of operation. An additional soft-starting circuit which employs a time delay and resistive network provides an adjustment which insures optimum starting voltage for the first five seconds of operation. Film feed and take-up sprockets are geared to the motor. The two sound drums are film-driven. Each sound drum is individually stabilized by its own damping wheel.[3] The take-up spindles are belt-driven from pulleys geared to the driving motor. Spring-loaded idlers, with continuously adjustable tension, are employed to

* Presented May 20, 1948, at The SMPE Convention in Santa Monica.

maintain optimum belt tension. The 35-mm feed and take-up brackets are designed to accommodate 1000 feet of film. The 16-mm raw-stock feed bracket and take-up bracket accommodate 1200 feet and 400 feet of film, respectively.

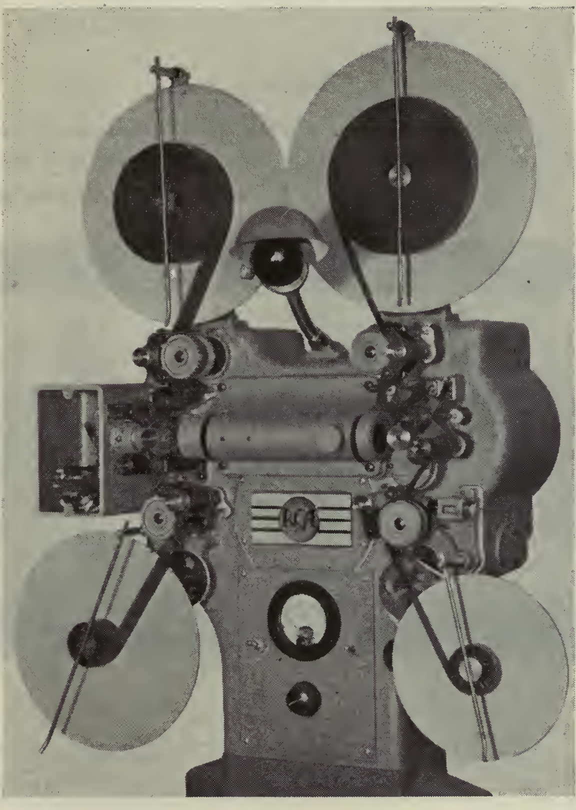

Fig. 1

The printer optical system includes an exposure lamp, illuminating system, and an objective lens barrel. The latter contains two objectives and a cylindrical lens assembly, which provide for a $2^1/_2$-to-1 reduction along the line of travel and approximately 85 per cent reduction laterally. Facilities are provided for vertical and horizontal positioning and for rotation of the exposure lamp.

The control panel contains a rheostat for adjusting exposure-lamp voltage, a 0- to 150-volt direct-current meter for indicating exposure lamp voltage, a lamp off-on switch, and a motor off-on switch. Additional facilities mounted on the printer are a Ruby pilot lamp for use while threading and a footage counter which reads in feet of 35-mm film.

The operating mechanism of the printer is mounted with supporting columns on a four-footed pedestal, which insures stability.

III. Technical Data

The operating speed is 180 or 150 feet per minute on 60- or 50-cycle power supplies for the 35-mm negative. Likewise it is 72 or 60 feet per minute for the 16-mm print. Driving power is obtained from a

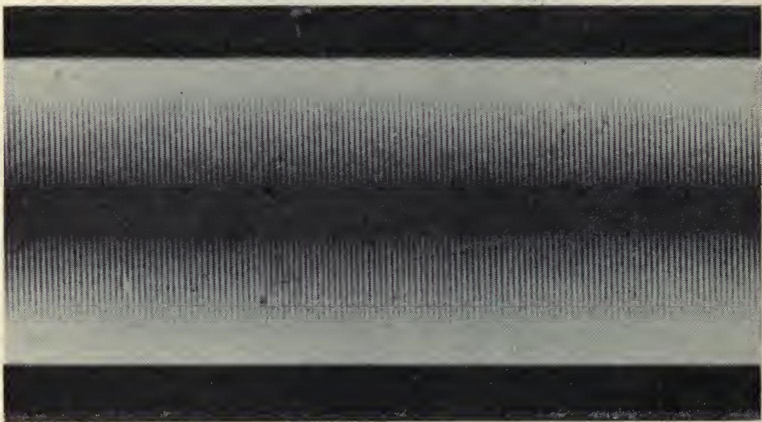

Fig. 2

60/50-cycle, 230-volt synchronous-type motor operating at 1200/1000 revolutions per minute and producing approximately 100 mechanical watts. Stabilizing time from start is 10 to 12 feet of 35-mm film or 4 to 5 feet of 16-mm film. Stopping time is 6 to 8 feet of 35-mm film or $2^1/_2$ to 3 feet of 16-mm film. Speed regulations as shown by motion studies indicate a total flutter content of 0.1 per cent in the 16-mm print. Fig. 2 illustrates a photomicrograph of a 6000-cycle, 16-mm print exposed at 80 volts lamp voltage on Eastman Type 5302 fine-grain positive stock having a density of 1.4 using a fine-grain negative master with a density of 2.6 to 2.9. The exposure lamp is a 120-volt, 100-watt, CC-13 filament, bayonet base, projection type. Track-placement alignment of both 35-mm and 16-mm films are controllable by lateral positioning of the film at the respective sound drums by means of adjustable guide rollers. All optical adjustments are factory-set and sealed for normal operation whereby the emulsions of each film face each other and the 16-mm stock is type-B wound. Variations in this procedure are possible by refocusing and realignment.

IV. Conclusion

The Type PB-177 printer permits the transfer of sound recording from 35-mm to 16-mm films with superior quality. It is capable of high daily output due to its high operating speed. Film motion compares very favorably with that of high-quality 35-mm studio-type recorders.[4] Color-corrected optics and coated lenses provide excellent image definition and in conjunction with a 120-volt, 100-watt exposure lamp make possible the exposure of Kodachrome, the slowest film likely to be used in the printer.

Acknowledgment

Grateful acknowledgment is tendered to Messrs. C. E. Hittle, L. T. Sachtleben, A. W. Freeman, and George Worrall whose efforts contributed to the design and construction of this printer.

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Films for Television*

By JERRY FAIRBANKS

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Summary—Film will be the backbone of television programming, requiring the motion picture industry to prepare pictures for this new medium. When television becomes as advanced as radio is today, video stations will devote more than 50 per cent of their program time to film because film is the only proved method by which a show can be planned, rehearsed, staged, edited, previewed, and telecast with professional perfection. Film photographed for theatrical release is not satisfactory for television. New lighting techniques must be used, long shots avoided, and television's small gray screen kept in mind during production if quality transmission is to be obtained.

With twenty-seven stations† on the air in May, 1948; with construction permits for another 66 issued; with more than 229 applications (146 of which are in hearing) now pending before the Federal Communications Commission; and with these figures climbing rapidly weekly—it is apparent that television is no longer just around the corner.

With the National Broadcasting Company planning to have 32 stations and affiliates on the air by December; with other networks now lining up stations across the nation; with the sale of sets expected to reach the 700,000 mark this year; and with the number of stations predicted to number 65 in 42 cities by the end of the year, 1000 by 1953—it is obvious that television is here to stay—and destined to become one of the nation's major industries.

It is equally obvious that film will be one of the main sources of video programming and that a tremendous new motion picture industry to supply this entertainment is certain to develop.

When television is as advanced as radio today, video stations will devote more than 50 per cent of their program time to motion pictures because film is the only proved method by which a show can be planned, rehearsed, staged, edited, and previewed and telecast with professional perfection.

* Presented May 21, 1948, at the SMPE Convention in Santa Monica.

†Note: As of October 14, 1948, there were 40 stations on the air, 83 additional construction permits, and 311 applications (186 in hearing).

As you are well aware, film eliminates the "human errors" which constantly threaten "live" productions. A mistake is easily edited on film; scenes done badly can be photographed again. It is the only safe method of presenting a sponsor's message. The advertiser knows his blades will not cut the shaver; his aspirins will dissolve immediately; no gadgets from his refrigerator will come loose and clatter to the floor.

All of our tricks of the trade—process shots, miniatures, slow and accelerated motion, animation, optical tricks—are either difficult or impossible to do in "live" telecasts. But they can be accomplished easily on film and add tremendous production value to any program. Exterior scenes, always of vital importance whether for westerns, dramas, or comedies, are extremely difficult to do "live," especially if interspersed with interiors. Film, however, makes possible the use of as many exterior scenes as are desired, adding life and realism to all programs.

Film is the only method by which unlimited action can be obtained. A television program using "live" talent has the same limitations as a stage production. All action at any given time is on a single set and because the action is continuous, the players are held to a single costume. With film there are no intermissions, locale is not restricted, and as many sets and costumes as needed can be used. Films free the writer, the director, and the producer from the shackles of the "live" stage.

Film overcomes the present-day broadcast problems of time. Sponsors using film will be able to book shows at whatever hour they wish and at whatever stations they desire. It is the most practical way for a sponsor to achieve immediately a national network; it will be especially important in tying together small and remotely situated stations during the early stages of television.

Film photographed for theatrical release, however, is not, and never will be, satisfactory for television. Many stations now are telecasting old pictures because of the scarcity of program material. Once films shot especially for television are shown, however, the telecasting of these old pictures will stop because of their poor reproduction quality. In televising theatrical pictures, deep-shadow effects lose their effectiveness and sometimes turn white on video receivers. Long shots blur and it is difficult to recognize players. Television film should and must be shot expressly for telecasting. New lighting techniques must be used, long shots avoided and television's small screen and limited gray scale kept in mind during production if quality transmission is to be obtained.

In preparing our "Public Prosecutor" and other television series for NBC we are using new techniques developed during nearly three years of research. This series, the first to be filmed especially for video, is being photographed in a very high key with back lighting emphasized. We are using much more camera movement than we would use in theatrical filming because of the close grouping of players. This camera movement, of course, gives the viewer the feeling he is seeing more action than actually was photographed.

Close grouping of actors is a must because of the smallness of video screens. If large, sharp images and facial reactions are to be clearly received on video sets, players must remain closely grouped. Half figures are the rule, not the exception. Pan and dolly shots should be emphasized and there are many more, and larger, close-ups than would be used in preparing film for theatrical distribution.

In filming for television, the camera must be carefully centered on the players and action because of the curvature of the television receiving tube. Any action on the edge of the picture is likely to be distorted because of this curve. Extreme blacks and whites should be avoided because they will not televise satisfactorily. Rapid pan shots will blur and large sharp lettering should be used in all titles.

Even the technique for sound recording is different. In theatrical pictures the voice is recorded "big" to go with the "large" picture being projected on the theater screen. For television, the sound should be "small" for the small receiving screen. Sound for regular pictures is designed for large auditoriums. Sound for television, like radio, should be recorded for hearing in an average living room.

Sets for the series we are filming for NBC are constructed smaller than the sets we build for theatrical pictures. This is being done so that a larger section of the background is visible to the viewer, thus creating more atmosphere and more quickly establishing a locale. If larger sets were used, the video audience would see a smaller section of the background because filming for television necessitates the camera's being closer to players and sets.

In an effort to provide television films with the same intimacy of radio, we have borrowed the technique of making the camera a person. The camera is "you," the television audience. In brief, "you" examine the clues; "you" accompany the Prosecutor as he makes his investigation; "you" are a part of the drama. Players frequently talk to "you" and "you" are given the same opportunity to solve the crime as the players in the film.

All timing is faster for video film. The theatrical film is designed for an audience of hundreds. The television picture should be made for an audience of five, five people at home, with all the distractions of home. Scripts should be prepared in such a way so that the viewer can follow the plot by listening, and not be required to remain glued to the set at all times to follow the action. On the other hand, the dialog should not explain every happening. In short, television-film writing should be a careful blending of radio and motion picture scripting.

The acting technique for television motion pictures is a combination of stage and screen. Long shots for television require the cast to play scenes somewhat "broader" than would be necessary for theatrical film. The reason is obvious. Facial expressions are lost in longer shots because of the small video screen. In close-ups, however, the technique is the same as for regular motion pictures.

It is our belief that television film also will differ from theatrical pictures in format and running time. Video executives now believe that the basic time periods of television will be ten and twenty minutes rather than the fifteen- and thirty-minute programs of radio. This is understandable because on television so much more can be told and shown in the same period of time. As a result, our programs are scheduled for ten- and twenty-minute times. The "Public Prosecutor" series runs twenty minutes including the sponsor's message. An "open-end" technique is being used, allowing space for the advertisement at the beginning and at the end of programs. Shows of the series are designed to play individually or serially and each program is a complete show.

Television will create thousands of new positions and opportunities in the motion picture field. It will be responsible for the development of a tremendous new film industry, an industry devoted to the making of quality entertainment especially for television.

How large will this industry be? Only time will tell. But if television requires films for fifty per cent of its programming, as we believe, it will eventually total a need for more than 300 hours of film a week. This figure, when compared to the present Hollywood output totals a tremendous new prosperity for all motion picture employees.

It should be remembered, however, that there will be no "box office" for television films. Motion picture standards of this new film industry must be, and will be, scaled down to junior size. The bill for these films will be footed by the sponsor and, obviously, no sponsor ever will be able to afford two million dollars for a program. The extravaganza movie, the two- or four-million-dollar showcase picture, never will have a place in video.

Television film will be a new and completely separate industry from the present motion picture industry. Lower wage scales throughout all crafts will be necessary to get the industry rolling. Although these scales will be lower, the total annual earned income of employees will be as large or larger because the men will be working twelve months a year, not as they now get calls from producers, on a picture-to-picture basis.

Footage cost of video films must be lowered from current "theatrical" picture footage costs if this new industry, this new prosperity for movie workers, is to get under way properly. Heavy labor demands at the present time will greatly endanger the development of video films.

Will television, and this new video film industry, be harmful to the present motion picture industry? Obviously it is far too early to say for certain. Most television executives and many film producers, however, do not think that it will hurt box-office returns. There are many of us, on the contrary, who believe that television will provide exhibitors with a greater drawing card, with larger returns.

Television, for one thing, provides a means of publicizing motion picture coming attractions in the home. Most exhibitors will agree that the trailer is one of the most important means of advertising new products. Thanks to video, the exhibitor now can show a sample of his wares to thousands of potential theater goers, thousands who do not now go to shows regularly.

It has been estimated that a top-quality picture only attracts an aggregate audience of 25 million admissions. Television, if it follows the development of radio, as is now believed, will eventually be seen by more than 90 per cent of the population of the nation. In short, exhibitors will enter 37 million homes with their trailers and will have the opportunity of attracting roughly 50 million more ticket buyers to their box offices.

There also are many of us who see the day when the theater goer will be able to see a television newsreel of the day's events. And we think that it will not be too long before the regular feature is halted and a special telecast is shown audiences of the winning run of the Rose Bowl game or the World Series.

Television will enhance theater programs, provide a greater drawing card, and prove a greater incentive to go to a show.

Film, for theater and for television, has a very bright future.

Sensitometric Aspect of Television Monitor-Tube Photography*

By FRED G. ALBIN

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Summary—The performances of the iconoscope and orthicon pickup tubes and kinescope monitor tubes constituting a television system are considered in regard to the response versus level characteristics. A nonlinear electrical network is advocated for combination with the iconoscope to equalize the gamma variations to a constant gamma approximately complementary with the monitor-tube gamma. Another nonlinear electrical network is advocated for combination with the orthicon to reduce the gamma of this camera to the same gamma as the corrected iconoscope camera.

A direct positive photographic technique is described using a negative monitor picture obtained by electrical phase reversal, and the toe region of the positive film characteristic. A general mathematical expression for the shape of the film toe as a function of the gammas of the television camera and monitor as required for linear over-all performance is derived.

The merits of such a photographic technique are economy, simplicity, rapidity of processing, and greater average screen brightness.

Introduction

Photography from a cathode-ray tube onto motion picture film of television pictures which were primarily intended for direct viewing on a home receiver is an increasingly popular procedure. The television broadcast studios and stations require photographs of their programs as a record of past shows and for use by their own or other stations for repeated or delayed broadcasts. Also, theaters require photographs of televised show material on standard motion picture film which may be subsequently projected before their patrons with standard film projection equipment.

I. Television System Characteristics

In order to incorporate a television system into an over-all reproducing system involving photography, a knowledge of the performance characteristics of the television system as well as the photography is required. The sensitometric method of measuring performance lends itself well to television as it does to photographic film.

In photography, the mensuration of the response characteristics

*Presented May 21, 1948, at the SMPE Convention in Santa Monica.

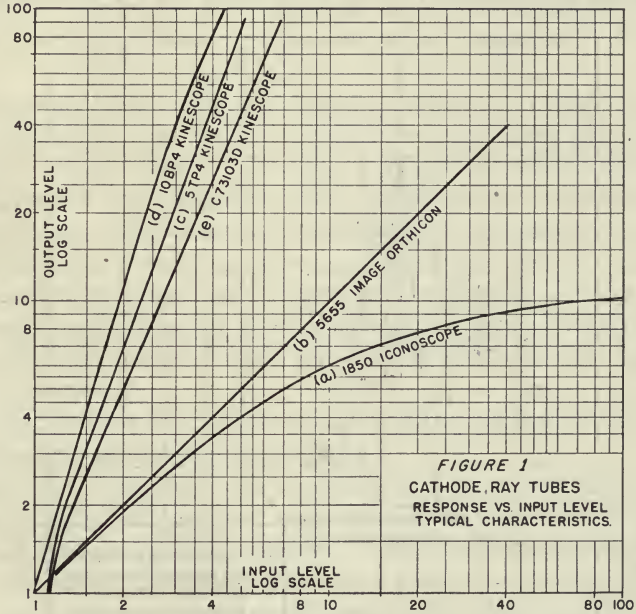
makes use of the *H*-and-*D* curve, which is a plot of log-exposure increments as abscissas against the negative log transmission increments or density increments as ordinates. Similarly, a measure of the over-all photographic system involving a negative and positive photograph is a "print-through" *H*-and-*D* curve, which is a plot of log negative exposure increments against the resulting log positive transmission increments. The slope of the straight portion of either of these curves is a measure of contrast and is the popularly known term "gamma." This concept may be expanded to represent the slope at any point on the curve and identified by the term "instantaneous gamma."

It can be proved by a rather simple mathematical treatment and illustrated graphically by means of the "tone-reproduction quadrant diagram" of Jones[1] and Mees[2] that the gamma of the over-all photographic system is equal to the product of the gammas of the negative and positive which constitute the over-all system. Jones and Mees go further to show that faithful reproduction of the original is achieved only when the over-all gamma is unity, except that in practice an adjustment is made in this value to an over-all gamma of approximately 1.5, to allow for unaccounted-for factors or to satisfy subjective requirements.

In the photographic art the exposures are confined largely to the straight-line portions of the *H*-and-*D* curve where the gamma is a constant single value. Where the mean exposure of the negative is determined by the mean illumination of the subject and this together with the printer light determines the mean exposure of the positive, a certain latitude of variation of these mean values is allowed without affecting the gamma or linearity of the over-all performance. This latitude is a virtue of the constant gamma of the negative and positive films.

A corollary to the photographic theorem, applicable to a television system might be stated as follows: "A system containing two or more nonlinear elements is linear over-all if the over-all product of gammas at corresponding points on the response curves of all nonlinear elements is unity." This general statement covers a photographic system which is usually linear over-all and is comprised of a negative and positive, both nonlinear. It covers an ideal television system, and a system combining television with film which might involve four or more nonlinear elements.

The present-day television system with which we are dealing involves (1) a pickup tube, (2) an amplifier and transmission system, and (3) a reproducer tube. For the purpose of this paper, the second item may be considered as linear. The response characteristics of the pickup tubes and the reproducer tubes taken from published data[3] are illustrated by Fig. 1. Here, the abscissa is a log scale of relative input levels and the ordinate is a log scale of relative output levels. For the pickup tubes (*a*) and (*b*), the input is instantaneous light



flux and the output is electrical volts in response thereto. For the reproducer tubes (*c*), (*d*), and (*e*), the input is instantaneous electrical volts and the output is light flux in response thereto. Plots (*b*), (*c*), (*d*), and (*e*) being straight lines represent constant gammas. Plot (*b*), having unity slope or gamma with a positive sign, represents a linear function. But (*a*) is a curve having variable gamma ranging from 1 at low levels to $^1/_8$ at high levels. This variable gamma must be reckoned with because the over-all system gamma is consequently variable as a function of the reference level of illumination of the scene being reproduced by the camera containing this tube.

In Fig. 1, (*d*) is a popular direct-viewing type of kinescope used in home television receivers. It exhibits a gamma in excess of 3. Fig. 1 (*c*) represents a projection-type kinescope currently used in larger home receivers, with a gamma of approximately 2.75. Fig. 1 (*e*) represents a kinescope similar to (*c*), but provided with a flat face and a blue-light phosphor. Fig. 2 (*a*) illustrates the spectral characteristics of this kinescope and (*b*) the spectral sensitivity of nonsensitized monochromatic photographic film of the release-print type. The effect of this narrow spectrum of blue light in photography is to lower[4] the gamma approximately 15 per cent below the white-light charac-

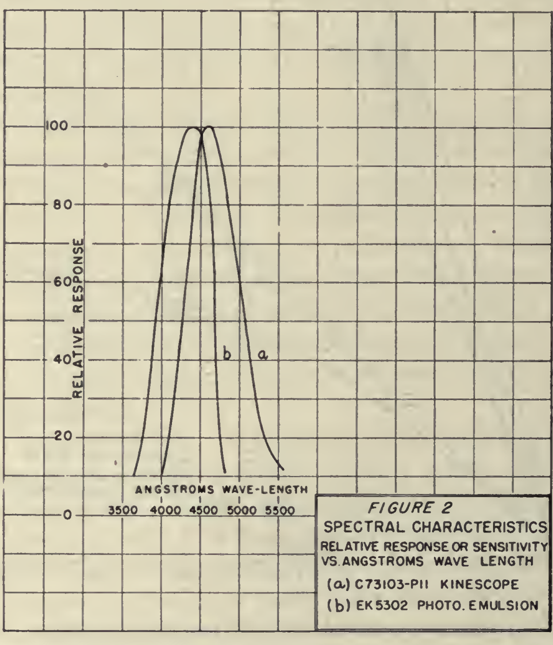


FIGURE 2
SPECTRAL CHARACTERISTICS
RELATIVE RESPONSE OR SENSITIVITY VS. ANGSTROMS WAVE LENGTH
(a) C73103-P11 KINESCOPE
(b) EK5302 PHOTO. EMULSION

teristic. Hence the gamma of 1 (*e*) used for photographic exposures is illustrated as being 2.35, lower than the otherwise similar white-light tube 1 (*c*).

If a television system were to reproduce faithfully the scenes in front of the camera, the over-all gamma should be constant at unity, or to be in accordance with professional photographic practice, about 1.5. Accepting a predominating gamma for reproducers at a constant of approximately 3, the camera gamma should be a constant at 0.5. The over-all gammas resulting would be approximately 1.7 for the direct-viewing home receiver and 1.18 for the photographic exposures. Thus 0.5 gamma for the camera appears to be a good compromise.

The iconoscope pickup tube tends toward a low gamma characteristic and the kinescope reproducing tube tends toward a high gamma characteristic.[5] Thus, when used in one system, these two tubes are complementary, but only connotatively speaking because of the manner and extent to which the gamma of the iconoscope varies each way from an optimum value of 0.5. The present effect of the combination of iconoscope and kinescope is excessive gamma in the shadows or lowly lighted scenes, and deficient gamma in the high lights.

To complicate television reproduction further, it is present practice to use iconoscope cameras and orthicon cameras interchangeably in the same televised show. The picture quality from such dissimilar cameras cannot possibly match, and if one is considered proper with a certain receiver characteristic or adjustment, the other cannot be with the same receiver characteristic or adjustment. Thus, to correct the over-all system gamma by lowering the receiver gamma is not only uneconomical because of the large number of receivers involved, but would result in inconsistent performance when different types of cameras are used.

This leads to the following required system modifications in order to obtain consistently good performance:

Correct the characteristic of each camera so that the gamma function has a single value over the range used. This value should be complemental to the reproducer gamma. There are several alternatives:

(a) Adjust all cameras (transmitting system) to some arbitrary value, say $\gamma_c = 1$. Adjust all receivers to the complemental value, $\gamma_m = 1$. This becomes uneconomical when a large number of receivers is involved.

(b) Accept a value of receiver gamma at $\gamma_m = 3$, thus avoiding changes in a large number of receivers. Adjust transmitter gamma to a compromise value $\gamma_c = {}^1/_2$.

Alternative (b) is advocated because besides being more economical, it improves the signal-to-noise ratio of transmission, since for a given high-level limit of video signal, the low levels will not drop as low with a low gamma characteristic of transmitted signal. Keeping the low levels up thereby keeps them higher relative to the noise and maintains good signal-to-noise ratios during transmission.

II. Gamma-Control Networks

Electrical networks can be built to exhibit a nonlinear level response characteristic as required, within limits.

Nonlinear networks must contain one or more nonlinear elements. In all cases, if a response curve obtained by plotting output levels as ordinates and input levels as abscissas is curved, the network is nonlinear. A concave upward curve denotes high gamma and a concave downward curve denotes low gamma. These data for output and input levels may be plotted on logarithmic scales in which case the slope of the curve at any point is the gamma of the network at that point. For a circuit element, a plot of applied potentials as abscissas and the resulting currents as ordinates will be straight for a linear element, indicating constant conductance, and curved for a nonlinear element indicating conductance variable as a function of voltage or current. A concave upward curve designates a high gamma element and a concave downward curve a low gamma element.

A high gamma element in a series arm of an electrical network imparts a high gamma characteristic to the network. Similarly a low gamma element imparts a low gamma. Conversely, a high gamma element in a shunt arm imparts a low gamma characteristic to the network and, similarly used, a low gamma element imparts a high gamma characteristic.

In practice, a single nonlinear circuit element exhibits a single value of gamma other than unity for only a relatively narrow range of level. Outside of the range of constant gamma, the gamma may gradually change toward unity gamma, or it may suddenly become discontinuous and become zero or infinite, depending upon the nature of the nonlinear element employed. To achieve a wide range of constant gamma other than unity, the elements may be arranged in stages, the stages operated in a cascade order of levels so that over the level range for which the network is designed, one or more stages operate, each stage within its narrow level range of gamma control.

The instantaneous gamma of a network is the product of the instantaneous gammas of the individual stages. To achieve a network gamma control greater than that of a single stage, two or more stages may be arranged to control the gamma simultaneously by overlapping the level ranges over which the individual stages are operative.

Linear circuit elements, when associated with nonlinear elements, tend to veer the gamma toward unity, except when a bridge circuit is formed. In a bridge circuit, the network gamma may exceed the element gamma, especially near the level when a null in output level occurs.

Such a network has a loss, the maximum value of which is a function of the amount of gamma correction and the latitude L_2/L_1 of signal range at the input or where the gamma is unity. This decibel loss is expressed by the product $(\gamma - 1)$ times the decibel signal range and must be compensated by equivalent amplifier gain.

Some nonlinear circuit elements are:

(1) High Gamma Devices
- (a) Vacuum-tube diode 3/2-power-law characteristic
- (b) Amplifier-tube grid-toe characteristic
- (c) Copper-oxide, selenium, germanium, or other contact devices
- (d) Silicon carbide, aluminum silicate, etc.
- (e) Gas-discharge tubes or ionization devices
- (f) Carbon-arc or thermal-resistance device
- (g) Discontinuously functioning device such as a rectifier
- (h) Any saturable insulation

(2) Low Gamma Devices
- (a) Vacuum-tube shoulder characteristic
- (b) Metallic thermal-resistance device
- (c) Any saturable conductance

For the use of a nonlinear network referred to in this paper, the action must be practically instantaneous to act well within the period of the highest video-frequency cycle. For this reason the susceptance must be low relative to the conductance. This requirement rules out many of the items in the above list such as the thermal and gas devices having inertia.

On the other hand, reactive components can be employed in conjunction with nonlinear components to produce a desired new parameter of gamma control which is a function of frequency. By this means the gamma for high frequencies may be made greater than the gamma for low frequencies, thus improving detail contrast which tends to be impaired by halation and aberrations in the optical systems, and by other high-frequency losses.

Fig. 3 (*a*) illustrates in symbolic form a popular form of nonlinear network which provides flexibility in the shape of the characteristic response curve. It employs vacuum-tube diode or contact rectifier discontinuously functioning devices X_1, X_2, X_3, primarily as switches or valves to open or close the respective circuits in the ladder-type attenuator in response to changes of electrical level in the circuit. The threshold controls E_1, E_2, E_3, for the respective circuits are adjusted to cause these circuits to close in succession as the input voltage of the network is increased. The input and output voltages, E_A and E_B, respectively, are adjusted simultaneously to establish the threshold of the network.

Fig. 3 (*b*) is the idealized resulting response curve attainable only with an infinite number of stages. The sharp discontinuities, which otherwise would be evident as each successive stage becomes opera-

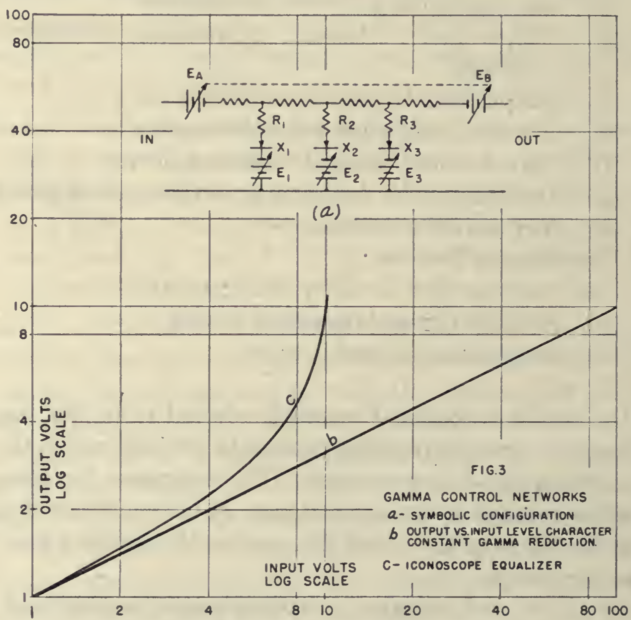


FIG. 3
GAMMA CONTROL NETWORKS
a- SYMBOLIC CONFIGURATION
b OUTPUT VS. INPUT LEVEL CHARACTER CONSTANT GAMMA REDUCTION.
C- ICONOSCOPE EQUALIZER

tive, are smoothed out by the toe in the characteristic curves of the nonlinear elements X_1, X_2, X_3, etc. Curve 3 (*b*) is the characteristic of an electrical network which is advocated to be combined with the orthicon or other linear pickup tube to become an integral part of the camera. The over-all gamma of the camera thereby is constant with a value of $^1/_2$ or so as desired to fit into the system. Curve 3 (*b*) thus is characteristic of the corrected camera also.

Curve 3 (*c*) is the characteristic of an electrical network which is advocated to be combined with the iconoscope pickup tube to become an integral part of the camera. The configuration of Fig. 3 (*a*) might be used with different constants and threshold adjustments. The over-all gamma of the camera is thereby made constant with a value the same as with all other cameras of the same system, as illustrated by 3 (*b*). In this case, since the curvature of the iconoscope gamma is compensated by the curvature of the network gamma, it is imperative that the level references of the iconoscope correspond with the level reference of the network such that the two characteristic curves are complementary throughout. Hence, these level references must be maintained exactly in the system setup and operation. It is largely for this reason that the network should be closely and inseparably associated with the iconoscope in the camera. The camera having constant gamma then enjoys independence of reference level relative to other system components.

III. PHOTOGRAPHY

The television system, corrected as described in the foregoing section and operating in the normal manner, will produce a positive picture which is a faithful reproduction of the original scene within the limits of capability of the system. This picture may then be photographed by a photographic technique which in itself is linear, thereby reproducing the television picture faithfully.

The conventional negative-positive film technique, for example, is capable of excellent results and preferred if several positives are required. It requires a separate negative film and processing, printing to one or more positive films, and processing of the positive films.

If only one film is required, the commonly used chemical reversal technique is more economical. The reversal and redeveloping technique is more involved than the simple processing of a separate negative.

Electrical Reversal

For producing films of televised scenes for theater use where only one film is required, it is feasible and more economical to reverse the television picture from a positive to a negative by merely reversing the phase of the electrical circuit preceding the picture-reproducing cathode-ray tube and employing a direct positive type of photography. Only one film is required, and the processing facilities and time are reduced to a minimum, resolved to the minimum basic steps, developing, fixing, washing, drying.

But the character of a negative television picture obtained by electrical phase reversal is not the same as the character of a negative photograph of a positive subject in respect to exposing the photographic positive. If we assume that the television-system characteristics are predetermined by the direct-viewing conditions already outlined above and the negative picture obtained by phase reversal, we can then determine the response characteristics of a positive photographic film necessary to reproduce the televised picture faithfully.

As will be seen from the description which follows, the over-all television and photographic system under consideration involves the three nonlinear elements or steps, the television camera, television monitor, and the photographic film. The empirical characteristics of the uncorrected camera and monitor can be expressed mathematically only by higher-order terms which cause the analysis on this basis to become cumbersome. But with cameras which are corrected to a constant gamma approximately complemental to the inherent constant gamma of the reproducers or monitors, the mathematical analysis is greatly simplified.

For the purpose of this paper, each of the three steps is represented by a hypothetical case and can be expressed in simple mathematical terms. The three hypothetical conditions are chosen to be complemental to an over-all linear system condition.

In addition, each hypothetical condition is allowed to vary independently both ways from the initially chosen value, whence the end result in the over-all system and its departure from the linear condition indicates the effect of varying the characteristic of each step from the initially chosen value. Thus, the effects of prevailing empirical conditions on the over-all system performance can be determined by inspection.

A graphical representation, Fig. 4, is used here after the manner of the tone-reproduction quadrant diagram of Jones, except that six quadrants are required to represent this over-all system. Fig. 4 (*f*) illustrates the relation of the output to the input, and thus the over-all response characteristic of the system. The six sections of Fig. 4 representing the five major component steps of the over-all system plus an over-all characterization are arranged in the manner of the tone-reproduction quadrant diagram wherein the output of the first step is applied as the input to the second step and so on through all steps in sequence, finally completing a cycle by returning to the input of the first step. This procedure will be made clear by following Fig. 4 with the descriptions of the sequential steps as given below:

Fig. 4 (*a*) represents a television camera which produces an output voltage V_c in accordance with the input illumination I. This input illumination is assumed to be in direct proportion to the scene brightness. The characteristic response curve of this camera is shown as being concave downward, typifying low gamma. The general expression for this characteristic is given with the gamma factor γ_c as an exponent of I. A corrected camera is represented in this illustration with a constant value of 0.5 used for γ_c, which represents the characteristic of the pickup tube after correction with a nonlinear network as described in Section II. The output voltage becomes the input voltage for the next step.

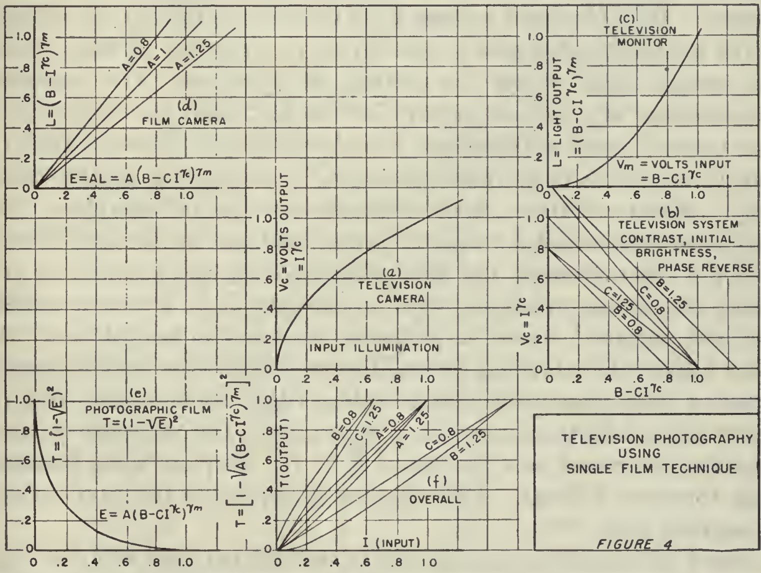


Fig. 4 (b) represents the television equipment and electrical transmission system involving variable values of contrast C and initial brightness B. It also involves phase reversal wherein the output voltage varies inversely with the input voltage. The initial brightness B is a constant term added to the signal voltage (negative) and is the voltage producing an initial monitor-tube brightness when the camera output voltage is absent. The contrast factor C is a coefficient multiplying the input voltage, or, in other words, is a control of the electrical signal gain of the system. The negative sign indicates phase reversal. The output voltage of this system involving the initial brightness voltage, the contrast factor, and the signal voltage from the camera is expressed by $B - CI^{\gamma_c}$. The nominal values for B and C are both unity which condition is illustrated by the central plot. Plots are also given for $B = 0.8$, illustrated by the lower plot, and $B = 1.25$, illustrated by the upper plot. In these cases C is maintained at its initial value of unity. Plots are similarly given for two additional values of C in which B is maintained constant at unity. Thus the effects of independently varying B and C are illustrated. In all cases the characteristic curves are straight lines. Therefore, this step is linear except for reversing the phase.

Item 4 (*c*) represents the cathode-ray picture-reproducing tube or monitor. Here the input voltage V_m is the same as the output voltage of the preceding step and is plotted as the abscissa of this curve. The output light values are plotted as ordinates. The response characteristic of a cathode-ray tube of this sort when plotted is a concave upward curve as illustrated and therefore is nonlinear. The exponent γ_m, which is the gamma factor, in this case is greater than unity. A value of 2 for γ_m is the nominal value used in these plots. In the plot of the over-all, a value of 3 is also used and the results plotted.

Step 4 (*d*) represents the film camera having the function of exposing the photographic film with an exposure E in accordance with the light output L from the preceding step and in accordance with other factors A embracing several factors such as the optical speed, exposure time, magnitude, actinic value of the exposure light, or any factor which affects exposure as a multiplier. The exposure is consequently expressed as a product of $A \times L$. All plots being straight lines, this step is linear. This exposure is applied as the input to the subsequent step.

Step 4 (*e*) represents the exposure of the photographic film and this figure illustrates the relationship of the exposure of this film and the consequent transmission after processing. The hypothetical relationship chosen here is the required characteristic for producing over-all linear performance as will be illustrated in the next step. The relationship of exposure and transmission of this hypothetical film for the ideal case of linear over-all performance is given by the general expression as follows:

$$T^{\gamma_c} = \frac{1}{C}\left[B - \left(\frac{E}{A}\right)^{1/\gamma_m}\right].$$

When each constant A, B, and C equals unity,

$$T^{\gamma_c} = 1 - E^{1/\gamma_m}.$$

In the illustrated case, $\gamma_c = 0.5$ and $\gamma_m = 2.0$. This relation is illustrated by the parabolic curve

$$T^{1/2} = I - E^{1/2}.$$

The plot of 4 (*e*) is made with these values. This step is not only nonlinear, the gamma is not constant.

Item 4 (*f*) illustrates the over-all response characteristic of the system under all of the various conditions provided in the preceding

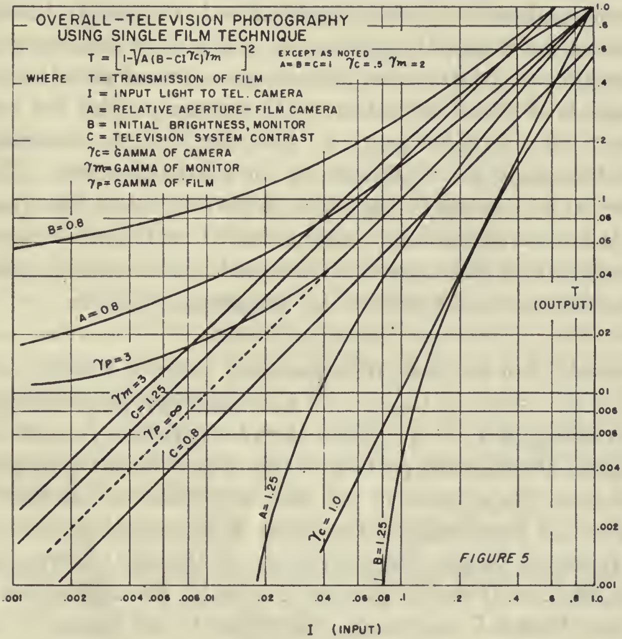


FIGURE 5

steps, and the relationship of the transmission of the film and the input illumination of the camera. It is assumed that the reproduced picture brightness is directly proportional to the transmission of the film. It is also assumed that the input illumination in the television camera is proportional to the original scene brightness. The ideal curve therefore is the centermost plot of Fig. 4 (*f*) which is a straight line. The other curves, all identified, illustrate the effects on the over-all characteristic caused by independently varying A, B, or C either way from their nominal values of unity.

In Fig. 4 (*f*) linear relationship of input and output of the over-all system is illustrated by a straight line of any slope passing through the origin. Fig. 5 is a plot of the same data used by Fig. 4 (*f*) except that logarithmic scales are used for both the abscissas and ordinates. Plotted in this manner, linearity of output versus input of the over-all system is represented by any straight line with unity slope. Here as in Fig. 4 (*f*) the effects on linearity caused by independently varying A, B, and C each way from their nominal unity values are illustrated by plots appropriately marked. Several additional plots are also given in Fig. 5 and will be discussed later.

The characteristic of photographic film is commonly illustrated in the form of an H-and-D curve which is a plot of density increments as a function of log-exposure increments. The slope of the straight-line portion of the H-and-D curve is represented by the commonly used term photographic gamma. Furthermore, the straight portion has the highest slope of all parts of the H-and-D curve. The region represented by exposures less than those producing the straight-line region is known as the toe. In Fig. 6 are four H-and-D curves of the hypothetical film characteristics included in the over-all system previously described and expressed by the general relation

$$E^{1/\gamma_m} + T^{\gamma_c} = 1$$

are plotted. For all cases it is apparent that for a value of $E = 1$, $T = 0$. The slope in this region therefore approaches infinity, and equals infinity at $E = 1$. Since the photographic gamma of film is the slope of the steepest portion of the H-and-D curve, in each hypothetical case the gamma of the film according to common nomenclature would be infinity. The plots of hypothetical film shown in Fig. 6 represent largely the toe regions of H-and-D curves, and since in each case the H-and-D gamma is infinity, the differences between these four H-and-D curves are differences in the shapes of the toes.

In the ideal case which produces linear over-all performance, the gamma of the camera was arbitrarily chosen as 0.5, complementary to the gamma of 2 for the picture-reproducing tube. In present practice, orthicon cameras are frequently used without corrective networks as described in Section II for which then the gamma is practically unity. The over-all gamma of such a television system used in a normal manner for direct viewing would thus exhibit an over-all gamma of 2, which is excessive. In Fig. 5 a plot identified as $\gamma_c = 1$ is made for this condition in the subject system employing photography of a negative television picture which results in a straight line but with excessive slope or over-all gamma of 2, the same as though the system were for positive viewing.

In the hypothetical ideal case the gamma of the monitor was taken as 2. In Fig. 1 it is shown that this value may be 3 or higher. A plot for this value is given in Fig. 5 and marked $\gamma_m = 3$. It appears from a comparison of this plot with the ideal case that the departure in slope is not great except in the high-light region exceeding 50 per cent transmission. In this region the contrast would be reduced below normal. This is the opposite effect from what might have been anticipated as a result of increasing the gamma of the monitor. The paradox is attributed to the reversal of the television-monitor picture, and to the great nonlinearity of the film over the region used. If it is desired to obtain linear over-all performance with a monitor gamma of 3, this value may be applied to the general equation expressing the film characteristic to obtain the required shape of the *H*-and-*D* curve.

From an inspection of the curves of Fig. 5 it is apparent that the values of A and B have a very pronounced effect on the over-all performance of the system. It is also apparent that variations of A and B have like effects and that one can be varied to counteract the effect of the other. It is also apparent by inspection that variations of C affect the brightness but not the contrast or gamma of the over-all.

The significance of the nominal values of unity for each of these might be described as follows:

Black Level—At black level, or a condition of zero input illumination to the television camera, the following values result in the successive stages of the system (see Fig. 4):

$$I = 0,\ V_c = 0,\ CI = 0,\ L = B^{\gamma_m},\ E = AB^{\gamma_m}.$$

Under these conditions the reproduced picture should be just black. Thus

$$T = 0;\ E = 1;\ AB^{\gamma_m} = 1.$$

Thus A and B^{γ_m} are reciprocal factors. In practice, the combination of A and B should be so chosen that with no light entering the camera the exposure of the film should be adjusted to result in the film's being just black.

White—A white subject, when illuminated to a level lying within the operating range of the system, will produce an input illumination to the television camera identified as white level with an arbitrary magnitude of 1 for I and T, and the following values result in the successive stages of the system:

$$I = 1,\ V_c = 1.$$

Under these conditions the reproduced picture brightness should be maximum. Therefore

$$T = 1, E = 0, L = 0, V_m = 0, B - CI^{\gamma_c} = 0, B = CI^{\gamma_c}, B = C.$$

Thus, since B was established in its relationship with A by black-level considerations, C is subsequently set so as to make the reproduced picture brightness of white level conform with white-subject levels. In practice then, a white subject which has a brightness value which is just white, and has a brightness ratio to the picture, black subjects not exceeding the brightness range capability of the system, say 50 to 1, should be adjusted by variable C to be reproduced *just white.*

Results of Tests

Photographic tests of the inverted system were made, using the facilities and factors as listed:

Cathode-ray monitor tube....................	C73103D
Spectral emission peak........................	4600A
Potential—2nd anode........................	28,000 volts direct current
Current—2nd anode—average................	15 microamperes
Raster area..................................	15 square inches
Film camera lens aperture...................	f/2.5
Shutter open period per frame................	1/30 second
Phosphor persistence—effective (P11).........	1/2 millisecond maximum
Film..	EK 5302
Developer formula...........................	Modified D 16

In modifying the developer, the metol and bromide concentrations were increased somewhat above D 16 formula.

Fig. 6 illustrates empirical data on the toe region and a portion of the straight-line region of the H-and-D curve of the above film developed to a time-scale gamma of 3. Also, in Fig. 5 identified as $\gamma_p = 3$ is illustrated the effect on the over-all characteristic of a film with a maximum gamma of 3 in lieu of infinity as theoretically required. It is apparent that for transmission values from 3 per cent to 90 per cent corresponding to a picture brightness range of 30:1, the departure from the hypothetical is within 10 per cent of the ideal transmission at any point. This equals conventional practice in motion picture professional photography.

A further advantage in using this toe region of the positive film is that the mean transmission is approximately 50 per cent as compared with 25 per cent in professional practice, thus providing increased average screen brightness with the same light source.

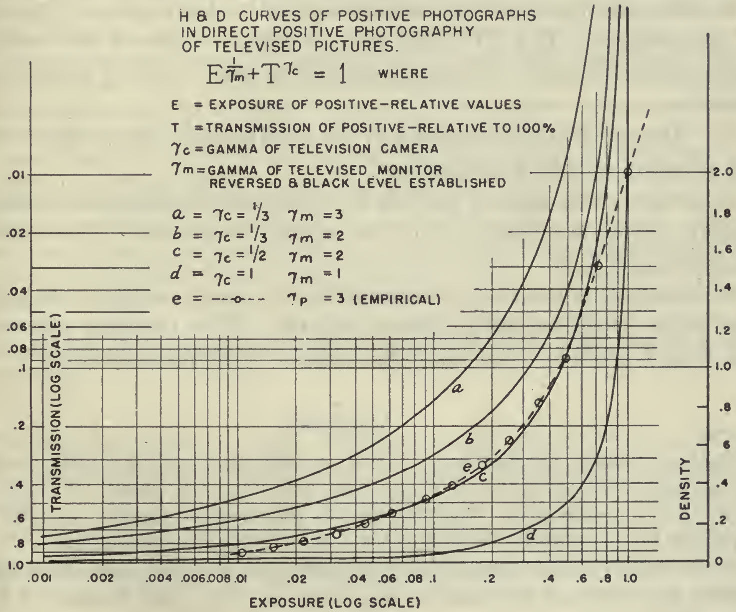
Practical Application of General Film Equation

The several factors involved in the general expression for the film characteristics are recapitulated as follows:

1. Contrasted with conventional 2-film photography, the camera gamma γ_c and the monitor gamma γ_m need not be complemental for over-all unity gamma.

2. Theoretically, any combination of γ_c and γ_m can be accommodated, resulting in over-all unity gamma. However, an *H*-and-*D*

FIGURE 6



curve approximating that of Fig. 6(*c*) can be realized practically more readily than a curve such as Fig. 6(*d*). Furthermore, to satisfy subjective requirements, the over-all gamma preferred is approximately 1.5 rather than unity.

3. γ_m value is not optional. For economic reasons where a large quantity of apparatus is involved, the actual value cannot be changed. Furthermore, the assumption of a value different from actual affects constancy of over-all gamma.

4. γ_c has a direct effect on the over-all gamma. If the actual value is used in the general film equation, the over-all gamma will be unity. An actual value higher than the value assumed for the

equation will produce a correspondingly higher over-all gamma, and higher by the same percentage.

5. The initial brightness of the monitor and the corresponding film exposure under conditions of zero scene illumination must be at the exact value which results in an over-all reproduced picture being just black.

In consequence of the above factors, the recommended procedure for obtaining an over-all characterization with constant gamma at a value of 1.5 to satisfy subjective requirements is as follows:

6. Measure by empirical means the effective photographic[6] gamma of the monitor. If a C73103D tube is used, a value of 2.35 will be sufficiently accurate. This value should be used for γ_m in the general equation.

7. Assume a camera gamma of 0.5 arbitrarily, and use this value for γ_c in the general film equation.

8. Adjust the camera gamma to an actual empirically measured gamma 50 per cent higher than the assumed value, or 0.75 to obtain an over-all of 1.5.

9. Solve the general equation with the values assigned and plot the curve with logarithmic co-ordinates. The resulting curve is the *H*-and-*D* curve describing the required film characteristic.

Appendix

(1) L. A. Jones, "On the theory of tone reproduction, with a graphic method for the solution of problems," *J. Frank. Inst.*, vol. 190, p. 39, comm. 88; 1920.

(2) C. E. Kenneth Mees, "The Theory of the Photographic Process," chapter 10.

(3) RCA Tube Handbook HB-3, vol. 1–2 Sec. 3, issue of October, 1947.

(4) J. G. Frayne and V. Pagliarulo, "The effects of ultraviolet light on variable-density recording and printing," *J. Soc. Mot. Pict. Eng.*, vol. 34, pp. 614–632; June, 1940.

(5) D. G. Fink, "Principles of Television Engineering," chapter VIII, sections 49, 53.

(6) In determining film characteristics by sensitometry, a time-scale exposure of relatively low color temperature is generally used while the actual exposures of the film by a cathode-ray tube have variable intensity of high color temperature and very short time. Thus, for film, this sensitometry should be used only as a control and not as the means of determining the exact optimum values. Also, the data given here for tube characteristics are typical and are not necessarily accurate for specific tubes, especially with newly designed tubes subject to changes and appreciable tolerances. Fortunately, the tolerance of the observers to over-all performance apparently is large, based upon the present acceptance of conditions so far from ideal.

Colorimetry in Television*

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Summary—The colorimetrically exact reproduction of color in simultaneous television is now possible, through the congruence of the camera spectral sensitivities to definite characteristics specified by colorimetry and through the combination of the camera signals in both positive and negative amounts by suitable circuits and amplifiers. The negative sensitivities of the photopickups formerly required for certain spectral wavelength intervals are obviated by these signal-mixing circuits, and simultaneous color television, both as to color range and accuracy of reproduction, is capable of the finest color reproduction available anywhere. The mixing circuits perform a function resembling that known in color photography as masking, but whereas the latter is always approximate and often a hit-or-miss procedure, the television system can approach perfection without undue complication. The basic concepts and relations of trichromatic colorimetry are here developed. Many of these relationships are of immediate importance in color reproduction and are stated explicitly, with the aid of a concise notation. In addition, certain rather philosophic aspects of television as a means for the communication of sense perception are discussed and a plea is made for the extension and compilation for television purposes of knowledge about the properties of the eye.

Color television, when developed, will bring to the public a new service and a new field of entertainment and artistic expression. For the communications engineer it will multiply the problems of the kind with which he is already familiar. It will further make necessary his acquaintance with an entirely different subject hitherto never regarded as belonging in communications. This subject is colorimetry. It is outlined here with particular regard for the problems and point of view of the color-television engineer.

The General Problem of Color Television

The object of a television communications system is to provide to the receiving person the same sense perceptions he would experience were he present and observing the scene transmitted. The attainment of this ultimate ideal is bounded by considerations of economy and by the limitations of technology. Consequently a great variety

* The original and longer version of this paper appeared in the *RCA Review*, volume 8, number 3, pages 427–459; September, 1947.

of sense perceptions regarded of secondary importance have been omitted entirely from modern television systems. These omissions have to do largely with the olfactory and tactile senses and with the perceptions of mechanical motion and vibration. However, a great deal of information is also deleted pertaining to the two major senses, sight and hearing, with which television systems are ordinarily concerned, namely, the absolute levels of the sound volume and of the scene brightness, the absolute scale of size (with the viewing angle reduced to that of a small screen), and practically all perception of perspective. In the last category are included not only binaural and binocular perspective, but the sound and sight perspectives obtained through head motion and the visual perceptions obtained through the natural process of focus accommodation of the eye and through its limited depth of focus. Present television systems attempt merely to transmit a single sound signal and the video signal associated with a simple flat image of the scene.

While the visual perceptions produced by such a flat image are recreated by the television receiver through the generation of appropriate physical stimuli, it is of course unnecessary for these stimuli to be physically identical with those of the original subject image. The eye is notoriously unable to distinguish fine differences of one sort or another in light images of this type, and in the case of color vision we shall find that lights of certain very different spectral distributions have identical appearances. One might suppose that the quality of the reproduction would depend on how close its physical properties approached those of the original. However, effort expended in a precision of reproduction finer than the eye's discriminating ability certainly is wasted, and the exact or closely approximate duplication of the physical properties of the original light pattern is quite beyond the technical capacity of any television system. The information inherent in the dependence of intensity of light on wavelength, position in the image, and time, which constitutes an adequate physical characterization of the stimuli giving rise to the visual perceptions, fundamentally exceeds by far the information-transmitting capacity of a communications channel, even disregarding the usual limitations of bandwidth and reproducing equipment.

Every television system necessarily must effect a tremendous reduction in the information to be communicated. This is done by judicious selection, from a comparatively much smaller number of sets of physical stimuli which can be generated in the reproduction, of that one which produces the same set of visual perceptions as is produced by the original image of the television scene. A system, successful in such endeavor for all subjects it is called upon to televise, certainly may be regarded as perfectly performing its function. Thus it is possible, through the limited resolving powers of the visual process, for conventional black-and-white television to create the appearance of a continuously luminous and continuously moving image with a single spot of light. This is moved to form a raster simulating a two-dimensional still image and then moved again to present successive images portraying motion. It will be seen that in a similar manner, by the selection of combinations of three stimuli alone, it is possible for a color-television system to reproduce accurately the visual perceptions produced by original subject images through very many different spectral distributions.

The television system must select from a relatively limited number of possible sets of physical stimuli corresponding, in their consequent visual perceptions, to a great number of possible sets of stimuli presented in the original subject. The correctness of such selection depends on whether the original and the reproduction are not noticeably different. Hence all engineering judgment in the design and development of new apparatus, and in the comparison and preference for one system of transmission and reproduction over another, hinges critically upon the characteristics of the visual process. It is necessary to know just what properties of the reproduction will be perceived by the eye, in what ways the consequent visual perceptions will be the same for the reproduction as for the original image, in what ways differences will be perceived and whether these differences can be ignored or tolerated, and in what ways marked discrepancies will appear and whether objectionable and disagreeable effects will take place. For example, the occurrences of flicker and color breakup in sequential color television were important reasons for its being deferred in favor of simultaneous systems.

With the correlationships of physical stimuli which give rise to the same sensation playing so vital a part in the television problem, and governing choices between technically different modes of transmission and presentation, there is clearly a very great need for a thorough exploration and tabulation of the visual properties of the eye. The various properties, resolving powers, and acuities, and the manner in which they change with time and differ from one person to another, should be stated in a systematic way such that they can be connected immediately with the technical television problems of spot size, number of lines, field frequency, bandwidth, and so on. Of course there have been many reliable investigations of the phenomena of vision, and a large amount of literature is available on the subject, but the objectives in most of these investigations were sufficiently diverse and removed from the field of communications that the data are not suitable for direct application in that field. Certainly there has never been an adequate compilation and codification of those data for television purposes.

The principal categories of visual properties, stated with reference to a two-dimensional chromatic image, are accounted for according to the situation. Where there are no time variations and the space variations are independent of wavelength the properties cover monochrome visual acuity and resolving power. Where there are neither temporal variations nor significant spatial variations the properties include most of colorimetry. Where there are spatial variations but no temporal variations they include color resolution and acuity. Where there are time variations but no space variations they include flicker, sequential color mixing, and after-image effects. In addition, there are important cross influences as of one type of variation on the perception of another and as of the interrelation of different parts of the same class of perceptions. Thus, for example, what the eye sees in one part of the field of view depends to some extent on what is present in other parts. Furthermore, the characteristics of different people's eyes are different, and beyond this the characteristics of an individual eye change from time to time, under different nonvisual stimuli, and after different previous experience. A knowledge of the magnitude and frequency of such deviations in properties is also valuable for proper engineering judgments in television.

COLORIMETRY

It has been found quite generally that a substantial portion of the properties of most people's eyes which have to do with the perception of color can be tabulated and codified under the comparatively simple system of data known as trichromatic colorimetry. These data apply within the broad range of light intensities to which the eye ordinarily is subjected and except the two extremes of nearly complete darkness and of viewing highly incandescent bodies. Also they refer to foveal vision, which is of chief interest in television (except perhaps for the case of flicker perception), since presumably the television screen is the center of interest in the field of view and its image falls on that central part of the eye's retina called the fovea.

With the exception of color blindness, which usually constitutes a marked departure from the norm, the dispersion of visual properties in different persons and at different times is sufficiently small that the norm, expressed as the characteristics of a standard observer, is satisfactorily representative of the majority group. Thus in the discussion which follows, reference to the characteristics of the standard observer may just as well be interpreted as reference to the characteristics of any ordinary individual, excepting for small quantitative differences.

Largely as a consequence of the tristimulus system of codification found possible in colorimetry, there has been developed the theory of three-color vision in which the eye is thought to contain receptors possessing three different spectral sensitivities. These three receptor types are all associated with the cones in the retina, for it is the cones which are believed responsible for color vision. The rods, also light-sensitive elements in the retina, are responsible primarily for scotopic or darkness vision, and in any case are believed not present in the foveal part of the retina. Colorimetry itself, however, can be understood entirely as a phenomenological description of the color properties of the eye, and is in no way dependent on any explicit theory of vision. The present discussion is from this phenomenological standpoint.

Colorimetry is concerned with those of the visual properties directly associated with the wavelength dependence of the intensity of the light being seen. That is, it deals purely with color perception, and, strictly speaking, is confined further to the correlation and codification of color matches and color mixtures. It is concerned with perceptions of solely spectral origin. However, all of the properties of the eye are affected in more or less degree by the intensity dependence on wavelength, and conversely the spatial and temporal dependence of the intensity also have their effects on color perception. For example, visual acuity depends upon the colors and color relationships in the field of view, while in the opposite sense, the color perception of one region of the field of view may be altered by the properties of the immediately adjacent areas. Colorimetry seeks to avoid complications of this nature. In the collection of data, as in its principal instrument which is the colorimeter, time variations and spatial inhomogeneities are carefully suppressed, with perhaps the exception of one bifurcation of the field of view to enable color matches to be made.

The colorimeter consists essentially of optical means for presenting to the eye two immediately adjacent, uniformly luminous fields, usually two adjacent semicircular disks, and means for quantitatively altering the light intensities and combinations in each of the two fields separately. One of these fields, the sample field, may take a variety of forms, depending on the kind of sample that is to be examined. For instance, it may be a pigmented surface illuminated with a definite light source, the combination of pigment plus illuminant constituting the sample as a whole, since the kind of light emitted by the field is dependent on both. The basic colorimetric data, however, are concerned only with the visual effects of the light itself, and not with the origin of its spectral characteristics. As will appear presently, it is better that the sample distribution come directly from a source and illuminate a white field in the colorimeter so that other lights can be mixed in with it. Thus the sample field and the standard or matching field of the colorimeter may both be white matte surfaces, capable of being illuminated simultaneously by several light sources whose intensities are continuously variable while their respective relative spectral distributions, that is, their spectral character, are carefully held unchanged.

Measurements with the colorimeter are performed by adjusting the intensities and mixtures on the standard side until the line of demarcation between the sample field and the standard field disappears. There is thus no visual distinction between one side and the other (except location, of course) and the two colors are said to match. Sometimes it is advisable to rotate the demarcation line by some optical means, so as to allow for possible anisotropies in the eye structures. There is always a small interval in the intensity settings over which the match is equally effective. This is an indication of the limited color-discriminating capabilities of the eye. Furthermore, with the same adjustment of the instrument, a mismatch may be observed at some later time or by a different observer. This is indicative of that variability of the visual characteristics which was mentioned before. Nevertheless, on a statistical basis a match is a definite observable relationship.

Following the above outline, two different forms of conventional colorimetric data are obtained in the colorimeter, depending upon whether the light sources for the standard or matching field consist of three primary sources, as defined below, each with a constant relative spectral distribution, or whether they consist of one source of white light and a monochromatic source of variable wavelength. A white light commonly used is the so-called "C" illuminant which has a certain standardized spectral characteristic and is rather easily reproduced. As will be seen later, there is in principle no restriction on the spectral nature of the white light, nor on the three primary sources, for data taken with them can be, from their spectral distributions, converted over to data corresponding to any other set of sources. Of course, whenever the color gamut of the samples to be examined will allow, it is more convenient and more precise if the matching sources are capable of effecting direct matches. In general, directly additive matches, in which the matching sources illuminate the matching field alone, and the sample source illuminates the sample field alone, are not always possible. In order to effect a match it is sometimes necessary to divert one or more of the matching sources from the matching field to the sample field, and, so to speak, dilute the light from the sample source with the lights from some of the matching sources. In these cases the matching light intensities added to the sample are said to be added to the matching field with negative intensities. With allowance for the use of such a device, which henceforth always will be assumed, it is possible to match any sample with light from any set of three primary sources or with light from the white and monochromatic sources.

Two color sources are said to be primary with respect to each other if, when they are regarded in the two fields of the colorimeter, no nonzero adjustment of their intensities can produce a match; three color sources are said to be primary with respect to each other, and form a set of primaries, if no one can be matched by any combination of the other two.

The results of colorimetric investigations with different spectral distributions and also with monochromatic light of various wavelengths have led to the formulation of two fundamental laws which express the trichromatic basis of color representation and the linearly additive colorimetric nature of light:

(1) The light from any sample light source, at any given intensity, which is in its effect a color stimulus or simply a color, can be matched by one and only one combination of a given set of three primary sources.

(2) The combination of two colors matches with the combination of their matches.

In addition to these laws, from which follow the relations that will be used in the subsequent discussion, the colorimetric data yield three functions or combinations thereof, which are conventionally tabulated as the colorimetric distribution functions and often symbolized by $\bar{x}$, $\bar{y}$, and $\bar{z}$, numerical quantities dependent on wavelength. These functions are to be interpreted as the intensities of the three ideal primary sources needed to match unit intensity monochromatic light of the corresponding wavelength. It is important to realize that although functions of wavelength and at the same time representing intensities, these quantities by no means represent the spectral intensity distributions of the primary sources. Their connection with the latter is quite indirect. Furthermore, when the data are converted to a given set of primaries in actual use, the resulting functions likewise do not describe the spectral distributions of the primaries. They state what intensities of the primaries, with all their spectral distributions, are required to match various monochromatic colors. These colorimetric functions state, therefore, what total intensities of the primaries are required in a given case, not what spectral distributions in the primaries are required. Thus it turns out that while a chosen set of primaries may have zero intensities over considerable portions of their spectra, the appropriate distribution functions of wavelength are never zero (within the visible spectrum) except perhaps at a few singular wavelengths.

The various colorimetric relationships consequential to the two basic laws and necessary for the proper utilization of the numerical data are usually expressed in a rather cumbersome notation which requires the frequent writing of triplets of symbols and formulas of similar type. Since these relationships are given here in some detail, a more convenient notation has been adopted. Fortunately this notation is not new. It has been taken from the absolute calculus and should be quite familiar to those acquainted with tensor analysis. It will be described here from the point of view of its special application.

The first colorimetric relationship is an obvious deduction from law 2, and may be stated as follows:

Relation 1—If two colors match, and their intensities are changed by the same factor, the resulting colors also will match.

Accordingly, it is convenient to write an appropriate factor explicitly. Let S be a sample source which is being matched in the colorimeter, as by a set A of three primary sources, A_1, A_2, and A_3. If E is the total energy intensity of the sample as it illuminates the field of the colorimeter, let $EI_s^{A_1}$ be the corresponding intensity of the A_1, primary source as it effects the match with S. Then $I_s^{A_1}$ is the relative intensity of the A_1 primary, or the actual intensity if the sample had unit intensity. The superscript identifies the primary source effecting the match and the subscript identifies the sample source matched. If the latter is monochromatic, of wavelength λ, it is more convenient to write the relative intensity as $I_\lambda^{A_1}$. For the given set of primaries, the three quantities $I_\lambda^{A_1}$, $I_\lambda^{A_2}$, $I_\lambda^{A_3}$, depending on the wavelength of the monochromatic sample, are thus functions of λ. To have the notation consistent, since the spectral intensity distributions of the various sources are also functions of wavelength, they will also be represented by letters with λ as an index. Again it is convenient to separate the total intensity and the relative spectral distribution, so the spectral intensity distribution of the sample S is given by ED_s^λ, while the relative spectral distribution of the primary source A_1, or its actual intensity distribution when adjusted to give unit total intensity, is given by $D_{A_1}^\lambda$. λ is written here as a superscript and when in connection with I, as a subscript, in part to show the different dimensionality of the two quantities.

Consider now sets of three primary sources A_1, A_2, A_3, and B_1, B_2, B_3, etc. By a, or by a', is denoted any one of the sources A_1, A_2, A_3, and by b, or b', any one of B_1, B_2, B_3. Thus any relation involving a is to be read first with $a = A_1$, then with $a = A_2$, then with $a = A_3$, and so on. Thus I_s^a stands indifferently for any of the three relative intensities $I_s^{A_1}$, $I_s^{A_2}$, $I_s^{A_3}$, and any equation written in terms of a holds whether a is replaced by A_1 (the same throughout the equation), by A_2, or by A_3. Similarly, when λ appears as an index, the equation holds for all values of wavelength. In this manner there are nine quantities I_b^a denoting the three sets of each three relative intensities of the A primary sources matching the B sources and there are nine different quantities I_a^b for the relative intensities of the B primary sources matching the three A sources.

The usual summation convention is also adopted for this present notation: whenever, in a product, the same index appears twice, the expression is read as the sum of the several like expressions in which this index is replaced successively by each of the values it can assume. For example, $ED_a^\lambda I_s^a$ is read as $E(D_{A_1}^\lambda I_s^{A_1} + D_{A_2}^\lambda I_s^{A_2} + D_{A_3}^\lambda I_s^{A_3})$. Thus there are 81 quantities $I_b^a I_{a'}^{b'}$ (with regard for the summation convention the primed and unprimed indexes are not considered the same, even though they refer to the same primary set), 9 quantities $I_b^a I_{a'}^b$, and 1 quantity $I_b^a I_a^b$. In the event that λ is a repeated index, since λ can assume a continuum of values, the notion of summation is replaced by that of integration with respect to wavelength. For colorimetric purposes it is sufficient that the limits of integration include all visible wavelengths, but the original notion of total energy intensity must likewise be confined to the same limits, about 380 to 750 mμ*. In dealing with photoelectric devices in connection with colorimetry it is therefore most essential to ensure that the physical apparatus is also thus confined. From the definition of D_s^λ as the relative spectral distribution, it follows accordingly that

$$\int_{380\mathrm{m}\mu}^{750\mathrm{m}\mu} D_s^\lambda \, d\lambda = 1$$

for any source S. From the present convention a similar integral is formed by the repetition of the index λ, for

$$I_\lambda^a D_s^\lambda \text{ is read as } \int_{380\mathrm{m}\mu}^{750\mathrm{m}\mu} I_\lambda^a D_s^\lambda d\lambda.$$

Relation 2—Since any sample color of relative spectral distribution D_s^λ may be regarded as the combination of all the monochromatic colors with appropriate relative intensities in that distribution, while the matches to the latter are given by the three functions I_λ^a the combination of these matches is the match to the original color, by application of law 2. In terms of the adopted notation, this colorimetric relationship may be expressed as $I_s^a = I_\lambda^a D_s^\lambda$. Should members of a primary set B be employed as samples, this expression would be written as $I_b^a = I_\lambda^a D_b^\lambda$.

Relation 3—If a sample source S at intensity E is matched by a set of three A primary sources with intensities EI_s^a, and if each of these primaries, when adjusted to unit intensity, is separately matched by a second primary set B with relative intensities I_a^b, then the sample S can be matched directly by the B set with intensities EI_s^b where $I_s^b = I_a^b I_s^a$. Replacing S by λ for monochromatic samples, one finds also that $I_\lambda^b = I_a^b I_\lambda^a$.

Relation 4—A consequence of the above relations is that if each of primary set A with unit intensity is matched by a primary set B with relative intensities I_a^b and if each of the set B is matched by the primary set A with relative intensities I_b^a, the two sets of intensities are related by the equations $I_b^a I_{a'}^b = \delta_{a'}^a$ where the symbol $\delta_{a'}^a$, the Kronecker delta, is 1 or 0, depending on whether $a = a'$ or $a \neq a'$, respectively. The three systems of three simultaneous linear

* mμ = millimicron = 10^{-9} meter.

equations can be solved either for the I_b^a or the I_a^b. For example,

$$I_{A_1}{}^{B_1} = \frac{I_{B_2}{}^{A_2}\, I_{B_3}{}^{A_3} - I_{B_3}{}^{A_2}\, I_{B_2}{}^{A_3}}{|I_b{}^a|}$$

where, in the determinant, the superscript denotes the row, the subscript the column.

Relation 5—It follows either from relation 4, or more directly from the uniqueness rule expressed in law 1, that if two identical primary sets A are matched with each other, $I_{a'}^a = \delta_{a'}^a$

Relation 6—The quantities $I_{a'}^a$ in relation 5 may be computed with the aid of relation 2, and take the form $I_{a'}^a = I_\lambda^a D_{a'}^\lambda = \delta_{a'}^a$.

Relation 7—The condition that a set B of three sources be primary, that no one can be matched by a combination of the other two, can of course be applied to the matches by set A of each of the set B. Thus $I_{B_1}^a$ must not be a linear combination of $I_{B_2}^a$ and $I_{B_3}^a$, that is, that there be no nonzero solutions x^b to the three simultaneous equations $I_b^a x^b = 0$. This requires that the determinant of the coefficient of x^b be other than zero: $|I_b^a| \neq 0$.

Relation 8—The luminosity of a color is not defined solely in terms of colorimetric matches, but some of the most important properties of the well-known luminosity function or curve of eye sensitivity versus wavelength are contained inherently in the standard colorimetric data. This is by virtue of the properties believed of the luminosity of a color, that it is a single numerical quantity, the same for all colorimetric matches, and that the luminosity of a combination of colors is the sum of the luminosities of the components. The luminosity L_λ of unit-intensity monochromatic colors is in consequence a linear combination of the functions I_λ^a where the A sources are any primary set. This can be seen easily if the luminosity of a monochromatic color is expressed in terms of the luminosities of the matching primary set which in turn are the sums or integrals of the luminosities of their monochromatic components: $L_\lambda = I_\lambda^a D_a^{\lambda'} L_{\lambda'}$. The expression on the right is obviously a linear combination of the three functions I_λ^a. L_λ is also known as the standard visibility function.

Luminosity is one example of the several visual perceptions connected with the spectral distributions of the light received yet recognized as common to, or possessed in different degree by different distributions which are not colorimetric matches. Another such perception is that of hue, another that of chroma or saturation. They are properties of color possessing a certain degree of uniqueness with respect to other properties and yet not always capable of objective operational definition. For instance, the ability of hue identification and discrimination differs very greatly among individuals and at the same time is very much a matter of experience and training. Conceivably it may be an entirely acquired visual ability, learned from ordinary experience with the dilution of dyes and pigments by white. Of these visual perceptions, luminosity appears to be the best defined and established. Large luminosity differences between colors are easily recognized, even though the colors are otherwise very different.

When the relative spectral distribution is unchanged, luminosity varies directly with intensity and this as a simple proportionality. There is of course substantiating evidence for this assumption. For example, the luminosity, measured by comparison with a steady source of the same relative spectral distribution, of light subject to rapid time variations, is the same as the time average of the instantaneous luminosities. The homochromatic comparison of the luminosities of the light from two fields may be done very easily in a colorimeter or similar instrument, which is then regarded simply as a photometer. Heterochromatic photometry is substantially more difficult, and since exact comparison when the colorimetric properties of the sources are widely different is almost impossible, the measurements are usually done in a step-by-step process in which a series of slightly different sources are compared. Thus in the determination of the luminosity-versus-wavelength function, two monochromatic lights of almost the same wavelength are equated in luminosity by adjusting their relative intensities until their visual differences in the colorimeter appear to be minimized. Then this procedure is repeated, using one of the monochromatic lights already used, and so on down the wavelength scale.

Although the procedure of step-by-step comparison outlined above constitutes the necessary operational definition of luminosity, from which it is subsequently found that the luminosity function is a colorimetric function in accordance with relation 8, a very much less tedious method of heterochromatic photometry is available in the use of the flicker photometer. Here the two light sources to be compared are alternatively presented in the same field of view and their intensities are adjusted so as to minimize the critical flicker frequency. This is the frequency of alternation of the field at which, as the frequency increases, the flicker arising from the alternation just disappears. While this method is subject to the criticism that flicker perception is a separate phenomenon, connected primarily with time variations and not necessarily at all with luminosity perception, and furthermore, flicker perception is due, at least in part, to the rods in the retina, which are perhaps inactive in color vision, nevertheless, the flicker photometer has been considered by many as giving good results in heterochromatic photometry.

With the aid of the colorimetric laws and relations which have been given, all that is necessary for the codification of colors for reproducing and matching is the numerical values of the functions I_λ^a for some definitely specified set of primaries A which are accepted as standard. In accordance with relation 2, therefore, all spectral-intensity distributions D_s^λ would be uniquely characterized in their colorimetric properties by the appropriate sets of three quantities I_s^a. Since both the functions I_λ^a and D_s^λ are empirical in origin they are not conveniently represented by simple functions and the process of computing the integrals $I_\lambda^a D_s^\lambda$ is usually one of numerical integration. For this procedure it is very inconvenient to have negative values of I_λ^a and since the choice of the standard primary set is arbitrary in the first place, it would be best if a choice could be made which would, if possible, avoid these negative values. Furthermore, the luminosity function is a linear combination of the general expressions I_λ^a and it is also always positive. Hence the total luminosity can be a very convenient extra dividend obtained when computing the I_s^a values of a color, if the luminosity function is itself one of the I_λ^a. Now supposing the actual color data to be taken with a definite set of primaries B, by relation 3, $I_\lambda^a = I_b^a I_\lambda^b$. The quantities I_b^a are determined uniquely from the quantities I_a^b by the equations of relation 4, $I_b^a I_{a'}^b = \delta_{a'}^a$. The quantities I_a^b, on the other hand, are fixed by relation 2, $I_a^b = I_\lambda^b D_a^\lambda$. If the functions D_a^λ are chosen arbitrarily it is possible to assign any set of values to the quantities I_b^a. Thus it is at once possible to choose I_b^a so that $I_\lambda^{A_2}$ is the luminosity function. Since the latter is always greater than zero for visible light, as has already been pointed out, two more independent combinations of the I_λ^b can be found which are nonnegative. Of course the values at either end of the visible spectrum are all always approaching zero, and thus in particular it is possible to find at least one such independent combination* which approaches zero somewhere

* In the neighborhood of 503 mμ the $\bar{x}$ function comes near but does not quite touch zero. This facilitates computation and saves co-ordinate space in the chromaticity diagram by bringing the curve of spectral colors close to the y axis.

toward the middle of the visible range. In addition, the function I_λ^a may be multiplied by appropriate numerical factors so that all three

$$\int_{380\mathrm{m}\mu}^{750\mathrm{m}\mu} I_\lambda^a d\lambda$$

have the same value. Hence, a light source whose intensity is independent of wavelength, called the standard "E" illuminant, will have tristimulus values all of the same numerical value. It so happens in the colorimetric data that for wavelengths greater than about 550 mμ, one of the functions, say $I_\lambda^{B_3}$, can be expressed as a linear combination of the other two, to a very good approximation. It is therefore convenient to choose the I_λ^a so that the residual third function is approximately zero in this wavelength region.

The above considerations have been taken into account and the choice of the standard distribution coefficients I_λ^a has then been fixed* by the specification of the trichromatic coefficients of a certain three monochromatic wavelengths and the standard "B" illuminant, which has a specified spectral distribution that, incidentally, gives a white color. The conventional designation for the distribution coefficients, which have been standardized and tabulated is, $\bar{x}$, $\bar{y}$, and $\bar{z}$, the $\bar{y}$ function (of wavelength) being also the luminosity function (Fig. 1). It is not possible to state exactly what the spectral-intensity distributions of the three corresponding ideal primaries are because the distributions are not uniquely specified nor required by the functions I_λ^a or $\bar{x}$, $\bar{y}$, $\bar{z}$. Relation 6, that $I_\lambda^a D_{a'}^\lambda = \delta_{a'}^a$, however, does give evidence of one important condition on the D_a^λ, namely, that for all the I_λ^a to be positive, for some wavelengths the D_a^λ must be negative. Now since no light source can have negative intensity, over any part of its spectral distribution, it is clear that the ideal primary sources are imaginary. To be sure, they can be obtained directly in the colorimeter by the artifice of negative addition but each primary would then consist of two light sources. Fortunately there is no real need for the direct use of these imaginary, ideal primaries. Their utility arises in colorimetric tables, charts, and computations.

In order to secure a graphical representation of the colorimetric relations and of various color differences and similarities, a color chart in the form of a chromaticity diagram (Fig. 2) generally is used. While

* The transformation from existing experimentally derived distribution coefficients to the standard distribution coefficients was thus specified by the Colorimetry Committee of the Eighth Session of the International Commission on Illumination, Cambridge, England, September, 1931.

many types of color charts have been invented with this object in view, the standard chromaticity diagram is capable of a fairly complete, objective representation although it cannot be used for direct visual comparison with sample colors unless it be printed with an appropriately shaded colored background. It is constructed from the tristimulus values of the sample colors to be represented on it, and since the diagram is two-dimensional it is appropriate to discount from the color specification that factor having to do primarily with

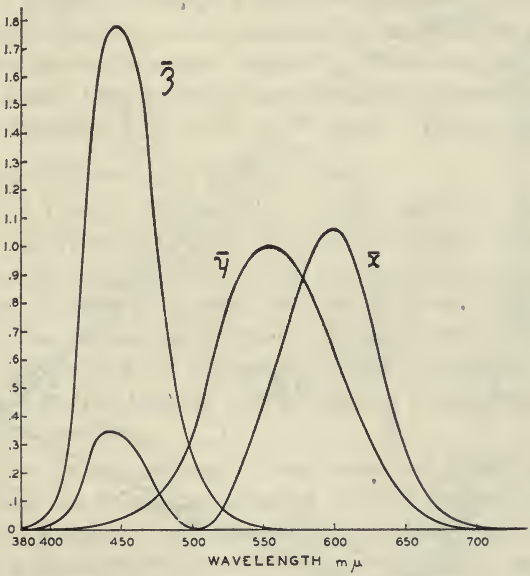

Fig. 1—Standard tristimulus values of equal energies of the spectral colors.

intensity and preserve in the representation those quantities representing properties seemingly more intrinsic to the notion of color. In this way the tristimulus values of a sample, which are the quantities $EI_s^a = EI_\lambda^a D_s^\lambda$ when the I_λ^a are $\bar{x}$, $\bar{y}$, $\bar{z}$, and are denoted conventionally by X, Y, Z, are formed into two ratios

$$\frac{X}{X+Y+Z} = \frac{I_s^{A_1}}{\sum_a I_s^a}, \qquad \frac{Y}{X+Y+Z} = \frac{I_s^{A_2}}{\sum_a I_s^a}.$$

These two ratios, called the trichromatic co-ordinates of the sample, x and y, have values between 0 and 1, and together with the value of

Y, the luminosity, completely specify the colorimetric properties of the sample in the same way as do the quantities I_s^a. There is a third trichromatic co-ordinate,

$$z = \frac{Z}{X + Y + Z}$$

but since, always, $z = 1 - (x + y)$, it can usually be ignored.

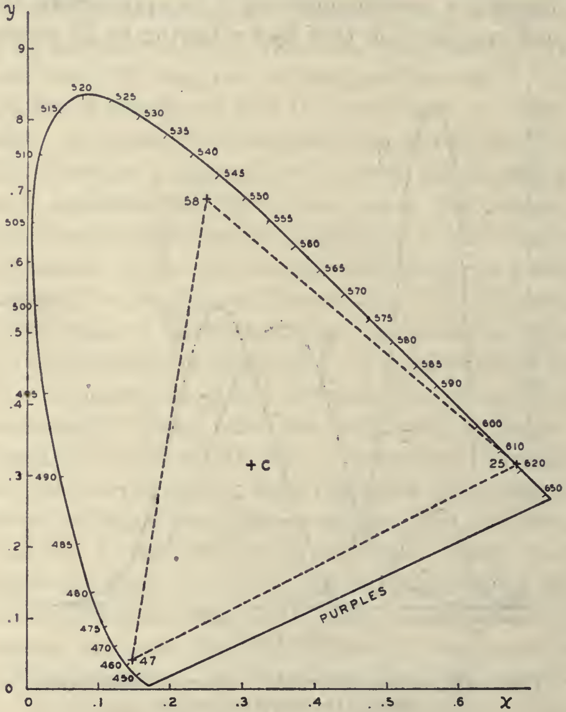

Fig. 2—International Commission on Illumination standard chromaticity diagram, showing the line of spectral colors and of pure purples, the location of the standard "C" illuminant, and Nos. 25, 47, and 58 Wratten filters in combination with that illuminant to illustrate the reproducible triangle of a receiver with these as primaries.

The chromaticity diagram is based on Cartesian co-ordinates with respect to which are plotted the trichromatic co-ordinates of the samples to be represented, the value of x along the x axis and the value of y along the y axis. In this manner, all colors which differ in visual characteristics only in luminosity correspond to the same point on the chromaticity diagram. Every monochromatic line of the visible spectrum has such a point and the points corresponding to successive wavelengths turn out to be on a horseshoe-shaped curve. The red side of this horseshoe is very nearly a straight line. Such a property is to be expected when, as has been mentioned before, in this wavelength region, one linear connection exists between the quantities I_λ^b.*

Relation 9—One of the most important characteristics of the chromaticity diagram, which is a simple consequence of its method of construction, is that the point standing for the additive combination of two colors lies at the center of gravity of the two points standing for each of them, they being assigned weights proportional to their respective quantities $\sum_a I_s^a$ or $X + Y + Z$. This notion similarly applies to the combination of several colors.

It therefore follows that all colors which are real, meaning that the spectral distributions of the light of the colors are made up of positive intensity contributions of the various monochromatic wavelengths, must lie inside of the area bounded by the monochrome horseshoe and the line joining its two ends. Daylight and sunlight, which each have roughly uniform intensities of light throughout the visible spectrum, are in this manner represented by points lying near the center of the horseshoe.

Relation 10—In consequence of the center of gravity relation 9, it is clear that the points representing a set of primary colors on a chromaticity diagram are necessarily noncollinear. Any color matched by a positive combination of such a primary set, whatever the relative intensities, must lie on or within the triangle formed by the three points representing the primaries.

*This linear relationship must be homogeneous, that is, contain no additive constant, since all tristimulus values pass to zero in the infrared. Thus the linear interdependence of the x and y for yellow and red monchromatic lights may be shown through algebraic manipulation of their formulas. In the case of the standard tristimulus values, that $\bar{z} = 0$ for these wavelengths makes this linear interdependence particularly easy to see. Since the homogeneous linear relationship may be written as $Z = aX + bY$, the formulas for x and y become

$$(a + 1)\,x = \frac{(a + 1)\,X}{(a + 1)\,X + (b + 1)\,Y},$$

$$(b + 1)\,y = \frac{(b + 1)\,Y}{(a + 1)\,X + (b + 1)\,Y} = 1 - (a + 1)\,x,$$

the last equation showing the linear interdependence of x and y.

Some additional properties of the chromaticity diagram may be noted as follows. The purity of color, corresponding very closely to the visual perception of saturation or chroma, is intended to indicate how nearly monochromatic a color is, or conversely, how degraded with white. If a straight line is drawn from the point on the chromaticity diagram representing white, for which the standard "C" illuminant is usually taken, through the point associated with a given color, on to meet the monochrome line or line of spectral colors, the purity of the given color is defined as the ratio of the line segment between white and the color, to the total length. If the given color is a purple, it is necessary to close the diagram by joining the two ends of the monochrome line with a straight line which may be thought of as representing the pure purples. The meeting point with the monochrome line mentioned above indicates a particular wavelength which is known as the dominant wavelength of the given color sample. In the case of purples this wavelength is not so defined, but rather is taken at the intersection with the monochrome line of the line from the given color extended through white. This corresponds, as will be seen later, to the dominant wavelength of the color complementary to the given purple, and therefore is distinguished by the suffix *c*.

From the properties of the diagram already given, it can be seen that the combination of white and monochromatic light of the dominant wavelength, or its equivalent negative combination of white and the complementary dominant wavelength in the case of purples, when in amounts indicated by the purity and the total luminosity, will provide an accurate match of the given color. Obviously therefore, the location of a color on the chromaticity diagram is equally well specified either by its trichromatic co-ordinates or its dominant wavelength and purity.

In connection with judgment as to the approximate reproduction of colors, a very useful representation of color tolerances may be made on the chromaticity diagram by plotting local contours of least chromaticity differences perceptible to the normal eye.

The combination of colors as it is understood in colorimetric relationships and data and as it is expressed on chromaticity diagrams, involves the combination of light fluxes impinging on the eye and has nothing whatever to say about the manner in which the spectral-intensity distributions were secured originally. The artifice of negative addition of light has referred merely to the addition of light flux to the sample side of the colorimetric balance, rather than to the matching side. Unfortunately, from the point of view of terminology, the notions of primary colors, color combinations, and charts have been applied to a large group of processes associated with color production which themselves have received a collective misnomer, subtractive processes. They are concerned with the ways in which dyes and pigments modify the light impinging on them and the consequences of mixing and combining different pigments and dyes. For the present brief discussion of subtractive processes, the actual atomic properties which give rise to the color characteristics of these substances will not be considered but the spectral reflectances and transmittances will be assumed.

The spectral quality of light passing through a dyed medium or incident on a dyed surface is altered by the selective absorption of some wavelengths of the light. The characteristic transmittance of the dye, like the reflectance of a pigment, is a proportional function. While the light which is absorbed by the dye may be thought of as subtractive (hence the term subtractive process) the subtraction is really logarithmic, since the amount subtracted is in proportion to the amount initially present. When two dyes are mixed, the same ray of light is acted on by both of them and the resultant transmittance is the product of the separate transmittances of the two. Thus, even if the illuminant is specified and the light passing through a definite quantity of a given dye may therefore be assigned a unique set of tristimulus values, the light which passes through a combination of two dyes is in general totally different from an additive combination of the light passing through each of the dyes separately.

There is no unique relation between the colorimetric specification of the original dyes and of their combination. Their mixture characteristics depend on the entirety of their original spectral transmittances, are colorimetrically nonlinear, and do not obey the colorimetric relations for the combining of colors. For example, there is no single point on the chromaticity diagram which corresponds to a given dye, even with a specified light source unless the quantity of dye passed through is also specified. The light transmitted by zero density of dye has, of course, the trichromatic co-ordinates of the source, that is usually in the white, and as the density of the dye increases, the point moves outward along some generally curved path. With the density increasing without limit, the point approaches the position of the monochromatic light of wavelength corresponding to the peak transmission of the dye, although the total amount of light transmitted becomes vanishingly small. Another example of the irregularities of the so-called subtractive systems is encountered when mixing a dye with each of two dyes which at the given density have identical appearances. Notwithstanding the colorimetric equivalence of the latter two dyes in combination with the chosen white source, the final mixtures may yield entirely different colors.

While for the most part pigments or pigmented surfaces share in the subtractive properties of dyes, their properties in mixtures are more complex because the modification of the light by absorption is accomplished not only during direct transmission but also during multiple reflection and diffusion among the pigment particles. Consequently the mixture characteristics of a pigment cannot be completely specified by even an entire spectral-reflectance curve. If the pigment particles of a mixture are of such a nature that an element of incident light must, on the average, pass through or be reflected by many particles before it is returned to the surface and emitted in its modified or attenuated form, then the mixture characteristics of the components will be substantially the same as those of dyes. If, however, the particles are so opaque or so sharply back-reflecting that a single particle can re-emit from the pigmented surface as modified, most of the light incident on it, each part of the mixture contributes additively to the emitted light.

Although of perhaps more widespread use, the notion of primary colors in subtractive processes is much less precise and has more limited applicability than has been used here for the additive combinations. Merely relative differences in the logarithmic transmittances of three dyes are not sufficient to ensure that all colors can be matched, while in the subtractive processes there is no useful analog to the negative combinations in the colorimeter of the additive systems. Through this artifice of negative addition an unlimited number of different primary sets were possible in the additive combinations, even though a comprehensive gamut of colors could be matched with only positive values by relatively few sets, such as a high-purity red, a high-purity green, and a high-purity blue. If the same gamut of colors is to be covered in a subtractive process, these high-purity primaries themselves must be attainable. Ideal dyes may be conceived of, which would achieve this, and accordingly are often identified with the manner in which they control the effective amounts of appearance of the additive primaries. Thus with white light at the start, the dye which controls the amount of blue is the one which removes blue from the white light, hence "minus blue." Applying the rules of additive mixtures to white light and a negative amount of blue, we see from the chromaticity diagram the resulting color is yellow. Hence a yellow dye which has that color by virtue of fairly uniform high transmission in the red and green parts of the spectrum and deep absorption in the blue is capable of being the "minus blue" subtractive primary. Similarly the "minus red" is a blue-green or cyan dye, and the "minus green" is a magenta or purple, which transmits red and blue light and absorbs green. Because the subtractive characteristics rarely approach the ideal of sharp spectral selectivity and because pigments sometimes show a little of the additive characteristics besides, the common primaries in pigments are generally blue, yellow, and red.

The color produced by a "minus" dye in combination with white light and the color controlled by this dye in subtractive processes are said to be the complements of each other. An additive combination of the two produces white. They appear conjointly in the well-known eye-fatigue phenomenon in which a bright design of one color is viewed fixedly against a white background, and then a blank white surface is viewed, wherein the same design in the complementary color appears for a time as an illusion. As has been indicated before, what is called white requires an arbitrary standardization, but all the properties of complementary colors are consistent if the same white is referred to. From this point of view, the dominant wavelengths of two colors determine their complementary properties, although the artistic values of this relationship usually refer to complementary properties of hues, there being an almost one-to-one correspondence of hue and dominant wavelength.

With regard to subtractive processes it must be remembered, however, that all true colorimetric specifications are referred to additive combinations of light sources, and that the conditions on additive combinations must always be satisfied to achieve color matches whether the intermediary steps by which the colors are produced are additive or subtractive. The simultaneous television receiver is an excellent example of the additive method of forming color with superposed light from three different light sources.

COLOR REPRODUCTION

From the foregoing section on colorimetric matching it should be clear that the visual identity of colors may be stated uniquely in terms of the identity of their tristimulus values. Therefore the function of a color-reproduction system is to provide colors with the same tristimulus values as occur in the original. While reproducing the original spectral distributions would indeed satisfy this condition, such a procedure is clearly not necessary, even for exact color reproduction, and it is not possible in a practical sense. Admittedly a three-color system which is exactly right for one person may not be quite perfect for someone else, and in addition engineering tolerances may prevent exactly correct reproduction in any case. In general, however, for any three-parameter system, the precision of color reproduction possible on the basis of colorimetric matching is vastly better than can be achieved by any method of approximately reproducing spectral distributions. Therefore, in all systems of color reproduction, in photography, printing, and color television, and wherever a three-color system is used, no attempt is made, nor would it be desirable, to approximate the spectral distribution of the original colors. This is an important example in communications of the selection of physical stimuli of markedly different physical specification from that of the original in order to give rise to the same sense perception.

In terms of the facts and relationships of colorimetry, to achieve accurate color reproduction in a color-television system, the correct signals must be expressed in the light intensities of the three color sources in the receiver and this requires, in effect, that the television system operate as an electronic colorimeter, individually for each picture element. Assuming linearity of the three receiver primary light sources, or appropriate correction for nonlinearity, the electrical signals controlling these sources must, with two exceptions, correspond, when the transmitting camera is viewing a color sample S, precisely to the quantities EI_s^b, which have been discussed in the preceding section, and represent the intensities when matching S in the colorimeter of the three primary light sources B which also are the receiver light sources, i.e., kinescope phosphors plus light filters.

The first of these exceptions is merely that in conventional television practice no attempt is made to duplicate in the receiver precisely the same brightness level as occurs in the scene being televised, but the adjustment of scene brightness is left to the selection of the individual viewer. Thus the quantities EI_s^b may be in error by some proportionality factor common throughout the picture.

The second exception arises from the difference in purpose of colorimetric matching and color reproduction. In the former the securing of quantitative relationships was the primary purpose, and the modification of the visual effect of the sample by the negative addition of the primaries was quite admissible. In reproduction the sample is not available to be so modified nor is such desired, for the sample should be reproduced like the original. Therefore complete accuracy of reproduction will be confined to those colors which require only positive combinations of the three primaries. As was shown before, these colors lie on or within the triangle on the chromaticity diagram determined by the three primaries and at the same time their luminosities are limited to the luminosity range of the receiver primaries. Therefore in the design of television receivers it is of considerable importance to select receiver primaries which will cover the desired gamut of accurately reproducible colors. In the present three-kinescope-type simultaneous receivers this is very largely a problem in phosphor composition. Fortunately phosphors are available with very satisfactory spectral characteristics although there is ever a need for more luminosity. Some of these phosphors, in combination with optical filters, are capable of saturation so nearly approaching that of monochromatic light, at well-separated points of the chromaticity diagram, that simultaneous receivers can accurately reproduce the colors from virtually all natural and artificial dyes and pigments. They are not able to reach pure monochromatic colors such as a spectroscope will produce but they can easily reproduce rainbow colors which are, as usual, diluted with a small amount of white light. The available color gamut is greater than in most other color-reproduction systems and appears adequate.

Within the range of reproducible colors, the function of the camera and transmitting equipment is to derive from the light of the sample S the quantities EI_s^b and impress them on the primary sources at the receiver. The unique physical specification of the sample S is its spectral distribution ED_s^λ which is all the signal information available to the camera. Conventional ideas as to how the camera should obtain the proper signals from this spectral distribution have, until recently, followed the pattern that each of the three signals EI_s^b should be obtained by a separate operation on the light ED_s^λ. Thus in the sequential color camera the plan was for the scene first to be scanned and the "red signal" $EI_s^{B_1}$ to be derived for all elements of the picture, then for the scene to be scanned with the "green signal" $EI_s^{B_2}$ derived, and so on. In the simultaneous color camera the plan was for all three of these operations to be done at the same time but each by a separate camera tube. That, as they are, these methods are fundamentally unworkable has not always been appreciated, and when it has, the attitude has been largely to do as well as possible with the system and accept the compromise. While not wholly responsible for this unfortunate viewpoint, two erroneous ideas have contributed to it and it is well to repudiate them explicitly before describing systems which will fully accomplish the desired result.

The first of these misconceptions is a consequence of attempts to approximate the spectral distribution of the original color. This distribution was to be divided into three adjacent blocks, roughly red, green, and blue, by being scanned through three filters with rectangular spectral cutoff characteristics. With the three receiver primaries having similar rectangular spectral distributions and being controlled each by one of the signals derived from scanning, the reproduced spectral distribution would approach the original in the manner of a block diagram approaching a continuous curve. If it were otherwise feasible to increase the number of blocks by having perhaps ten or more receiver colors and signal channels, color reproduction by this method would have good quality, but with only three parameters available, the results are necessarily far inferior to colorimetric reproduction.

The second common misconception involves some concession to colorimetry in that it is recognized that spectral-sensitivity curves peculiar to the nature of the receiver primaries must be obtained in the color camera. The mistake lies in supposing that the weight by which light of a certain wavelength is to be counted in the camera must be the same as it appears in the receiver primary; in other words, that the contours of the spectral sensitivities of the camera should be the same as the spectral-intensity distributions of the receiver colors which they each control. Actually the correct sensitivities are the functions I^b_λ, which scarcely resemble the primary distributions D^λ_b. If the reasoning of colorimetry is to be abandoned momentarily for the sake of a crude intuitive explanation, the reason that the above idea is wrong can be seen from the fact that a combination of the light from the receiver primaries can give the same visual impression as light whose wavelengths are totally absent from all these primaries.

The fundamental idea as to how the color camera is to derive the three signals EI^b_s is based directly on the colorimetric relations by which these same quantities may be computed, namely, by a process of multiplication and then integration with respect to wavelength. Thus $EI_s^b = ED_s^\lambda I_\lambda^b$, with the integration with respect to wavelength indicated by the repeated index λ. This process might be performed very easily by a photosensitive camera tube, for its total response is the integral of its response at each wavelength, and this spectral response is characteristic of the nature of the photosurface. The incoming light distribution may be further modified by a multiplicative function which is the transmission characteristic of an optical filter so that the effective sensitivity T_λ^c, where c may stand for cam-

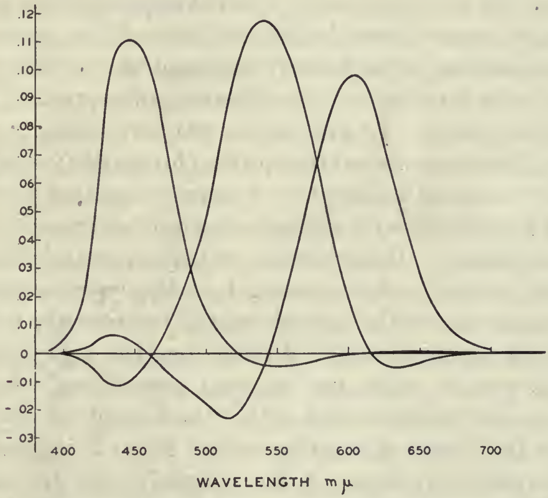

Fig. 3—Transmitter camera sensitivities required for the primaries of Fig. 1, assuming that each receiver primary is separately derived. (The curves show negative values for some spectral wavelengths.)

era tube and filter combinations C_1, C_2, or C_3, is the product of the filter transmission and camera photosurface sensitivity. Where, as in usual ideas for either the simultaneous or sequential color camera and transmitting equipment, each camera tube and filter combination has sole control over one receiver primary, so that each C may be identified with one B, the effective sensitivities may be written as T_λ^b.

To satisfy the unique colorimetric requirement on the camera, therefore, it must be that $T_\lambda^b = I_\lambda^b$, except for constant proportionality factors which apply in effect to the amplification gains in the three channels. Herein lies the difficulty with the idea of the separate derivation of the three signals. The functions I_λ^b necessarily must be negative over some part of the wavelength spectrum (Fig. 3). This is a logical consequence of the colorimetric relationships and is most easily seen in relation 6, where it must be remembered that the receiver primaries here considered are perfectly real light sources and have only positive spectral intensity distributions D_b^λ. Thus, for example, the requirement that

$$\int_{380}^{750} I_\lambda^{B_1} D_{B_2}^\lambda d\lambda = 0$$

means, since $D_{B_2}^\lambda$ is always positive and of appreciable amplitude over a considerable range of wavelengths and since $I_\lambda^{B_1}$ is, as shown before, a linear combination of the linearly independent functions $\bar{x}$, $\bar{y}$, and $\bar{z}$, and hence can be zero only at a few discrete points, that $I_\lambda^{B_1}$ must have some negative values. To provide an intuitive background for this fact it should be remembered that on the chromaticity diagram, colors outside the triangle of a primary set require negative amounts of at least one of the primaries for a match, and monochromatic colors come under this category. The television camera operates along this procedure, that it finds out the amount of the receiver primaries required to match each of the monochromatic wavelengths in the sample and then adds up the result, and thus along the way these negative amounts have to be taken into account even though the final sum represents a color which is well within the triangle of the primaries.

While by the choice of suitable optical filters it is possible to approach the positive portions of the curves I_λ^b with the camera sensitivities T_λ^b, as yet no camera tubes have been developed which yield, in effect, negative photoresponse in some wavelength intervals. Hence it has not been possible to realize the negative portions of the I_λ^b functions which are essential to accurate color reproduction when the three receiver signals are derived separately. The frequently suggested remedy, that a constant or bias be added to the I_λ^b functions so as to make them positive, the camera sensitivities be adjusted to the result, and then subsequently a constant signal be subtracted, is of course useless because the "constant" signal is a function of the incoming light characteristic. On the other hand, if there were provided another camera tube for each of the ones in the conventional arrangements, such that the effective sensitivity of one corresponds to the positive part of the I_λ^b, and the sensitivity of the other to the negative part, the differences of the outputs would give precisely the desired signals.

In contrast to the cumbersome, objectionable ways available to attain the camera spectral sensitivities I_λ^b necessary to accurate color reproduction when the receiver signals are each derived by a separate photopickup arrangement, an elegant method of deriving the signals in simultaneous systems becomes evident upon a more thoroughgoing application of the colorimetric relationships. From relation 3 it is apparent that the I_λ^b may be expressed as independent linear combinations of analogous functions applying to other primary sets, as for instance the C set of primaries later to be identified with the separate camera tubes: $I_\lambda^b = I_c^b I_\lambda^c$. Similarly the I_λ^c may be expressed as linear combinations of I_λ^a where the A set of primaries are the standard ideal set and hence the I_λ^a are also the conventional $\bar{x}$, $\bar{y}$, and $\bar{z}$. Now if three camera tubes with effective sensitivities $T_\lambda^c = I_\lambda^c$ are used to scan the sample color, their separate outputs will consist of the integrals $EI_\lambda^c D_s^\lambda$ just as in the conventional schemes in which the receiver contained the primary set C. These signals then are combined by algebraic addition in three different ways by linear networks in accordance with the three transformations defined by the coefficients I_c^b which are fixed into the network by potentiometers or the like. The output signals thus have the magnitude $I_c^b EI_\lambda^c D_s^\lambda$ which are exactly the same as the desired signals $EI_\lambda^b D_s^\lambda$. Clearly the C set of primaries have played an entirely intermediate role and they do not have to be actually realized. There is no requirement therefore that their spectral-intensity distributions D_c^λ be entirely positive quantities and consequently there is no reason why the functions I_λ^c have to have some negative values. The only requirement on the I_λ^c is that they be independent linear combinations of the positive functions $\bar{x}$, $\bar{y}$, and $\bar{z}$. Hence there is comparative freedom to choose these functions I_λ^c, first so that they are positive and make possible the design of optical filters which will give the proper camera sensitivities $T_\lambda^c = I_\lambda^c$ and yet so that the subtraction of signals which occurs in the combining networks represents, at least for white light, a comparatively small correction on the main signal strength going through each channel. This is asked because in subtraction, signal strengths may be diminished but noise always increases. Finally, in the interest of convenience the combinations of $\bar{x}$, $\bar{y}$, and $\bar{z}$ should be chosen such that, when the spectral sensitivities of the photosurfaces are divided out, the resulting filter characteristics which are required can be secured with obtainable dyes.

In the design of the light filters to provide the camera tubes with

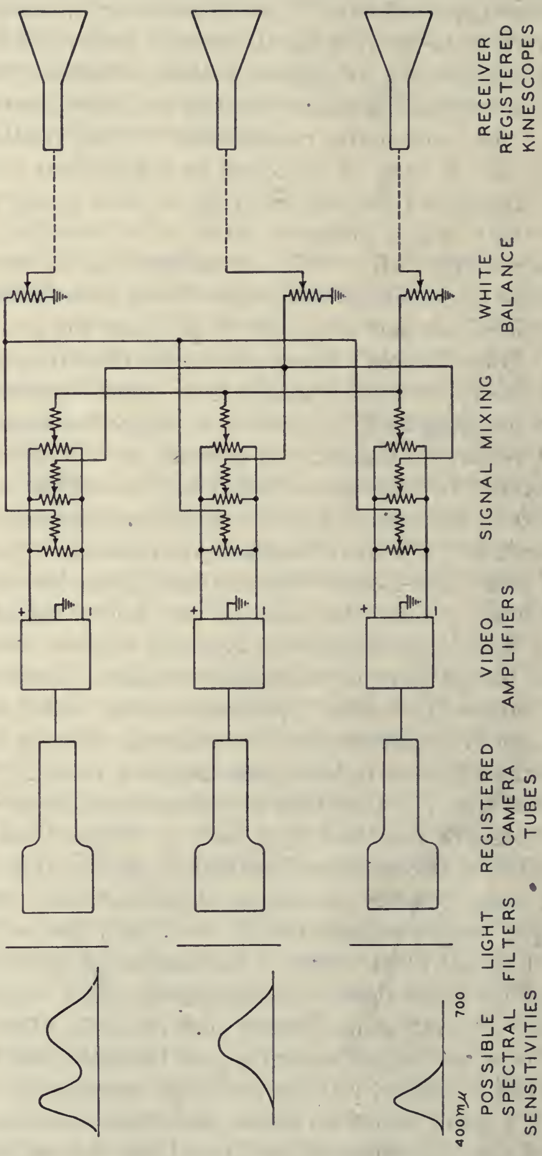

Fig. 4—Schematic of simultaneous color-television system capable of exact color reproduction.

the effective sensitivities T_λ^c which have been selected, additional characteristics are frequently incorporated to compensate for the light source illuminating the subject being televised. It very often happens that the light source is limited in its spectral characteristics by other considerations, as, for example, in the flying-spot slide and motion picture scanner where the phosphor must be of high intensity and very short decay time, and where the slides and motion pictures are ordinarily intended for projection with light from a tungsten lamp. Rather than applying an optical filter directly to the light from the phosphor, a very substantial saving in intensity can be obtained by modifying the effective sensitivities of the camera tubes so as to give the equivalent over-all characteristics as if the proper illuminant were used.

The network used for the algebraic addition of the camera signals usually requires some means of phase inversion to secure at the same time signals of both polarities. (See Fig. 4.) The combination of the signals is then easily accomplished by purely resistive elements which may have already fixed in them the appropriate constants I_c^b as computed from colorimetric relations 2 and 4 and the camera sensitivity and receiver-intensity distributions I_λ^c and D_b^λ. For reasons of avoiding these calculations and of avoiding the need for reliance on precision in the circuit components, it is perhaps better to provide adjustable circuit elements which can be set when the system is in operation. In spite of the large number of variables, usually nine or more, a rapidly converging procedure of adjustment can be secured through the obvious facts that the transmission of white must yield white and that the camera, when viewing a light source* of the same tristimulus values as any one of the three primaries in the receiver, together with the combining networks, must yield a signal in the corresponding channel controlling that primary, and in no other channel. The adjustment of the white requires a balancing of the three signals output to the receiver and for this purpose it is more convenient to provide separate gain controls in the output channels even though there is then a duplication of variables.

As a result of the rigorous application of colorimetric information to simultaneous color television which is admirably well suited to the purpose, a new medium for the reproduction of color is becoming available. It is capable of by far the finest performance yet known in commercial processes, having at the same time a wide gamut of

* This source may conveniently be a dummy receiver.

colors, colors of very high saturation, and an intrinsically accurate means of adjusting these colors automatically.

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Origins of the Magic Lantern

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Summary—**A critical survey of old and new literature reveals the development of the modern slide projector out of the old "art of mirror writing" which in its turn can be derived from the silhouette. A wrong interpretation of a passage in an old book which describes a camera obscura caused the wrong opinion that the slide projector must have developed from the camera obscura. This contrivance, however, has been the forerunner of the modern photographic camera.**

It is usually held that the slide projector, formerly called the "magic lantern" has its origin in the "camera obscura" and in this connection the names of Porta (1538–1615) and of Athanasius Kircher (1602–1615) are mentioned. The latter was alleged to have constructed the magic lantern in the middle of the seventeenth century. He described it in the *second edition* of the voluminous and abundantly illustrated "Ars Magna Lucis et Umbrae" ("The Great Art of Light and Shadow," 1671) which publication is accompanied with two pictures, one of which is reproduced in Fig. 1.

A closer study of the literature of this subject, however, reveals another origin of the magic lantern, which may be traced back to the very old "silhouette show" and in this development the importance of Kircher and Porta is not so great as is generally accepted.

Before we continue with the subject an explanatory remark should be made on the principles of the camera obscura and the modern projector. The latter forms by means of a lens, the objective, a *real* inverted image of an object, which therefore can be projected on a screen. The nearer the object (slide, film) to the focus of the objective, the larger the image on the screen and the larger the distance between screen and objective. Thus in slide and film projectors the slide or the film is placed practically in the focus of the projecting lens. By moving the object from the objective the image will become smaller and smaller until it stands practically in focus when the object is at a great distance from the lens. In this way we have changed the projector into the camera obscura and therefore the essential difference between the camera obscura and the magic lantern lies in the position of the object before the lens.

The Italian Porta, who lived long after the invention of the camera obscura and thus is *not* the inventor as is often supposed, deserves, however, the merit of having popularized it in his famous book "Magia Naturalis" (first edition 1558, second edition 1589 in Naples), a curious mixture of science and charlatanry. The result was a wide application of the camera obscura, which in those days indeed had the dimensions of a "camera" (room, see Fig. 2), as a contrivance for performances of various character. In one of the walls a simple spectacle lens was placed and a hollow mirror was used to reflect the images of

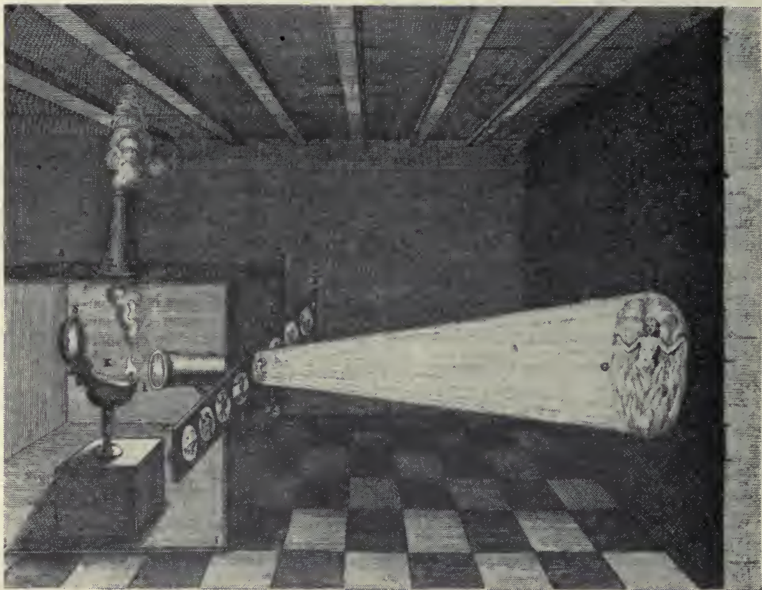

Fig. 1—Kircher's "magic lantern" (1671).

the objects outside the room in this lens; the pictures were thus projected on the screen, the opposite wall, right side up. As in the modern theater, the spectators sat facing this screen with their backs to the lens which was more or less hidden, making the performance a mysterious affair.

On an open space in full sunlight outside the "camera" and before the lens the different scenes were played. For instance, hunting parties were very popular in which the game was represented by disguised boys or wooden effigies. War scenes and passion plays were also presented. At night statues and large pictures painted on canvas lighted by torches were shown. In this way the public saw pictures of the emperor, scenes of the rising and setting of the moon and stars, and last but not least images of the devil to frighten the spectators who still looked upon the whole performance as an uncanny and supernatural affair. It must be noted that in its *application* the camera obscura came quite near the performances which were given with the "laterna magica" some seventy years later.

When in addition the well-known English chemist Priestley (1733–1804) in his work on the history of optics (1776) wrote that Porta also used transparent drawings as "slides," the close connection between the projecting lantern and the camera obscura seemed to be certain

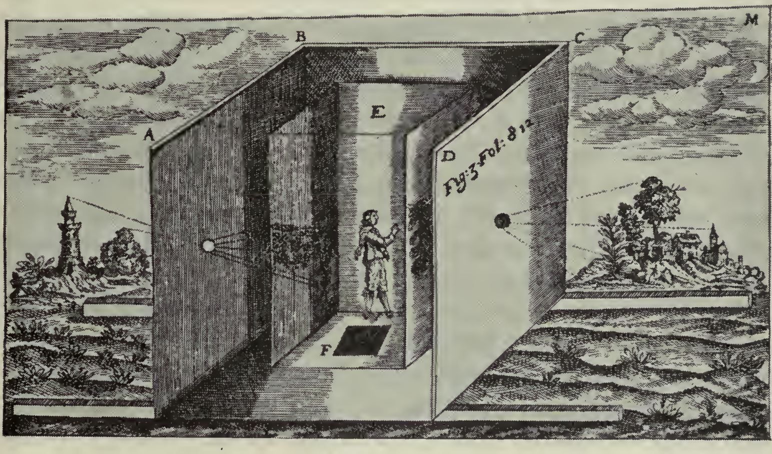

Fig. 2—The camera obscura in the sixteenth and seventeenth centuries.

and for a long time it was held that the former developed out of the latter. As has already been mentioned a careful study of the available old literature shows that another development is more probable. In Priestley's description Porta is said to have traced drawings on transparent paper attached to one of the sides of a hollow cube the opposite side of which was open and turned to the lens. From this transparent drawing, placed outside of the room, an enlarged picture was formed on the screen. The necessary light came from the sun. By making the slide movable Porta is said to have been able to attain effects which seemed positively uncanny to his contemporaries.

Priestley further supposed that the German Jesuit, Athanasius Kircher, following up on Porta's device, later invented the magic lantern (Fig. 1) which did the job of the camera obscura at night.

Thus Priestley refers to the "Magia Universalis" (1657) a work of Kaspar Schott, an assistant of Kircher. But in turn Schott refers to the *first* edition of Kircher's "Ars Magna Lucis et Umbrae" of 1646 in which the camera obscura was described, and after an explanation of the apparatus Schott wrote ("Magia Universalis," volume 1, page 198, Würzburg 1657): "In order that the spectator does not notice the small hole with the lens so that the effect is more mysterious, one attaches inside the room in front of the lens a hollow cardboard cube with blackened sides except the side turned to the lens which is open and the opposite side which is made of transparent paper. On this transparent paper one projects the image of cardboard objects placed outside the room which are turned upside down in order to get the pictures right side up on the screen. . . ."

Priestley thus made the mistake of supposing the cube to be attached *outside* the room and supposing the screen to be a "slide" for the drawings. Second, Porta was accredited with the technique, which, however, was developed long after Porta by Kircher to whom Schott refers. Owing to the authority of Priestley his mistake was repeated in the historical works of Joh. Carl Fischer and Poggendorff and from these in the more modern books.

Of course it may be imagined that the development of the magic lantern from the camera obscura had taken place after systematic research work on geometrical optics as is the practice today. By moving the object from a point far off to the focus of the lens and by constructing a device for optical lighting (condenser) which is a characteristic feature in a projector, one had changed the camera obscura into a magic lantern. But in Porta's days there was no question of systematic research. All investigation was more or less guesswork, for the greater part done by adventurers and charlatans who looked for ways in which to deceive the credulous public and to make quick money. As for the very small scientific world of those days, this was only interested in the magnifying power of lenses and their use in microscopes (Hooke van Leeuwenhoek) and telescopes (Galileï). So the principles of optic projection were invented by way of trial and error and in the just mentioned *first* edition of Kircher's "Ars Magna" of 1646 we can find a good starting point for the historical development of the slide projector, for on pages 907–917 we read about experiments which, traced backwards, point to the "silhouette show" and on the other side directly lead to the first magic lanterns of Christiaan Huygens and Thomas Walgensten.

Kircher, who was at that time in Rome, carried out these experiments because he was fascinated by the old "art of mirror writing." From passages in Agrippa von Nettesheim's works on occult philosophy (sixteenth century) we learn that this art is very old, even the name of Pythagoras (500 B.C.) being connected with it. The ancients seem to have experimented with a system of long-distance communication by writing on a plane or concave mirror which was reflected on a screen placed at some distance. Thus a kind of optical telegraphy was constructed to be used for messages to army leaders in battle or for other emergencies. Von Nettesheim tells us the fantastic story that Pythagoras, while in Italy, in this way communicated with his friends in Byzantium. He wrote the letters with his blood and reflected the mirror to . . . the moon!

Figs. 3b and 3c show schematically how the Ancients planned—and perhaps put into practice—their "art." On a mirror *Sp* the reversed letters (represented by the figure *F*) were traced which did not reflect the rays of the sun, thus forming shadowy figures on a screen *S* to which the mirror directed these rays. In fact mirror writing really is nothing but using a mirror to direct a certain shadow (Fig. 3a) to a certain spot (Fig. 3b). By using a concave mirror the Ancients tried to get larger images (Fig. 3c).

We learn in the primers on optics that the shadow of an object which is lighted by a light of some dimensions becomes less sharp as the distance between the object and the screen grows. The inner shadow grows narrower and the penumbra broader. Consequently the reflected writings are somewhat blurred at relatively small distance and badly blurred at greater distance. Now Kircher tried to improve on this method by means of a *lens*. That he chose a lens was very probably not the result of scientific reflections (see the end of this article), but of the fact that the lens, as an optical implement, was becoming more and more popular. The seventeenth century in which Kircher lived was the century of the rise of optical science and practice.

Snellius (1580–1626) had worked out his well-known law of refraction $\sin i/\sin r = n$ by which a rational construction of optical instruments had become possible. Christiaan Huygens (1629–1695) and later Isaac Newton (1642–1727) published their famous treatises on the nature of light and moreover constructed different optical apparatuses. The study of microscopical objects and celestial bodies went through a boom period and so it can be easily understood that minor scientists like Kircher tried the lens as an improvement in their

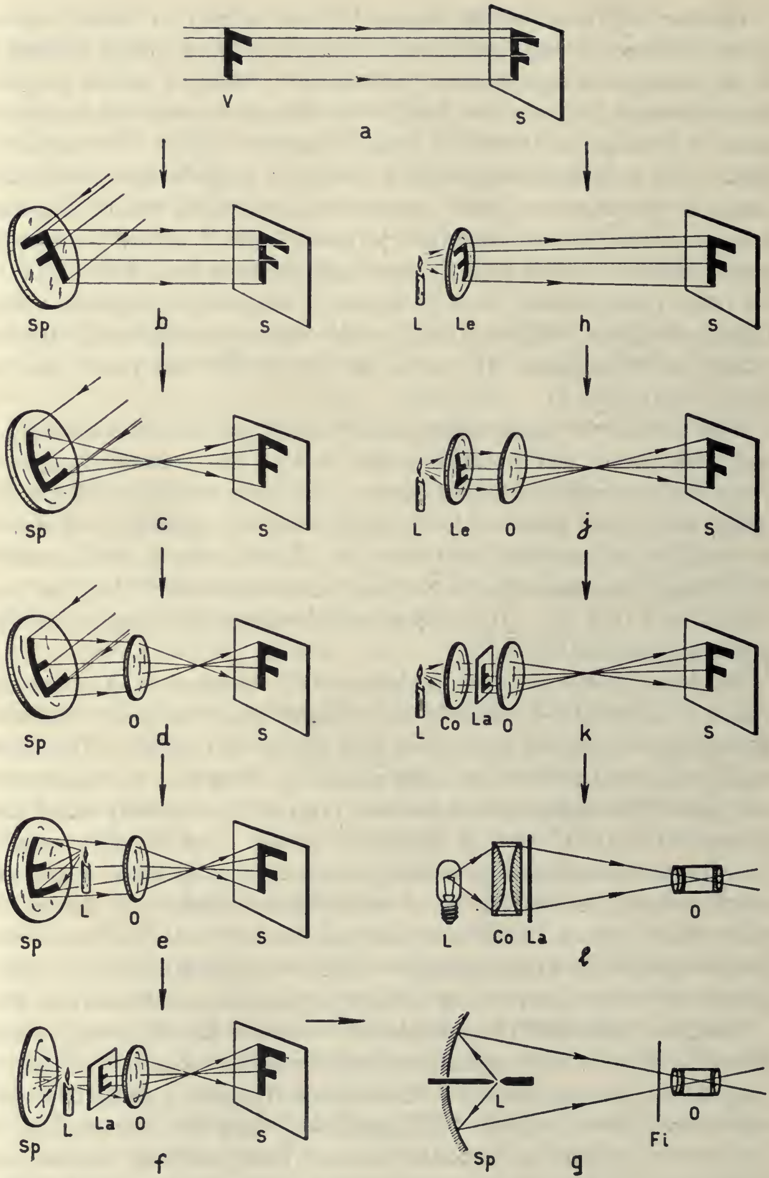

Fig. 3—Scheme of the development of the modern projection systems from the silhouette.
v = object; *s* = screen; *l* = source of light; *la* = slide; *fi* = film; *sp* = mirror; and *o*, *le*, *co* = lens (*o* as objective, *co* as condenser)

optical devices, boasting on priority when they had made an "invention." Moreover Kircher had read about experiments of another Jesuit, the Italian Bettini (Marius Bettinus, 1582–1657) which, according to Kircher might be very useful for his research. Bettini's experiments can be found on pages 26 and 27 of the "Apiaria Universae Philosophiae Mathematicae" (1642), which, translated freely, means "a miscellany of mathematical philosophy." Under the heading "Shadow Projection with the Lens" (Fig. 4), Bettini dealt with a "secret method with which, during the night, one can communicate

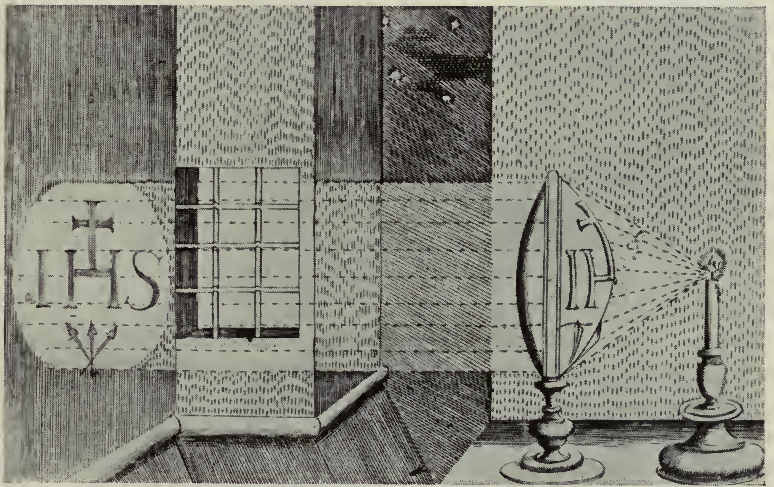

Fig. 4—Bettini's shadow projection with the lens (1642).

with a friend in another place with the aid of a hyperbolic lens, painted figures, and a source of light." The figures had to be made of materials which did not affect the polished surface of the lens, for instance, wax or clay.

It must be noted that the lens did not project an image of the figures. These appeared—as was the case with the figures on the mirror—as *shadows*. But the lens did achieve a *concentration* of the light and we may consider it as the first primitive *condenser*. The so-called "hyperbolic" lens only existed in the fantasy of the inventor, because the grinding of this kind of lens is, even with modern tools, almost an impossibility. So much for the experiments of Bettini who was able to perform "the art of mirror writing" at night.

The first thing Kircher did was to extend the distance between the mirror and the screen because, as he wrote, "it was hardly 20 steps..." He did this by placing a lens in the reflected rays, which produced a sharp, enlarged, and inverted image on the screen (Fig. 3d and Fig. 5). The plane mirror had a diameter of 4 centimeters and the lens a diameter of 3 centimeters and we may conclude from Fig. 5, which is a copy of the picture in the "Ars Magna" of 1646, that the lens must have had rather a great focal length. For it must be noted that the distance between the mirror and the lens is rather long and that the enlargement on the screen is rather small. Considering the technical possibilities of the seventeenth century this was the only means of avoiding the spherical and chromatic aberration. Kircher first projected texts which now "were clearly visible on a distance of 500 feet."

With two assistants, namely, Kasper Schott (well known for his book "Magia Universalis Naturae et Artis") and Georgio de Sepi (who acted as an instrument maker), Kircher industriously went on with his experiments. The mirrors were made of a special alloy because normal steel mirrors were affected by the ink. Neither were mirrors of glass of any use as the double reflection of the light rays in the glass produced a blurred image.

It was found that concave mirrors worked better than plane ones and this is understandable as the concave mirror reflects the rays in a *convergent* bundle on the center of the lens and so produces a sharper image than the plane mirror where the rays reflected in the margin of the lens are more refracted than those which are transmitted nearer the center (Fig. 3d). Further it was pointed out that it was very important to have a well-ground lens which had to be spherical or better still "hyperbolical."

The many performances which were given by Kircher and his assistants excited a lively interest and made a profound impression. First texts were projected, then the dial of a clock which was painted on the mirror, a pointer, made of paper indicating the correct time. Later geometrical line drawings, filled in with transparent paint were projected and Kircher was surprised at the fact that the colors appeared unchanged on the screen. He was pleased with this kind of projection and relieved his feelings in circumstantial treatises.

The experiments went on. Right in front of the mirror a cardboard puppet was placed, the limbs of which could be moved by invisible threads and...the spectators saw the first moving pictures! Then a fly was fixed on the mirror with honey and a terrifying monster appeared on the screen! By sticking a needle into the fly and moving a magnet behind the mirror, which in this case could not be made of iron, it looked as if the fly moved and were alive. This apparatus may be considered as one of the first primitive solar microscopes.

The spectators were profundly impressed by this kind of performance and the "moving pictures" even frightened them. However

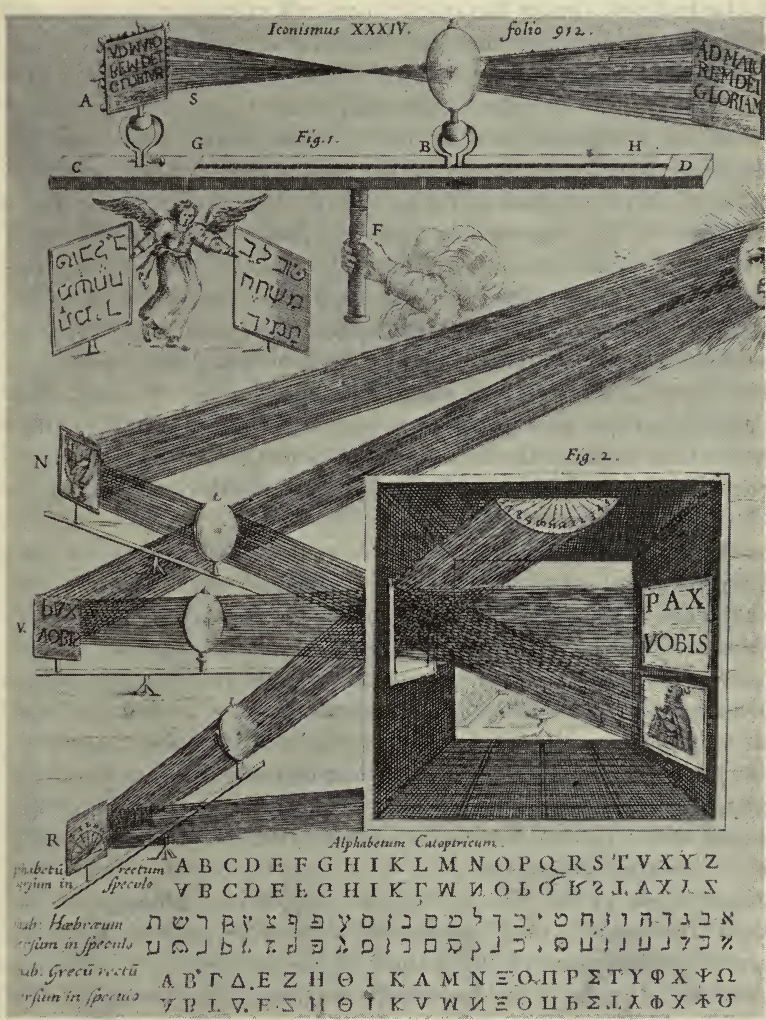

Fig. 5—Kircher's projection methods as an improvement of the old art of mirror writing (1646).

Kircher was not yet satisfied with these results. The public had to be impressed much more and the idea occurred to him that this might be achieved if the performances were given at night. Now he had to work with an artificial source of light and a burning candle was chosen which was placed in front of a concave mirror because a plane mirror would only reflect part of the divergent rays into the lens (Fig. 3e).

As he had not always the correct concave mirrors at his disposal, Kircher invented another device. Thinking of Bettini's method with which he had experimented before, Schott wrote about this "third art," "I have tried it with Kircher and it came out well"—the concave mirror was substituted by one of those rather large spherical flasks filled with water, which in the seventeenth century, were on hand in all sorts and sizes and were used by the physicians as "urine receptacles." The drawing or text was fixed or painted inverted and reversed on the water-filled flask at the side turned to the projection lens but, as the surface of the flask was spherical, it was not possible to focus all points of the figures on the screen and the image as a whole remained blurred (Fig. 3j). It is remarkable that Kircher, instead of using a second lens, chose a flask. Therefore we may draw the conclusion that lenses still were rare in the seventeenth century. Thus we may consider the device of Fig. 3e as the first primitive projector with the "*reflector lamp*" (Fig. 3g) and the device of Fig. 3j as the first with a *condenser* (Fig. 3l).

As the light of a candle is very feeble compared to that of the sun, only figures and short words as "Pax" and "Salve" could be shown, but the influence of the darkness on the spectators was so undeniable that the simple words made a more profound impression than the moving puppet in the sunlight. Kircher considered this kind of projection a very useful means to convert godless people. Therefore he took great pains to project on the windows of houses in Rome, the "panes" in those days being of paper. We may imagine the feelings of the sinful Roman citizens when suddenly they saw the bright figures in the darkness and supposed an ominous resemblance with the "Mene tekel..." of king Belshazzar.

Schott wrote in his "Magia Optica" (one of the volumes of the "Magia Universalis") that "these performances of images in darkened places were more alarming than those in the daylight." By this art godless people might easily be kept from committing sins, especially if one should fix a picture of the devil on the mirror and project this in a dark place. It is a pity that such views have hampered the development of the projection lantern. When, namely, in the course of time, the profound seriousness of the priests, concerned about the souls of the godless, had vanished, the "laterna magica" remained in the hands of charlatans and necromancers who used it to impress simple and superstitious minds. During almost two centuries the lantern had only been used to project terrifying figures and for other mysterious purposes. The development toward an instrument for the use of scientific instruction and education was for this reason hampered until about 1850.

However, in the seventeenth century there was somebody who, in Kircher's improved art of mirror writing, saw not only an instrument of wonder but something more. It was the Belgian Jesuit and mathematician Andreas Tacquet (1612–1660) of Louvain who was the first to give a lantern lecture. He had met friar Martin Martini, a Jesuit missionary, who had undertaken a far and dangerous journey to China and after his return to Louvain (1653) visited Tacquet and had formed the plan to hold a lecture upon his adventures. Tacquet who was acquainted with Kircher's method of projection, probably by having read the "Ars Magna," realized how Martini's lectures could gain in importance if they were accompanied by projected illustrations. And so it happened that during Martini's narrative, before the eyes of the interested and astonished spectators, pictures of foreign countries and peoples appeared which seemed to come out of nothing and also vanished into nothing....

It is again Schott who tells us something about this lecture in his "Magia Optica" (page 426) and in spite of the fact that he does not mention the use of slides, Tacquet must have used them, as it is impossible to accept the fact that the pictures were painted on the mirror and wiped out again during the lecture (Fig. 3f). Thus Tacquet must have introduced the first *lantern slides*.

All elements for a complete slide projector now were present and only the mind was lacking to unite these elements into a whole. This mind proved to be the well-known Dutch scientist Christiaan Huygens (1629–1695). He constructed a complete projector with a condenser and a calculated projection objective. Moreover, he had made *separate slides* (Fig. 3k). It is outside the scope of this article to describe Huygens' interesting work in this field because it is a chapter in itself. A new period in the development of the projection lantern now begins in which the names of Walgensten, Dechales, Zahn, Robert Hooke, and William Molyneux must be mentioned. That the name of

Huygens has receded into the background is the result of the fact that afterwards he felt somewhat ashamed of his activities connected with the projection lantern. Gradually the charlatans began to frighten the public with this instrument of wonder and picking its purse. That such a person as Huygens was above any form of charlatanry is understandable and he tried to forget the "incident" (as he called it) as soon as possible.

A final word about Kircher's "laterna magica" in the *second edition* of the "Ars Magna" (Fig. 1): When this picture met the eyes of the readers the projection lantern had already existed for ten years and therefore it is certainly incorrect to consider the device in Fig. 1 as the first magic lantern and Kircher as its inventor.

At the utmost he discovered *the principle* of optic projection when he, more or less by chance, used a lens to improve the art of mirror writing. In fact he had not the slightest idea of the importance of his "invention" and he was not able to develop it in a logical and systematic way. When, for instance, he writes about the clearness with which the projected writing can be seen, he claims that with the means at his disposal, a sharp image is obtained at a distance of 500 feet. "Thus" an instrument 24 times larger would give a sharp image at a distance 24 times greater, namely, 12,000 feet. Of course there would be "some difficulties," he mentions drily, and the images would be too large and too faint but many improvements could be introduced, for instance, by "using more concave mirrors." In which way this had to be performed Kircher did not mention "as time to make further experiments failed him." However, he "recommended his idea to other scientists for further reflections." And when Huygens had finished his lantern in 1659, one of his acquaintances, a certain Guisony, wrote him a letter from Rome (1660) remarking that Kircher was not yet very familiar with "the invention of the lantern." "The good old Kirkher (Kircher)," Guisony wrote, "is performing a great number of tricks with his magnet in the Collegium Romanum but if he had the invention of the lantern he should frighten the Cardinals with ghosts all the time."

According to this it appears that Kircher's knowledge about "the art of light and shadow" had not made much progress in the years after he had experimented with Schott and de Sepi and that the *application* of the magic lantern, namely, "frightening the Cardinals" was nearer to his heart than its construction. Indeed, if we have a critical look at Fig. 1, we notice that, for instance, the objective is in the wrong place and apparently Kircher had Bettini's art in his mind, so we are justified in concluding that Huygens in 1659, Walgensten in 1660, and Dechales in 1665 with their "lanterns" were nearer the goal than Kircher in 1671. Kircher's complaint in the second edition of the "Ars Magna," that "Walgensten had sold copies of his lantern at high prices in France and Italy to many prominent people" is therefore unfounded.

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Report of the Studio Lighting Committee*

Summary—This report contains information on three phases of studio lighting as follows: I. Various types of new equipment which have been recently developed and used are described and illustrated. II. New uses for standard commercial lamps are discussed. III. The results of tests conducted to determine the effect of variation of power-supply voltage and lamp maintenance upon color rendition of 16-mm commercial Kodachrome are given.

I. New Equipment

Special Effects with Remote-Controlled Shutters

Shutters of the Venetian-blind type have been used for some time on set lighting lamps for dimming, color-changing, simulating the turning off and on of lights in a room, and various other types of special effects. Wherever they have been used in groups a need for exact synchronization has been indicated. With manually operated shutters a man must be located at each lamp to operate his respective shutters upon receipt of a cue and with this mode of operation it is impossible to have all of the shutters operate in unison. A remote-control system was indicated where all the shutters would operate in synchronism and from one control point.

In response to this need the electrical department at the Metro-Goldwyn-Mayer Studios developed a direct-current self-synchronous system for remote control of the shutters in groups. They have obtained interesting results in special-lighting effects such as the simulation of the sunrise following the rainy season in "The Yearling," and the Easter sunrise service in the "Three Darling Daughters." The lighting setup for the sunrise effect in "The Yearling" involved remote control at an extremely slow speed with as many as 40 individual shutters operating in exact synchronism.

Direct-current self-synchronous remote-controlled shutters are now available (see Fig. 1) and are being successfully used in the studios. The shutter is an improved design of the Venetian-blind type which has been used in the studios for several years. The shutter motor is

* Original manuscript received by the Society August 9, 1948.

essentially a direct-current self-synchronous motor constructed integral with a gear-reduction unit. The transmitter is in the form of a rheostat whose brushes can be manually rotated by a handle external to the rheostat housing. Approximately 180-degree motion of the handle is required to rotate the remote-controlled shutter blades through their full travel.

Fig. 1—Remote-controlled shutter shown mounted on a set-lighting arc lamp, connected through cables and plugging box to a transmitter capable of positioning up to 15 shutters, as manufactured by the Mole-Richardson Company.

Friction slip clutches are provided in the shutter-motor gear-reduction boxes for synchronization. After a group of shutters have been set up and connected to the direct-current supply, one complete movement of the transmitter operating handle from its open to closed position, or vice versa, will result in the synchronization of all the shutter blades of all connected shutters. A reversing switch is included on each shutter motor. With this switch thrown to the "normal" position the shutter blades will follow the movement of the transmitter operating handle in the normal fashion; that is, moving the transmitter handle to the open position will result in the blades' opening, and movement of the transmitter handle to the closed position will cause the shutter blades to close. If the switch on a particular shutter motor is thrown to the "reverse" position, the operation of the blades on that shutter will be out of phase with the remainder of the units. Thus it is possible to cause some shutters to close as others open and vice versa in any desired combination.

Each of the transmitters is capable of operating one to fifteen shutters. The standard equipment includes a plugging box connected to the transmitter with 50 feet of 3-conductor rubber-covered cable. Various shutters can be plugged into this plugging box with their respective 25-foot cables, or a group of shutters can be interconnected in a series-parallel arrangement to the plugging box. If it is desired to operate more than 15 shutters in a unit, provisions can be made to operate more than one transmitter from a single handle.

A direct-current system has advantages over an alternating-current system in the following respects:

(1) Direct current is always available as a power supply on the sets whereas in some locations there might be no alternating current.

(2) The direct-current control motors produce no noise such as might be present in the form of a 60-cycle hum in the alternating-current motors.

(3) The direct-current self-synchronous motors cannot be damaged by overload if stalled out of correspondence.

(4) The direct-current system requires three conductors to each motor whereas an alternating-current system would require five.

The position of the shutter blades follows the position of the transmitter and the speed of the shutter-blade movement follows the speed of the movement of the transmitter. For dimming purposes the blades can be made to move as slowly as it is possible to turn the transmitter. There is a limiting maximum speed at which the system can be operated without having the shutter blades fall out of step or lose synchronism with the transmitter. However, in actual service with the shutters simulating the turning off and on of lights in a room from a snap switch, it has been determined that the shutter blades will travel from their full open position to their full closed position or vice versa in four frames on the film. Hence, the time required for the blades to rotate through their full travel is one sixth of a second. This speed is adequate for any situation which is anticipated in studio lighting effects.

"Snap-switch" operation of the remote-controlled shutters was well executed in a recent production at the Warner Brothers studios.

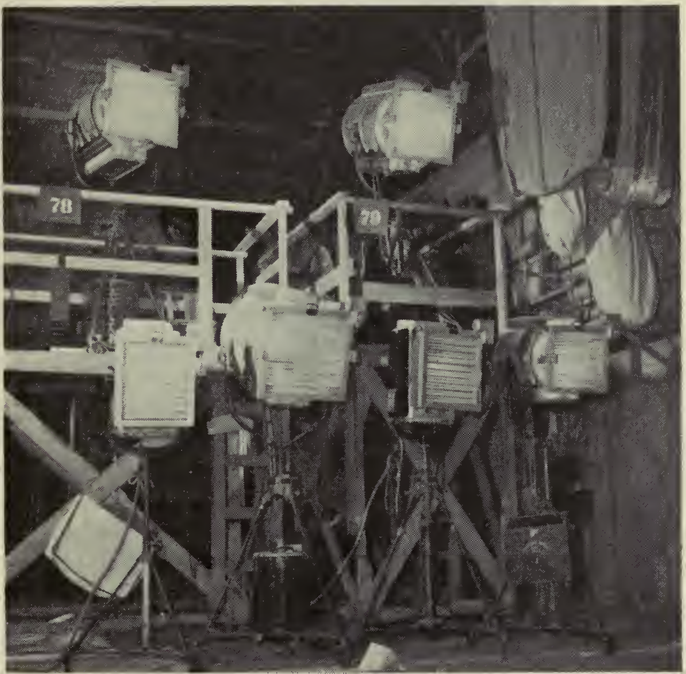

Fig. 2—A group of remote-controlled shutters mounted on arc lamp rigged for studio set lighting. Courtesy of Electrical Department, Warner Brothers Pictures, Inc.

In a scene in this picture an actress walks out of a living room, turns off the living-room lights, and enters a bedroom. She walks to the bed and turns on the bed lamp, then back to the wall switch and snaps off the main bedroom lights. The actress goes to bed and shortly thereafter turns off the bed lamp, at which time moonlight appears through the bedroom window. The set lighting for this rather complicated sequence of light changes was accomplished by means of the remote-controlled shutters on the set-lighting lamps operated by special motor-driven transmitters developed by the Warner Brothers electrical department. The control circuits for the shutters were connected to and operated by the various light switches which the actress operated in the scene. The synchroniza-

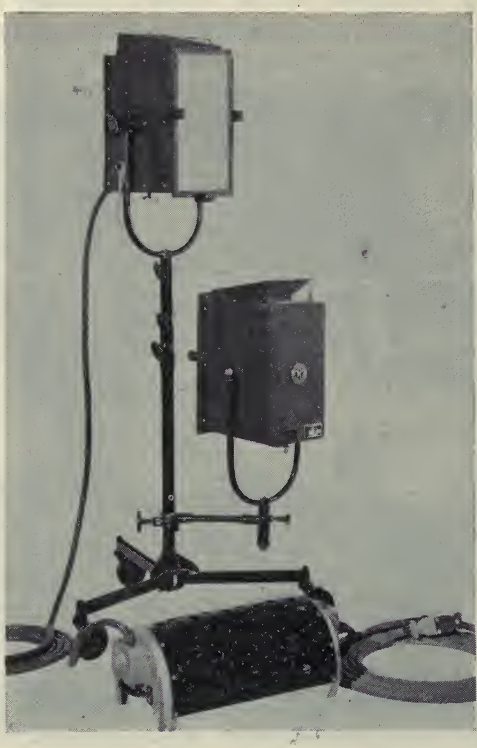

Fig. 3—Mole-Richardson Type 400 arc lamp.

tion of the variations in lighting with the operation of the various light switches was perfect, and there was no possibility of missing a cue.

The remote-controlled shutters were again used in a recent Warner Brothers production to simulate the illumination in a room coming through a window from a flashing neon sign. The neon sign, complete with its flashing mechanism, was installed on the set outside of the window. Its operation was such that it flashed from red to white, to green, to white, to red, to white, and so on. Lamps were rigged on the set with red filters to simulate the red portion of the neon-sign lighting, green filters to simulate the green portion, and no filters to simulate the white portion. Remote-controlled shutters operated by the specially constructed motor-driven transmitters were mounted on the lamps. The circuits between the transmitter and the shutters passed through relays which were electrically operated by the neon flashing mechanism. Thus the operation of the various shutters was automatically synchronized with the flashing mechanism of the neon sign, and a perfect lighting illusion was created.

Small Arc Lamp for Close-to-Camera Work

A small lightweight arc lamp is now available which can be located close by the camera lens or concealed behind relatively small objects (see Fig. 3). It is essentially one half of a Type 40 Duarc and when supplied with a reflector and diffusing glass will produce an intensity of 125 foot-candles at 10 feet with a spread of about 140 degrees. It can also be equipped with a spherical mirror and Fresnel lens to produce an intensity of 250 foot-candles at 10 feet with a narrower spread of about 80 degrees. The arc current is 40 amperes. The lamp weighs about 35 pounds and is capable of being operated in either the vertical or horizontal position. A separate grid unit is located about 25 feet from the lamp.

This small arc lamp has been used in several productions close by the camera for close-ups to produce a soft front fill light to wash out undesirable shadows, or in locations slightly on one side of the camera to give a close-in key light. Being small in size it lends itself to concealment behind relatively small objects, columns, or beams.

The "Brute" Lamp

The Mole-Richardson Type-450 "Brute"[1] (see Fig. 4), having twice and in some cases more than three times the illumination of any single source previously used, has proved itself to be an extremely valuable tool. One of its chief uses is to create an illusion of "one-source" lighting, casting single well-defined shadows through the complete scene of action. The Brute has in numerous cases made it possible to illuminate sets adequately with fewer lighting units than otherwise would have been required. For large, deep sets this lamp can provide the required level of illumination throughout the full depth of the scene. It has also been found to be useful for providing "booster light" on outdoor sets.

Small Incandescent Bulbs for Special Effects

One of the lamp-manufacturing companies has developed and introduced a small line of incandescent bulbs for special-effect lighting. One of these lamps is known as catalog No. 25S6 (see Fig. 5) and has a 25-watt, 115- to 125-volt filament placed in a bulb $^3/_4$ inch in diameter and about $1^1/_2$ inches long. This motion picture effect lamp has an average life of 50 hours. Another has a 25-watt, 50-hour filament placed in a small bulb $1^1/_2$ inches in diameter having a built-

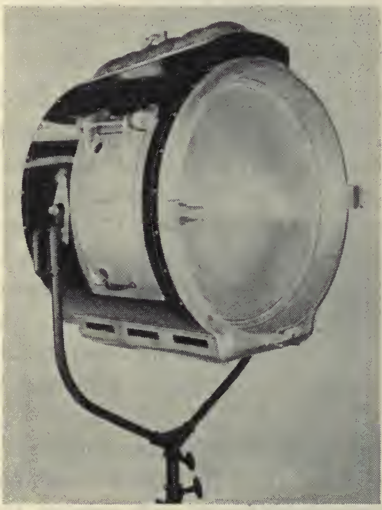

Fig. 4—Mole-Richardson Type 450 "Brute" Molarc.

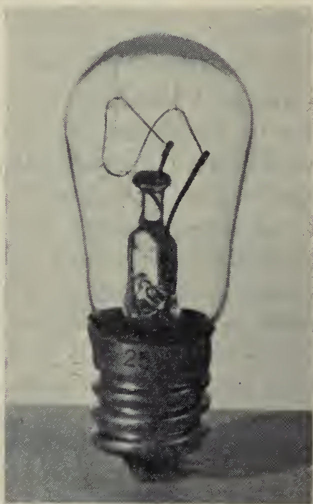

Fig. 5—Small special-effect incandescent lamp, Catalog No. 25S6.

in reflector and is known as catalog No. 25R12DC (see Fig. 6). It is in effect a miniature reflector photoflood. This lamp will produce a light intensity of approximately 75 foot-candles at 20 inches.

Both of the above midget-size lamps lend themselves to being concealed behind small objects and have a number of special uses for small lighting effects.

II. New Applications of Standard Commercial Lamps

Airplane Landing Lights Used for Automobile Headlamps

Out-of-door scenes simulating night conditions are frequently made in broad daylight with a filter over the camera lens in order to obtain a night effect but still have the entire scene illuminated so as to

Fig. 6—Small incandescent reflector lamp, Catalog No. 25R12DC.

produce good definition on the screen. Ordinary automobile headlamps under these conditions do not appear lighted unless perhaps the headlights are aimed directly at the camera. Many attempts have been made to illuminate more brilliantly the headlight lens by paralleling filaments in a bulb, using 50-candlepower bulbs, overvoltaging filaments, etc., with mediocre results.

An outstanding successful method is to use sealed beam-type airplane landing lamps developed for military craft which are rated at 450 watts and fit the regular sealed beam-lamp assemblies on automobiles (see Fig. 7). Such a lamp is so powerful that in a recent color picture the headlight beams on an actress's dress showed clearly on the screen as she walked in front of the automobile even though the picture was actually taken in sunlight with the camera filtered to simulate a nighttime setting. This lamp is available as a No. 4540 which is rated at 450 watts, 13 volts and No. 4541 which is rated at 450 watts and 28 volts. Both lamps have a 25-hour average life.

Fig. 7—Airplane landing lamp Catalog No. 4540.

Photo Reflector Lamps Applied for Fill-Light Illumination

A reflector photoflood designated as the RFL2 (see Fig. 8), a 500-watt, 115- to 120-volt floodlamp, was used in 1947 much more extensively than in the past for delivering a flood of light used for fill-in purposes on locations. Occasionally where greater distances were involved or where small key-lighting effects were desired, the RSP2 photospot was used. The photospot lamp is identical in size, shape, wattage, and color temperature with the photoflood but has a much narrower and several times more powerful beam. Generator capacity is often at a premium on locations and although these reflector lamps have a short life, they can be employed advantageously under such conditions to obtain a relatively large amount of light with the limited power supplied. Being light in weight these lamps simplify the transportation problems but,

Fig. 8—The RSP2 photospot, left, and the RFL2 photoflood, right.

however, do not allow the flexibility of control of illumination which is characteristic of the focusable Fresnel-lens units.

III. RESULTS OF TESTS PERTAINING TO COLOR RENDITION OF 16-MM COMMERCIAL KODACHROME

Effect of Arc-Lamp Supply Voltage Upon Color

Tests were recently conducted at the Mole-Richardson Company in conjunction with the Eastman Kodak Company to determine the effect of variations in arc-lamp conditions upon the color rendition of 16-mm Eastman commercial Kodachrome (3200-degree Kelvin) film. The tests were made using an M-R Type 170 Molarc lamp with a new Y-1 filter for illumination with a Wratten No. 83 filter and the proper emulsion color-correction filter over the camera lens. The normal current drawn by a Type 170 arc is 150 amperes with a line voltage of 115 volts. Photographic tests were made under the following three sets of conditions:

(1) The line voltage was varied from 108 to 118 volts with the carbons adjusted so that the arc current was maintained at the normal value of 150 amperes in each take.

(2) The line voltage was maintained at 118 volts and the arc current varied from 134 to 158 amperes by adjustment of the position of the carbons.

(3) The arc lamp was adjusted for normal operation of 150 amperes with a line voltage of 115 volts, and then the line voltage was varied from 108 to 118 volts with arc current varying in correspondence with the variations in line voltage.

In each take the lamp was spotted or flooded as necessary to maintain the same light intensity of approximately 1200 foot-candles on the subject. No noticeable visual effect in color was observed under the above variations of arc-lamp illumination.

The Committee plans to make similar tests, the results of which can be published in a subsequent report, to determine the effect of variations of incandescent lighting on the color rendition of commercial Kodachrome film. Information published in the Photo-Lab Index[2] indicates that the color temperature of incandescent illumination will not visually distort the color on the film unless it departs as much as approximately 100 degrees Kelvin from the correct value. The color temperature of photographic incandescent lamps changes from the rated value about 10 degrees Kelvin for each volt difference between the actual supply voltage and the rated voltage of the lamp. Hence a 115-volt lamp operated at 125 volts will have a color temperature which is 100 degrees Kelvin higher, or if operated at 105 volts its color temperature will be 100 degrees Kelvin lower than the rated color temperature.

The above tests would indicate that color is not appreciably affected by the usual expected operating variations encountered with illumination. However, the importance of maintaining correct line voltage should not be minimized. Even though line voltage can vary to a certain extent without appreciably affecting the color, such variations definitely affect the intensity of illumination and the efficiency of arc operation. Line voltage therefore should be maintained as closely as possible to the normal value in order that variations in light intensity and abnormal arc operation are kept to a minimum.[3]

Effect of Maintenance of Arc Lamps Upon Color

The importance of maintaining clean arc-lighting equipment was demonstrated in split-screen tests recently conducted at the Mole-Richardson Company in conjunction with the Eastman Kodak Company. A subject was illuminated with a clean M-R Type 40 Duarc lamp and photographed on Eastman commercial Kodachrome (3200 degrees Kelvin) film with a Wratten No. 83 filter and the proper emulsion color-correction filter on the camera. This exposure was made on one side of the film. The other half of the film was later exposed with all conditions remaining the same except that the clean Duarc was replaced by one whose front-door glass and reflector were considerably contaminated with the arc-flame residue material which accumulates with time if the lamps are not properly maintained. This split-screen test clearly indicated that the color in the picture tends strongly toward the yellow if dirty lamps are used for illumination. All arc-lighting equipment should be kept clean to avoid such off-color effects.

STUDIO LIGHTING COMMITTEE
1948

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SAMUEL EDWARD SHEPPARD
1882–1948

SAMUEL EDWARD SHEPPARD was born in Catford, England, and was educated at St. Dunstan's College and University College, London. At University College he obtained the degree of B.Sc. by research in 1903, for a thesis dealing with the theory of the photographic process, and involving a repetition and extension of the earlier work of Hurter and Driffield. This work was greatly extended in his research for the D.Sc. degree, which was granted in 1906 for a thesis which was published in 1907 jointly with that of C. E. K. Mees under the title of "Investigations on the Theory of the Photographic Process."

In 1913 Dr. Sheppard accepted an invitation to take charge of the sections of physical and colloid chemistry in the Kodak Research Laboratory, which had just been organized under the direction of Dr. Mees at Rochester, N. Y.

His work on photography covered the whole of photographic chemistry including the study of the process of development, the structure of the light-sensitive emulsion, the nature of the latent image, and the causes of sensitivity in photographic emulsion. In addition, he made some important advances in colloid chemistry, including the use of mixtures of powdered coal and oil as a fuel, and methods of electroplating rubber in thin coatings. His early work in the United States dealt principally with the physicochemical properties of gelatin, but about 1920 he turned his attention to the action of light on the silver halides and the nature of sensitivity, and published a series of papers on the theory of photographic sensitivity and the formation of the latent image.

The well-known sensitizing property of gelatin in the photographic process led to a systematic study of the difference between photographic gelatins in their sensitizing power and the nature of the substance in gelatin which conferred sensitivity. By a painstaking series of analyses, it was found that the sensitizer inherent in natural gelatin was concentrated in the liquors obtained by the acid treatment of the raw material after liming, and eventually it was found that the chemical properties of the sensitizer corresponded to those of allyl thiourea and that therefore the gelatin sensitizer was essentially one which could produce silver-sulfide specks in the silver-bromide crystals.

This discovery is perhaps the major advance made in Sheppard's scientific career. All further study of the photographic properties of gelatin, of the nature of the sensitivity of silver halides, and of the latent image have been conditioned by it. Its publication won for Sheppard instant recognition. He was awarded the honorary fellowship of the Royal Photographic Society in 1926, the progress medal of the Royal Photographic Society in 1928, and the Adelsköld medal of the Swedish Photographic Society in 1929. In 1928 he delivered the Hurter and Driffield Memorial Lecture to the Royal Photographic Society, and in 1930 received the Nichols medal of the American Chemical Society. He was made a Fellow of the Society of Motion Picture Engineers in 1944 and an honorary Fellow of the Photographic Society of America in 1946.

Since 1930, Dr. Sheppard's scientific work covered a prodigious range of knowledge. Besides the work on the latent image, he studied such matters as the photovoltaic effects, that is, the electrical response of silver halide to light, the colloidal structure of film-base materials and their physicochemical and elastic properties, the nature of development, and particularly the nature of dye sensitizing, the adsorption of sensitizing dyes to silver halides, the structure of the layers which they formed, and their sensitizing effects.

More than any other single worker, Dr. Sheppard has been responsible for our present knowledge of the theory of the photographic process. He explored every section of the chemistry of that process, and everywhere his studies brought light.

C. E. K. MEES

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