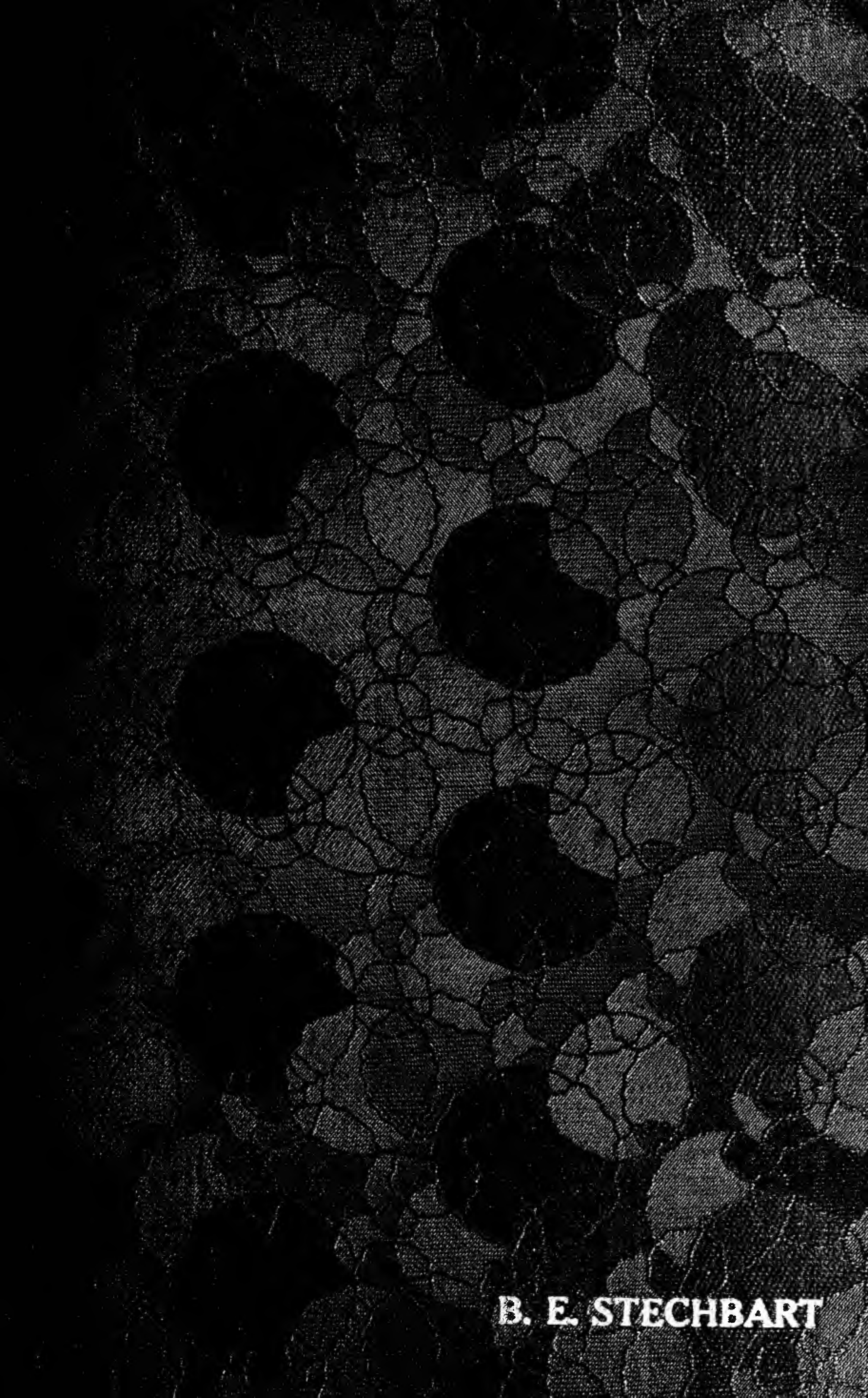

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ME XXIII NUMBER ONE

JOURNAL
of the
SOCIETY OF MOTION PICTURE ENGINEERS

JULY, 1934

HED MONTHLY BY THE SOCIETY OF MOTION PICTURE ENGINEERS

The Society of Motion Picture Engineers

Its Aims and Accomplishments

The Society was founded in 1916, its purpose as expressed in its constitution being the "advancement in the theory and practice of motion picture engineering and the allied arts and sciences, the standardization of the mechanisms and practices employed therein, and the maintenance of a high professional standing among its members."

The membership of the Society is composed of the technical experts in the various research laboratories and other engineering branches of the industry, executives in the manufacturing, producing, and exhibiting branches, studio and laboratory technicians, cinematographers, projectionists, and others interested in or connected with the motion picture field.

The Society holds two conventions a year, spring and fall, at various places and generally lasting four days. At these meetings papers dealing with all phases of the industry—theoretical, technical, and practical—are presented and discussed and equipment and methods are often demonstrated. A wide range of subjects is covered, many of the authors being the highest authorities in their particular lines of endeavor. Reports of the technical committees are presented and published semi-annually. On occasion, special developments, such as the S. M. P. E. Standard Visual and Sound Test Reels, designed for the general improvement of the motion picture art, are placed at the disposal of the membership and the industry.

Papers presented at conventions, together with contributed articles, translations and reprints, abstracts and abridgments, and other material of interest to the motion picture engineer are published monthly in the JOURNAL of the Society. The publications of the Society constitute the most complete existing technical library of the motion picture industry.

JOURNAL

OF THE SOCIETY OF

MOTION PICTURE ENGINEERS

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Published monthly at Easton, Pa., by the Society of Motion Picture Engineers.
Publication Office, 20th & Northampton Sts., Easton, Pa.
General and Editorial Office, Hotel Pennsylvania, New York, N. Y.

Entered as second class matter January 15, 1930, at the Post Office at Easton, Pa., under the Act of March 3, 1879. Copyrighted, 1934, by the Society of Motion Picture Engineers, Inc.

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REPORT OF THE COMMITTEE ON STANDARDS AND NOMENCLATURE*

Since the last report, this Committee has concentrated its efforts on the preparation of data for a new issue of the Standards Booklet. Much new material has been included, and some of the data contained in the old booklet have been rearranged and amplified. The material for the new booklet will be published in an early issue of the JOURNAL, and will contain data on cutting and perforating dimensions of raw stock with tolerances, for 35- and 16-mm. sizes. Charts showing dimensions and location of camera and projector apertures, and sound track location for 35-mm. and 16-mm. sound film will be included. The standard 35-mm. sprocket specifications have been revised.

The German standardizing body has accepted the dimensions of the S. M. P. E. standard 16-mm. film, but has made proposals differing from them in the following respects, contained in a communication from Mr. Flinker of the Standards Committee of the Deutsche Kinotechnische Gesellschaft, dated February 8, 1934:

> At first, it appeared that these proposals corresponded with those of the American Standards Committee, which had been published on page 478 of the JOURNAL of the S. M. P. E., Nov., 1932. Later, however, it became obvious that the proposals of the two Committees differed considerably, especially in two respects:
> (*1*) The position of the sound track relative to the picture.
> (*2*) The position of the emulsion side in the projector.

In regard to (*1*), the German proposal states that the location of the sound track on the outside (when film is passed through a projector operated from the right-hand side when facing the screen) has advantages in constructional possibilities of equipment. The claims relate to details of arrangement of sound reproducer parts, and the arguments depend upon the mechanical design under consideration. It seems possible to design arrangements having all the advantages mentioned, or rendering them impertinent, with the sound track on the inside.

In regard to (*2*), quoting from the German report:

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

> The German Standards Committee agrees with the opinion of the American Standards Committee that it would be advisable to establish for all types of film a uniform position of the emulsion side in the projector, in order to avoid a differential focusing of the sound optic; they have come to the conclusion, however, that this is not possible in every case without encountering serious technical difficulties. It would be desirable, however, to come to some agreement on the subject, so that the designer would know what position he must first of all take into consideration.

The German Committee recommends that the 16-mm. film be projected with the emulsion side toward the light, except in the case of 16-mm. reversal film. The S. M. P. E. Standard is to project all 16-mm. film with the emulsion toward the screen, except in the case of Kodacolor or Keller-Dorian color prints. The German Committee points out that contact printing would require that the emulsion be run toward the light. Preference is stated for optical printing with the emulsions facing each other, resulting in prints to be projected with the emulsion toward the light. For home use either reversal film or optically reduced prints are required, as the pictures are made by the user of the projector or obtained from a library. In both cases, the emulsion may be away from the light in projection.

As mentioned by Mr. Flinker, absolute standardization of the position of the emulsion side in the projector for all conditions seems to be impossible. The Standards Committee will study the proposals regarding this point, however, and endeavor to reach a mutual agreement with the German Committee. Conclusions regarding the most important types of prints depend upon the fields of application. The S. M. P. E. Standards Committee has not found that information received indicates any advantage in optical reduction printing by facing the emulsions toward each other; and, therefore, in this case, which is the more important one, the prints can be projected with the emulsion toward the screen.

Quoting again from the German communication:

> There are still other queries to be settled by the American and German Standards Committees; for instance, the longitudinal distance between the sound and the picture, shrinkage, and standardization of sprocket wheels, but no reference is made to these points in the report. The German Standards Committee is convinced that an agreement with regard to these questions can be deferred until a later date, and that no difficulties are likely to be encountered in this direction after the position of the sound track and the emulsion side in the projector has been agreed upon. It is the earnest desire of all German, and, we feel sure, also of American film technicians, that such an agreement should be

> arrived at. In Germany, the question whether or not it would be possible to adopt the American proposals has been studied very thoroughly.
>
> All large factories in Germany actually interested in the matter have thoroughly gone into it, but they have all come to the conclusion that in practice there are so many important arguments in favor of an alteration to the American proposals that even if they were to be adopted, the question of an alteration would be bound to turn up again in the near future; and that the sacrifices then incurred by an alteration would be even greater if, in the meantime, a further supply of projectors according with the American standards has been put on the market. The German Standards Committee is therefore of the opinion that it would be advisable for the American industry to reconsider the question now, and trusts that the American Standards Committee, after having studied the above viewpoints in regard to the position of the sound track and the emulsion side in the projector, will agree with the German proposal. As the ultimate date for the final decisions regarding German Standards is March 15, 1934, it would be necessary to have the decision of the American Standards Committee here in Berlin by March 5, 1934, in case they also desire an agreement.

This report was not received in time to arrange for a meeting of the S. M. P. E. Standards Committee to consider it, and reply before March 5th. In the absence of the chairman, Mr. C. N. Reifsteck transmitted a reply on the specific points mentioned.

The complete report will receive further consideration by the Standards Committee, so that the information in the Standards Booklet when submitted to the Board of Governors for approval will be final; and it is hoped will be acceptable to the German Committee.

No further action has been taken in regard to the proposals from the British Standards Committee for a standard film core for 35-mm. raw stock and a proposed universal sign for all 35-mm. safety film.

In the near future, the Committee plans to consider standards for 16-mm. sprockets having one row of teeth, as required for sound film. It is planned to study the results of the work of the Laboratory and Exchange Practice Committee, now studying the problem of standard reels for release prints.

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REPORT OF SOUND COMMITTEE*

In a communication addressed to the Chairman of the Committee by President Goldsmith, about the middle of March, the Committee was asked "... to formulate standards of sound recording and reproduction (audio-frequency characteristics) of such a type that the producing studios and the theater circuits can all agree to accept them at a reasonably early date after the standards shall have been agreed upon. The present state of sound recording and reproducing indicates that the matter is definitely urgent. There is an unnecessary amount of deviation in releases from the various studios, and it is obvious that the full advantages of improved methods of reproduction can not be realized under the present conditions. Such standardization is the most important problem facing the Committee."

In order to attack the problems indicated in the above paragraph it was thought advisable to establish two major sub-committees of the Sound Committee, one of the sub-committees to be representative of the East Coast and the other of the West Coast. Mr. M. C. Batsel has been appointed Chairman of the Eastern Sub-Committee, the remainder of the personnel being as indicated at the end of this report. Establishment of the Western Sub-Committee awaits advices from Mr. H. C. Silent, Executive Vice-President of the Society, who has been requested to assist in selecting its personnel.

On April 12th, the East Coast Sub-Committee met at the Hotel Pennsylvania, New York, at which meeting the discussions and conclusions that were reached were, it is believed, of particular significance to the Society and to the motion picture industry in general. The first question considered was, "Is it agreed that frequency characteristics measured in current or power are a measure of quality?" In answering the question, the Committee agreed that "in a linear, flutterless, noiseless system, frequency range measured in current or power is one factor that determines quality." It was agreed that for the purpose of study by the Committee, the sound system should be divided into four sections:

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

(1) Acoustics of the stage and characteristics of the microphone.
(2) From the output of (1) to and including the release print.
(3) From the release print to the input of the loud speaker.
(4) From the loud speaker to the ear.

One of the most difficult tasks was to determine a starting point for the discussion. It was the consensus of opinion, however, that a standard for determining frequency characteristics should be established. It was agreed that frequency characteristics should be measured in terms of calibrated prints of frequency film, this print corresponding to release prints. A print is being prepared, to be independently calibrated in the Bell Telephone Laboratories and in the laboratories of the RCA Victor Co., which, when completed will be kept in the offices of the Society as a reference standard. Data will be available in the S. M. P. E. office regarding the measuring circuits employed in calibrating the film, and the methods of making comparisons with sub-standards. This film will be available to studio personnel for use in calibrating secondary standards.

An attempt will be made, by the time of the next meeting, to obtain data on the frequency characteristics being used in the several recording studios in the East. These data will serve as a basis of discussion of present practices and methods followed in determining the characteristics now employed.

It is the aim of the Sound Committee to lay a foundation for one, two, or even five years' work, if necessary; and to formulate a plan so that at the completion of the program, systematic and comprehensive coördination between the production studio and the theater can be achieved. It is hoped that the industry, as a whole, may become more closely associated, and that the theater audience may enjoy to the fullest extent the benefits that the industry is technically capable of giving.

L. W. DAVEE, *Chairman*

East Coast Sub-Committee

M. C. BATSEL, *Chairman*

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R. M. EVANS	W. A. MACNAIR	R. O. STROCK
O. SANDVIK		S. K. WOLF

DISCUSSION

MR. SPONABLE: I received one of the first copies of the Standard test reel devised by the Projection Practice Committee, and have been using it almost constantly since the time I received it. There is an indication that the reel is gradually changing as a standard of frequency, also as a standard of sound quality. The Committee should investigate the question of how long a standard would remain a standard for frequency and speech and quality.

MR. DAVEE: When the films that we propose to make are calibrated, the circuits that are employed in the calibration will be in the Society's offices. Both the RCA Victor Company and the Bell Telephone Laboratories will calibrate the same film, and if a difference is found to exist between the calibrations, it will have to be eliminated.

When the circuits are submitted to the Committee, it is expected that they will not differ so much as to forbid a satisfactory correlation between the two, and a standard measuring circuit will be arrived at so that we can check the frequency of the standard film from time to time to find out whether it has deteriorated or not.

We do not particularly care what that frequency characteristic is; it can be anything, so long as we know what it is and can check it from time to time.

MR. KELLOGG: The calibration of such a film involves not only correction for the frequency characteristics of the electrical circuits and equipment, but complete specification of the characteristics of the optical system. The first and obvious item is the width of the scanning or slit image on the film. That is very readily defined. The next question would be the percentage of light falling within the nominal image width; and even the distribution of light in both directions might have to be specified, especially if we are much concerned with the very high frequencies. The correction of the solid angle of collected light on the photo-cell side would probably have to be specified in order to obtain the same ratio of scattered light to specularly transmitted light in all calibrations.

MR. DAVEE: Those points have already been discussed by the Sound Committee, and as soon as we have the circuits I believe they will be covered.

REPORT OF THE NON-THEATRICAL EQUIPMENT COMMITTEE*

A general survey of the many uses of films, both 35-mm. and 16-mm., as applied to non-theatrical purposes, has been begun by the Committee. There seems to be no question but that this field is growing in importance at a rapid rate, and bids fair to approach the theatrical field in importance, if not eventually in film footage used. The historical situation with reference to non-theatrical films may be of some interest. For more than a decade, individuals and organizations making use of motion pictures for non-theatrical purposes have urged theatrical film producers to provide pictures especially made for non-theatrical showing. To these urgings, the theatrical industry has made practically no response, but has maintained the general attitude that such production was the legitimate function of the theatrical producing companies, and would be taken up at some later date. In addition, the theatrical industry has generally been reluctant to permit a wide non-theatrical use of pictures originally made for theatrical exhibition. As a result, the supply of non-theatrical films and the ready availability of up-to-date theatrical films for non-theatrical purposes have been greatly limited.

With the introduction of personal movies, however, there came into being a means of modifying the existing situation with reference to non-theatrical film and film exhibitions. Before personal movies had been in use for any length of time, manufacturers of sub-standard equipment met the challenge of auditorium projection, with the result that it is now possible to fulfill practically every important non-theatrical film need with sub-standard equipment and film. The ready supply by the sub-standard industry of material that had been withheld by the theatrical producers has convinced non-theatrical interests that sub-standard projection and, in a large number of instances, sub-standard production, is the real answer to the non-theatrical motion picture problem. At the present time, the trend of non-theatrical film usage is toward the sub-standard widths. The special problem of supplying sub-standard versions of

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* Presented at the Spring, 1933, Meeting at Atlantic City, N. J.

standard sound subjects for non-theatrical projection is being given active attention at this time and the availability of such films is definitely on the increase.

Obviously, the scope of this committee is quite broad, but the following comprise the main divisions:

(1) Industrial Advertising: 35-mm. and 16-mm.
    Silent
    Sound
(2) Educational: 35-mm. and 16-mm.
    Schools
    Industrial employee training
(3) Medical
(4) Religious and ethical
(5) Research
    Industrial
    Medical
(6) Film Slides
    Industrial
    Educational
(7) Records
    Library
    Bank
    Industrial
    Medical
    Insurance
(8) Legal
    Insurance
    Accidents
(9) Government
    All the above
    Military and naval
(10) Amateur
    Sports
    Miscellaneous

(*1*) *Industrial.*—This is by far the most extensively developed non-theatrical film application. Reference is made to *Motion Pictures in Industry,* published by the National Advertisers Association, Inc., 537 South Dearborn Street, Chicago (50¢ per copy).

(*2*) *Educational.*—The interest of educators and the appreciation of the practical value of films for teaching purposes are increasing with surprising rapidity. For reasons of safety, convenience, economy, *etc.*, 16-mm. film is used for educational purposes to a much greater extent than 35-mm. film. With the possible exception of large institutions where a regular projection room and operator are available, 16-mm. film will probably supplant the 35-mm. for educational purposes. Movies have been used extensively in various arts, in museum activities, for recording the activities of college and alumni organizations, and for physical education in its various phases.

Various departments of the U. S. Government have for many years used films for instructional purposes. The Civilian Conservation Corps project brought this possibility to the fore. The United States was represented at the International Congress on the Educational Use of the Cinema held at Rome, in April of this year. More and more material is being published covering this field.

(3) *Medical.*—The value of movies for photographing delicate surgical operations has been appreciated for a long time. Sixteen-mm. film and the convenient cameras and projectors available for it have induced a rapid growth in the number of such pictures taken. Several medical papers have been presented in full as movies, and it is now quite customary for medical papers to be accompanied by a movie. The medical and dental supply houses have extensive film libraries, and usually conduct movie "clinics" in conjunction with medical conventions. Several medical films have been made in Kodacolor, and, where conditions permit taking, Kodacolor is invaluable. This process is as yet available only in 16-mm.

(4) *Religious and Ethical.*—Selected films are quite often shown at church bazaars, and the like. Judging from comments made recently in some of the trade papers (*The Spectator*, Hollywood), there seems to be a growing tendency toward the wider use of more specialized films in this field. The Religious Motion Picture Foundation has brought about a very active production of sub-standard films for use in religious work, including films depicting missionary activities and those giving instruction in religious rituals. The Federal Council of the Churches of Christ in America maintains a department devoted to increasing the use of films not only in supplementary religious work but also in religious services.

Many Parent-Teacher Associations and other organizations are grading pictures as suitable or unusuitable for showing to children. Pictures, usually educational in nature, but often purely entertaining, are often shown in schools and in the club-houses of Boy Scout and similar organizations.

(5) *Research.*—Movies are being used extensively for all kinds of

research, especially high-speed (slow-motion) shots of fast action. Micro-motion is a specialization applied to studies in industrial efficiency, and is attracting considerable attention. Movies for medical research purposes have particularly great value, and have already been referred to under section *3*, on page 11.

(*6*) *Film Slides.*—Single frames of 35-mm. film are being used in place of regular lantern slides. Application is found in the industrial and educational fields. The Committee hopes to be able to obtain further data on the subject at a later date.

(*7*) *Records.*—Many large libraries, including the Library of Congress, The Huntington, and others are photographing valuable records on film. The U. S. Department of the Interior is now engaged in photographing the famous Yale Historical Collection. Thirty-five-mm. film is used mostly for this type of work. A special device, the *Recordak,* has found extensive application in industry for photographing bank checks, bills, statements, *etc.* This unit utilizes 16-mm. film.

By using film, copies of rare or cumbersome material are made available in a cheap, compact, and convenient form. It seems likely that such applications will find more and more favor. Movies are used extensively for obtaining historical records. A large number of war films, movies of past-presidents, *etc.*, are becoming of greater and greater importance. In the industrial field, movies are made of building and constructional operations of all kinds. In the medical field, record movies are of great value and are finding application in pediatrics and similar fields for encouraging patients by demonstrating that they are making progress, even though slowly.

(*8*) *Legal.*—Every now and then one hears of a court case in which movies are admitted as evidence: accidents and false insurance claims, particularly.

(*9*) *Government.*—The U. S. Government employs motion picture films for a large variety of purposes, which can be covered generally under the other classifications. The main divisions of such uses are for records, research, instruction, and propaganda.

(*10*) *Amateur, Miscellaneous.*—The amateur use of film is firmly established; and in this country at least one publication covers the field exclusively, while practically all the photographic magazines have sections devoted to the amateur movie maker. The amateur film user has gone so far in emulating his professional prototype and produces results of such high grade that efforts have been made to establish a specific name for this class. In many cases the amateur has gone off on experimental paths of his own. The equipment at his disposal is excellent and, in Kodacolor, he has a three-color process that the theatrical filmer does not possess. In subject matter, the amateur has separated widely from the theatrical filmer, and the production of amateur photoplays cast in the professional or theatrical vein has been more and more limited. Some amateur experimenters, such as J. S. Watson, Jr., and Melville Webber, have been recognized by critics of the motion picture art as workers of as great endowment as any theatrical directors or cameramen. The Amateur Cinema League, organized on a similar basis to the well-known Amateur Radio League, is firmly established, and is the sponsor of a large number of cine clubs in all parts of the world. These clubs engage in every type of cine activity, from the making of civic and local film records to quite elaborate dramatic productions.

An Amateur Cine Competition has been held by the magazine *American Cinematographer,* which bids fair to be an annual event. At least one foreign amateur cinema magazine is sponsoring a similar competition; each year the Amateur Cinema League selects the best pictures submitted to it for review. Outside these more highly organized activities, there is a growing army of film users (16-mm., $9^1/_2$-mm., and 8-mm.), whose shots are of purely personal interests.

In the field of sport, movies find extensive application. Quite a few universities make a regular practice of photographing football games and using the films for checking faults and improving the teamwork of the players. Similarly, movies are found of great help in practically all branches of sport. This is especially true of slow-motion or semi-slow-motion pictures.

(11) Civil, Social.—Movies, mostly 16-mm., have been used extensively for making records of civic developments, new buildings, parks, clean-up activities, safety and traffic regulations, *etc.* Use of movies in social work is increasing; they are used to popularize and explain what is being done or attempted, and have been found helpful in raising funds for many such purposes.

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THE ENGLISH DUFAYCOLOR FILM PROCESS*

W. H. CARSON**

Summary.—*The Dufaycolor three-color additive system of color cinematography, employing a geometrical color-screen or réseau imprinted on the film base, is briefly described. As many as a million color elements per square inch are employed, and a correct color balance is achieved by adjusting the area covered by the blue dye in relation to that covered by the two other primary colors. No appreciable changes of equipment are required in applying the system commercially, either in photographing, processing, or projecting, from what is now found in use.*

Many may wonder at the presentation of a paper on a subject as old in color photography as a color-screen process. However, the developments of the past two years have proved the process to be no longer in the theoretical and experimental stages but on a practical and commercial basis, and for that reason a discussion of the new Dufaycolor system seems to be in order.

Any engineering group may rightly be skeptical of the recommendation or adoption of any innovation in the industry that can not conclusively demonstrate its basic soundness in both the theoretical and practical fields. However, past experience has shown that new scientific developments and improvements must be injected into the industry from the bottom up rather than from the top down. The introduction of sound into the motion picture industry came after years of research and the expenditure of millions of dollars in experimentation, which have been little recognized by the layman or the box-office patron. It was only through the tremendous pressure brought to bear by the sound technicians who visualized its future that it was finally grudgingly accepted by the producer and exhibitor and even more reluctantly by the public. Today it is impossible for silent productions to compete with talking pictures.

The whole technic of producing silent motion pictures, including

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

** New York, N. Y.

script writing, directing, acting, photographing, lighting, stage construction, processing, projection, and theater construction, has been revolutionized to serve the new medium of sound. But in return for all that, a broadened scope of dramatic and popular application of sound pictures with respect to their increased entertainment value has been found. Since we are dealing with an industry that depends for its continued prosperity on its dollar-and-cent value and an adequate return to its stock-holders, it must be admitted that the advent of sound motion pictures has enabled the motion picture industry to retain a position in the entertainment field through a most trying period, when almost every other industry in the luxury field has been forced into bankruptcy, if not completely annihilated.

Color in motion picture photography must enjoy the same consideration in planning productions, selecting subjects, actors, make-up, costumes, settings, in directing, lighting, and photographing, that is now being given to sound, if it is to contribute as fully to the progress of the industry; but it can not fail to assume a position of similar importance in the very near future. No claim for originality is made for these statements, and recognition must fairly be given to the pioneer work that has been done by Technicolor under the able direction of Dr. Herbert T. Kalmus along those lines. The progress that has been made up to the present in recognizing a distinct technic in color production lends some encouragement to the conviction that producers are awake to the possibilities of color, and are only waiting to be shown the practical means of application and be assured consistently satisfactory results on duplication before making it a major consideration in future productions.

The first question that arises is whether colored motion pictures having a true color fidelity throughout the full range of the visible spectrum can be produced commercially for a slightly increased cost, which increase might be justified by an increase either in the box-office receipts or in entertainment value, permitting the motion picture to maintain or improve its present outstanding value as *entertainment* so that financially it may continue to compete successfully against other and newer amusements.

No industry that occupies such a paramount position as the motion picture industry occupies in the amusement field can afford to "rest on its oars" during a time when changing conditions in the social order are creating a superabundance of leisure for the average person, who can now indulge more frequently in the pleasures that formerly he was able to enjoy only to a limited extent; or, if these are not sufficient to satisfy his need, seek new and other diversions with which to fill his time. Countless thousands of dollars are being spent to create, on an ever-increasing scale, extravagant and spectacular productions that must in time break down of their own weight. Some new and startling feature must be introduced to rejuvenate the appeal, a feature that would admit of simplifying or abandoning the costly artificial settings and bring into play a new artistic medium, which, while new in motion pictures, is one of the primal appeals to which human beings react—*color*.

After a comprehensive study of all the theoretical processes available and those that have been in a measure successful, the conclusion was reached that two-color and three-color optical and imbibition processes have not, with existing equipment, both taking and projection, given a result on the theatrical screen that will satisfactorily fulfill these various requirements. The ideal method of producing colored motion pictures would seem to be a system by which such colored pictures could be made with the existing cameras and lighting equipment, and supplied to the exhibitor for satisfactory use on his present projection equipment without expensive alterations; and, what is equally as important, to accomplish that result without any radical change in the present laboratory procedure. Thus it would be possible for every producing company to add color as a supplementary feature to its productions without disrupting its organization or making large capital investments. All these requirements are fulfilled by the Dufaycolor process, here described.

For ordinary transparency purposes little importance seems to be attached to the pattern of the screen so long as the three primary additive color elements are present in the proper balance and proportion. Dufaycolor, Lumière, Agfa, Finlay, or other transparencies that are really representative of these systems will all produce apparently perfect color rendition with suitable transmitted light if viewed at a distance of about eighteen inches by the average eye or projected from standard lantern-slide size to the usual small-screen size.

Where non-geometrical color-screens are used it necessarily happens that masses of the red, blue, or green units occur in the form of blotches or larger areas, and it is obvious that for achieving perfect effects on greater magnification better results can be attained when the three primary color elements are regularly broken up into the smallest possible units and uniformly distributed. For that reason the geometric matrix or réseau, as it is termed, seems to have a decided advantage. It is believed that the Dufay system is the first screen process in which projection from standard 35-mm. film to theatrical screen size has been seriously attempted. The application of a réseau of this kind to a film base by mechanical means, on a regular and comparatively inexpensive commercial basis, further seems to enhance its value as an acceptable medium for use in the professional motion picture field.

The idea of applying a series of colored lines or squares to the film base, originally suggested by Vidal in 1895, was used by Dufay in the further development of the process under discussion, wherein a contiguous series of red and green squares (or any two of the primary colors) were placed alternately between lines of blue (or the third primary color). Theoretically it would not seem to be of great importance as to what order was used in the application of the three primary colors. In practice it was found that on account of the high visual contrast of the blue line, the screen so constructed was much more visible when magnified to the extent necessary in motion picture work than a different arrangement. At present the screen is produced with blue and red squares and a green line, which has the effect of reducing the visibility of the screen on projection.

It is obvious that the smaller the area of each individual unit, the more perfect will be the blending of the color units by the eye, even upon excessive enlargement, and the less the effect on image definition. It was formerly believed that fifteen lines to the millimeter was the limit of practical mechanical production, but within the last year a screen having nineteen lines to the millimeter (*i. e.*, one thousand lines and spaces to the inch) has been very satisfactorily produced, and recent improvements point to a still further reduction of the line width. Even with the present line width it has been found that the réseau is not visible beyond the first six rows of the seats in the average theater. This provides the present screen with approximately a million color elements to the square inch, and further diminution will have a progressively startling effect in definition and luminosity.

The statement that such a screen or réseau can be produced mechanically, consistently, in large quantities, on a commercial basis, and at a reasonable cost, will bear some scrutiny; so the first question that arises is, has it been done? The answer is that it is now being done by a reputable and well-known English manufacturer on 21-

inch acetate motion picture base in 1000-foot lengths at the rate of 90,000 35-mm. ciné feet per week. Increased production is contemplated immediately, and the reception of the film by the English producers has been very enthusiastic.

The next question is, how is it done? A film base of suitable thickness (acetate base has been used exclusively because eventually legal restrictions will require it, but similar results are possible on nitrate) is first coated with a thin layer of collodion containing a dye, let us say blue, adjusted to the spectral hue of the blue primary. After drying, the film is then passed through a highly specialized type of rotary printing machine consisting of a steel roller milled one thousand lines to the inch (really five hundred lines, with an equal number of spaces between). The machine embodies an elaborate ink distribution device for the roller; and underneath, in contact with it, a soft rubber covered roller capable of minute vernier concentric adjustment for controlling pressure. The ink used on the press is a special kind, forming a moisture resistant line printed upon the basic color. The idea of using a greasy resist was first suggested by du Hauron and Bercegol in 1907. And here again reference should be made to the remarkable far-sightedness of Louis Dufay in the application of the basic principle of the geometric screen and the use of resistant medium for applying the primary colors to the film base by mechanical means.

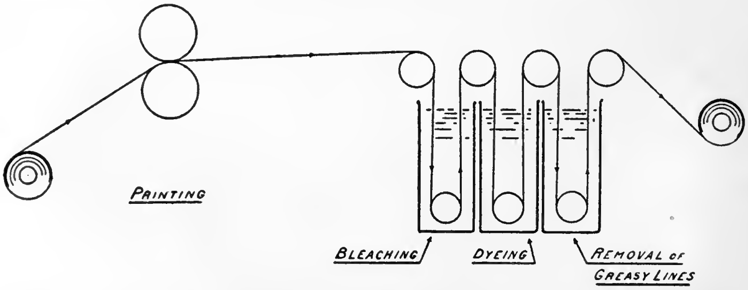

FIG. 1. Diagram illustrating the application of the resist, the bleaching of the spaces between the resist lines, the subsequent dyeing, and the scrubbing process for removing the protective ink.

In the development of any new idea, there must be some individual or group that has enough faith in its ultimate value to be willing to finance it through the sterile years when salaries must be paid and valuable council and encouragement given in the face of apparently meager progress. It has been fortunate that this process has been sponsored by Spicers, Ltd., of London. This firm, manufacturers of all kinds of fine paper products, is an old English family organization, whose commercial solidity has enabled them to keep their wheels turning through the past lean years, and who have provided the financial backing and the technical guidance of such men of their organization as A. Dykes Spicer and S. R. Wycherley to bring this process to its present degree of perfection. However, the credit for the practical application of the resist on a commercial scale must be given to Charles Bonamico, a French engineer with Spicer-Dufay. His engineering skill in perfecting a means of milling a steel roller for applying the lines, and the subsequent control of application of the ink, marks one of the outstanding factors in the success of the process.

Although the ink used in applying the resist is much thinner than would ordinarily be used for typographic purposes, under suitable conditions it assumes a partially dry state, providing lines having substantially sharp parallel edges and free from blur or creep, and when subsequently passed through a properly selected bleaching bath, produces perfectly clear white lines between the ink-protected lines.

In the same machine, which has been especially designed for the process, the film is then passed into a bath containing dye of such concentration that will give the primary red on the intermediate bleached white lines. Allowing time and space for suitable washing to remove the excess red dye, the film then passes into a solution and a mechanical scrubbing action removes the protective ink. A simple diagram illustrating the method is shown in Fig. 1. If at this stage the film be examined with a microscope, we shall find that it is covered with a fine grid of alternating blue and red lines, having the same width and with perfectly contiguous but not overlapping edges, and each line representing a perfect primary filter in the two colors named (Fig. 2).

After drying, the film is again passed through a similar rotary printing machine, but this time the lines on the printing rollers are at an angle of about forty-five degrees to the original lines (theoretically the best angle is not forty-five degrees: this has a very important bearing on other features of the process). The width of the lines applied in this operation is not the same as that of the lines applied in first, but is so controlled that the imprinted area alongside two contiguous squares, so formed, is equal to the area of each of the squares. The film is then bleached in a manner similar to that formerly described, the bleached line is dyed the third primary color (green), and the resisting ink is then removed in the same manner as described before (refer to Fig. 1). The film is then dried and wound up. This arrangement produces a perfectly balanced neutral grey screen when viewed or projected. When examined microscopically, a réseau such as illustrated in Fig. 3 is seen.

The next question refers to the emulsion to be applied to this réseau. While there are, of course, many applications for color film and the emulsion characteristics are correspondingly numerous, for the present only those that apply to cinematography will be considered.

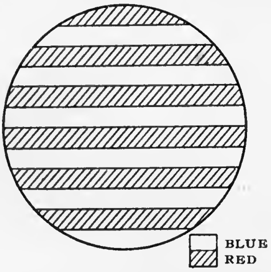

Fig. 2. Appearance of the film under the microscope, after the process illustrated in Fig. 1.

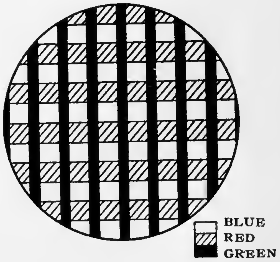

Fig. 3. Appearance of the réseau under the microscope, after application of the third color. (In recent screens the green lines are at an angle of approx. 45 degrees to the blue and red.)

It is interesting to note that in the very early stages of color development the theorists visualized an emulsion that was truly panchromatic and had a high speed and very fine grains. As no such emulsion existed at that time they approached the emulsion makers much as Macbeth sought the witches of Endor and suggested some diabolical brews that too often resulted in nothing more than toil and trouble, and never achieved results on a practical basis. For that reason it may be said that the development of color photography has had to mark time until the art of emulsion making could catch up with its theoretical requirements, and it is believed that that time has now arrived.

It would be of interest to review some of the problems of the photographic chemists. The art of emulsion making formerly depended upon controlling the balance of silver halide and gelatin characteristics, together with delicate manipulation of heating, digestion, washing, ripening, *etc.*, with more or less crude equipment. Today those factors have been so well correlated as to establish a science; and emulsion making equipment has become practically standardized, with automatic engineering controls that assure an accuracy permitting duplication of results within remarkably narrow limits.

Considering also the great strides that have been made within the past few years by all the large photographic manufacturers, both in this country and abroad, in controlling the size of grain of superspeed emulsions without increasing the fog or impairing the keeping quality; and further, in developing new sensitizers by means of which emulsions can be made selective to any portion of the spectrum, visible, infra-visible, and supra-visible, it can be understood that problems in the reproduction of color, that seemed insurmountable a few years ago, have now been resolved by the progress that has been made in the black-and-white field of the art. The application of these advances to color photography now realizes satisfactory results where before the same efforts met only with failure.

So now, for the requirements of this process, emulsions may be selected practically according to specification, provided the basic characteristics of the process are known. These factors are all well known, and are the same as those now operating in black-and-white technic: they may be briefly mentioned as speed, color-sensitivity, grain size, gradation, and gamma. With slight modification it may be said that a good panchromatic emulsion, rich in silver as compared with its gelatin content, with a color-sensitivity that will produce, as nearly as possible, the same density with all three of the primary colors, with a fine grain, and high speed will serve admirably for the process. Such an emulsion is now being used.

There are several important characteristics that had to be considered in selecting the emulsion that might be well discussed at greater length. First, the effect of wavelength on the gradation and gamma: Experience has shown that the effect of wavelength on gamma is negligible, provided it is measured at gamma infinity; but that, of course, must be considered in relation to exposure, development, and intermediate gradation. For that reason an emulsion has been selected that has a long straight line in its characteristic curve together with a short toe. So much progress has been made within the past few months that it is impossible to show by graphs the curves of the emulsion now being used, but it may be said that the range of latitude in the present emulsion is far greater than it was thought possible to produce a year ago. In any screen process it is imperative that the emulsion, no matter how thinly it may be coated, be capable of giving intense blacks, so that any colored area on the réseau may be effectually blocked out, allowing no dilution of the true color by the transmission of a foreign color that is not truly an additive component of the colors in the object being photographed.

Second is the question of the spectral value of the filters. Various statements have been made as to the proportion of the incident light that passes through the many types of matrices used in the various processes, and have ranged from ten to twenty-five per cent. In the Dufaycolor process the filter colors selected do not transmit in short narrow bands, but rather overlap from one to another much in the manner shown in Fig. 4. Whether that is theoretically the proper way to produce true color in a three-color additive process is of no particular concern if a result having a satisfactory color fidelity for the average eye is achieved. At the same time, such a procedure results in marked advantage as to the proportion of light transmitted to the emulsion on the taking film, and increases the luminosity of the resultant picture on the screen with ordinary projection light. (It has been noticed in this connection that a lower screen luminosity seems to be acceptable in color pictures than would be regarded as satisfactory in black-and-white.) The use of filters having such overlapping transmission characteristics may raise a question concerning the dilution of color on reproduction, but that will be covered later. The filters used also provide a remarkable in-

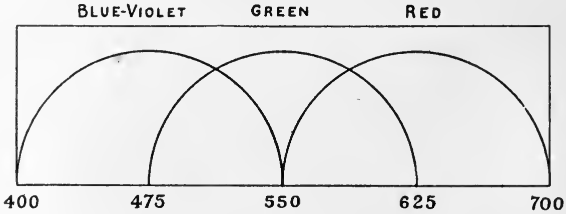

FIG. 4. Diagram showing the approximate overlapping of the spectral transmission of the color filters used in the Dufaycolor process.

crease in the latitude of exposure and development as compared with matrices in which filters having narrow transmission bands are used.

Much advancement has been made in England in the past two years in perfecting dyes capable of very much greater light transmission than was formerly attained, without sacrificing their spectral fidelity. These new dyes have been adopted by Dufaycolor. A method has been found to isolate them from the emulsion so that no desensitizing action takes place, and excellent adhesion between the matrix and the emulsion, which has heretofore often been unsatisfactory and extremely difficult to attain, has been accomplished. The two factors of increased speed of modern panchromatic emulsions and better dyes for the filters have made possible a film having a speed hitherto unattainable in screen processes.

Any color process that does not provide for duplication in unlimited quantities, of consistent fidelity, and on a commercial scale is, of course, not worthy of consideration. It is believed that methods have been found and patented by which to accomplish such results to such a high degree of satisfaction that it is almost impossible to distinguish between originals made in the camera for projection and copies made from the original master positive. Up to last year it was believed that the same type of emulsion would serve both for taking and for making subsequent copies or dupes. At present, however, it is believed that the master positive, which might be called the original (and made in the camera), should have a heavy coating of emulsion as compared with the stock used for copies. When it is reversed it seems quite flat and the colors feeble, but when duplicates are made from it by the latest methods on a suitable printing stock, the colors come up to full strength. The maximum density is about 1.2, and a very wide range of gradation is maintained.

It has not been found possible to produce an emulsion adapted to all light conditions, natural (daylight) and artificial (arc and incandescent), without using a compensating filter of some sort. Because of the fact that a large proportion of professional motion picture photography is done under artificial light it seems best for the moment to adapt the film to artificial lighting, and to compensate for other conditions by using the proper filters. While very fast emulsions have been developed for the system, no claim is made that the speed is comparable with that of black-and-white, since there must be a marked reduction in the transmission in any color process. However, a speed has been attained that makes it possible to fulfill the requirements of motion picture studios with the existing lenses and lighting equipment.

Now regarding laboratory treatment: Many studios are at present working on the "master positive" basis, on which a positive is made by reversal from the edited first print after the cutting and timing have been done in order to gain the advantage of reduced graininess and uniformity of density. Although no reference has been previously made, it is understood, of course, that the original film under this process is reversed to produce a positive result (it is possible to develop the film as a negative and make positive prints therefrom). The procedure in reversal is standard. Developers of various kinds have been tested, the best results having been achieved with *M-Q* ammonia of rather high concentration at 65°F. After the bleaching and the second exposure, the second development occurs in an ordinary metol-hydroquinone developer, and it is recommended that the second development be carried on under full illumination. It may be well to mention that by reversal the usual advantage of eliminating the larger grains of the emulsion is gained, leaving the smaller grains to form the reversed image. It should be noted also that the entire procedure can be accomplished on existing motion picture developing machines with only very slight, if any, modification, and is therefore adaptable without expensive changes in equipment or personnel by any producing company that operates its own laboratory.

No mention has as yet been made regarding the possibility of recording sound on the film; but that, of course, has been given full consideration. Several methods have been devised and patented for removing the screen or réseau, before the film is coated with emulsion, from the space along the edge of the film to be occupied by the sound track. In practice it has been found that such a procedure is not necessary, as the number of lines in the screen that is used is so great that any effect it may produce on the various types of sound recording equipment now in use will not produce a reaction within the audible range. Recording can be done by either the variable width or the variable density method if the intensity of the recording light source is increased enough to offset the reduction of light transmission by the réseau. Similar remarks apply to the reproduction of sound during projection.

The emulsion, which has been described as ideal for color reproduction, is of the same type that would be selected by the sound engineer as the best for true sound reproduction. Sound has been recorded on all the standard systems, including the Movietone News camera, wherein a sound record was taken, through the réseau, on the same film as that used for the picture. Originals and copies have given excellent sound reproduction and, although several English sound experts have expressed the belief that the réseau would interfere with some of the higher frequencies of the audible range, as yet no such interference has been detected in practice.

It has long been thought that it was impossible to reproduce from a screen transparency having a geometrical design due to the difficulty of exactly registering the colored areas in the original with the similar colored areas in the copy. The problem of avoiding moiré effects in reproducing through a geometrical screen has also been adjudged insurmountable but several simple and very ingenious methods have been developed to circumvent both those problems.

Most of the research in the development of this process, theoretical and scientific, has been done by T. Thorne Baker, a member of our Society. Many of the statements in this paper are based upon data that he has supplied.

Many technical points have been brought out in this paper that have not been fully covered; but as the purpose of this presentation is simply to describe the general process, it is hoped that further opportunity will be given later for their more detailed discussion.

DISCUSSION

MR. MITCHELL: What is the relative speed, compared to black-and-white?

MR. CARSON: Developments are occurring so rapidly that I hesitate to answer. I will say, however, that the film that I am showing here is approximately one-fourth as fast as black-and-white. We made some that were only one-third as fast. The fastest emulsion receives through the screen about one-third the light incident on the film.

MR. PALMER: Is the picture you are to show a reversal print or a print from the original?

MR. CARSON: Both. The first is an original or master positive, as made in the camera. The second will be a print made from some of the same scenes as a duplicate, made in England. It was developed under rather unfavorable conditions—by rack and tank, and not by machine; and the evidences of the rack marks are present in the print.

MR. POPOVICI: What kind of light was used for photographing? Arc or incandescent?

MR. CARSON: Arc and incandescent, I understand. I did not see the exposures made, as they were made in England.

DR. GOLDSMITH: Approximately how many lines are there across the screen?

MR. CARSON: Nineteen lines to the millimeter, or approximately one million elements to the square inch. With 25 lines to the millimeter, which is the screen that will be produced next, there will be approximately a million and a half to the square inch. The luminosity and the definition will both increase. The light we are using here is the standard light for black-and-white pictures. Even though there is stray light on the screen, which would not occur under good conditions, the picture is sufficiently bright. That is a fact that I mentioned in the paper—that a lower screen brilliancy seems to be acceptable with color than with black-and-white.

MR. BATSEL: Are the prints made by contact or by projection?

MR. CARSON: Projection. We are not ready to discuss the method of printing right now, for patent reasons; but I will say that it was the combined work of the Ilford group, under the direction of Dr. Renwick, who was formerly with the Dupont Company. The film was made by the Ilford, Limited.

MR. SACHTLEBEN: What difficulties, if any, are experienced in obtaining proper registration of the colors when making a print? How do you manage to have the greens green and the blues blue and not something else?

MR. CARSON: A means has been devised of interposing a prism type of lens between the two films on the projection printer, which divides into four each of the color areas in the original screen as it prints, so that any color area is bound to fall on one similar to it.

MR. CRABTREE: Was the original developed by machine or by rack-and-tank?

MR. CARSON: By rack, also.

MR. KELLOGG: One would expect, with the extent of the overlap of the spectral regions, that the printing process you just described would cost something in saturation.

MR. CARSON: Theoretically, each time you step down, a certain dilution occurs due to the overlaps. Here, again, means were found of eliminating the overlap in the printing operation. While there is some dilution, there is not very much. With proper laboratory treatment and machine control, duplicates can be produced that are entirely satisfactory for commercial use.

MR. SACHTLEBEN: Mr. Carson stated that the quality of the print was superior to that of the original. I believe that has been quite well borne out in this demonstration.

MR. CARSON: We don't consider it so. You misunderstood me.

MR. SACHTLEBEN: I found the second reel that was shown more pleasing than the first.

MR. CARSON: The fact of whether it is more pleasing to the eye or not is something that is more or less a matter of personal taste. What I meant to say was the spectral fidelity of the original is greater than the spectral fidelity of the duplicates. I do not believe that the duplicates are exactly as good as the original. If you saw the two run side by side, you could distinguish the difference. If you saw one run in one place and one in another, they would appear so nearly alike that you would find it difficult to say which was which.

OPERATING CHARACTERISTICS OF THE HIGH-INTENSITY ALTERNATING-CURRENT ARC FOR MOTION PICTURE PROJECTION*

D. B. JOY AND E. R. GEIB**

Summary.—*A detailed description is given of the high-intensity a-c. carbons, including the current-carrying capacity, the arc voltage, and the rate of consumption. The appearance of the arc and the carbons when the arc is burning is shown in a number of illustrations covering overload and underload conditions, and long, short, and medium arc lengths. The essential requirements for the feeding mechanism and transformer to operate the arc are outlined. It is emphasized that the carbons must be operated under certain definite conditions for the best results.*

The new high-intensity a-c. arc was first discussed before the S. M. P. E. at the Spring, 1933, Meeting[1] at New York, and additional data[2] were given in connection with another subject at the Fall Meeting of the same year at Chicago. Subsequently it was the subject of much consideration by the Projection Practice Committee. The writers contributed to the discussion and were later asked to put their comments in written form as it was felt that this information would be of value to both the users of the high-intensity a-c. arc and the equipment manufacturers. In this paper the high-intensity a-c. arc is described. In the following paper[3] the relationship of this arc to the light on the projection screen will be considered.

The above papers[1,2] gave a general description of the arc, the current and voltage ratings of the carbons, and approximate consumption rates. This is summarized in Table I.

TABLE I

Characteristics of Copper-Coated A-C. High-Intensity Carbons

	8-mm.	7-mm.
Current (Amperes)	75–80	60–65
Approximate Arc Voltage	24–29	23–26
Consumption (Inches per Hour)	4.0–5.5	4.0–5.5
Current Density (Amps. per Sq. In.)	970–1040	1000–1090

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

** National Carbon Co., Cleveland, Ohio.

A number of lamps and auxiliary equipment for using the a-c. high-intensity arc have recently appeared on the market and have been installed in a number of theaters. For that reason, a more detailed description of the arc and its operating characteristics will be helpful to those responsible for the operation of such equipment.

The high-intensity a-c. projection arc is essentially a high current-density, low-voltage arc. At the rated currents the current density (970–1090 amps. per sq. in. of carbon cross-section) is very much higher than that of the mirror arc carbons (140–188 amps. per sq. in.), and somewhat higher than even that of the high-intensity d-c. positive carbons (450–900 amps. per sq. in.). Another difference is that in the conventional d-c. high-intensity lamp the positive carbon is gripped at a point close to the arc, whereas in the a-c. high-intensity lamps both carbons are clamped near the holder end. It is therefore necessary to increase the conductance of the electrode by coating it with metal, which in this case is copper. The copper does not enter the arc stream, its only function being to furnish a low-resistance path for the current from the carbon holder to a point near the arc.

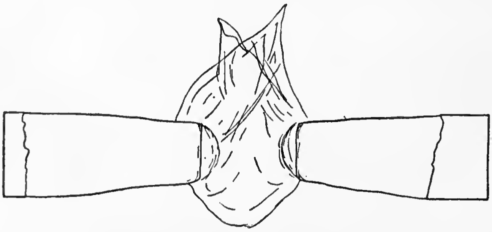

FIG. 1. 8-mm. a-c. high-intensity carbons, overloaded: 90 amperes, 35 volts.

By carefully observing the high-intensity a-c. arc in operation, it will be seen, as shown in the accompanying illustrations, that the copper coat ends an appreciable distance from the arc. As the carbons are consumed the copper coat continually melts away, so that it never is sufficiently close to the tip of the carbon to enter the arc stream itself.

This copper coat is designed to take care of the current rating of the carbon. If the current is too great, the copper will melt to a considerable distance from the arc, as shown in Fig. 1. The arc then becomes unsteady and is apt to blow out, and the arc voltage and consumption of the carbons are increased to such an extent that they may be outside the range of control of the arc-feeding mechanism. If, on the other hand, the current is too low, the copper will not melt away as far from the arc, the light will be very much reduced, and the current and voltage will not be constant. This condition results in an unsteady arc, which "flops" from the top to the bottom of the carbon, as illustrated in Figs. 2(*A*) and 2(*B*). If the current and voltage limits recommended in Table I are observed neither of these undesirable conditions will be encountered.

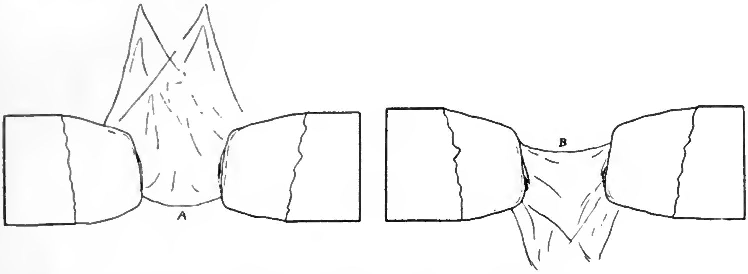

FIG. 2. 8-mm. a-c. high-intensity carbons, underloaded: 60 amperes, 24 volts; showing different positions of the arc as it "flops" about on the ends of the carbons.

The illustrations of the arcs shown in this paper are all traced from actual arc images, and show the true relationship between the different parts of the arc.

It is essential for good operation of the arc and good light projection that the high-intensity a-c. arc be maintained within certain definite arc lengths and that it have a characteristic shape which is easily identified. Fig. 3 shows the high-intensity a-c. arc burning under the correct conditions at 80 amperes and $25^1/_2$ volts between two 8-mm. carbons.

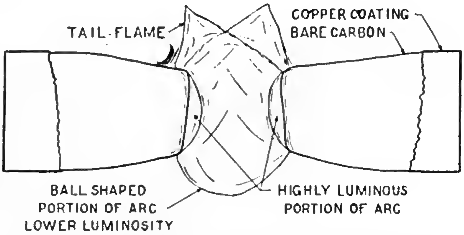

FIG. 3. 8-mm. a-c. high-intensity carbons: 80 amperes, $25^1/_2$ volts; good operating conditions.

The copper coats end 0.35 inch (8.9 mm.) from the ends of the carbons. The arc length is 0.27 inch (6.9 mm.) long. The end of the electrode is 0.225 inch (5.7 mm.) in diameter. The arc itself consists of a highly luminous portion close to each electrode, and a portion of lower luminosity almost the shape of a ball extending about as far below the electrodes as above them and ending at the top in two well-defined short tail-flames. It is interesting to note that the shape of the highly luminous portion of the arc near the electrodes approximates the shape of the intrinsic brilliancy curve across the electrode face, which was presented in an earlier paper[1] and is reproduced in Fig. 4. This highly luminous portion of the arc close to the electrode decreases in size as the current is decreased, and becomes very small at the lower current-densities, as illustrated in Fig. 2. This result gives, of course, a much lower intrinsic brilliancy curve and less light on the projection screen.

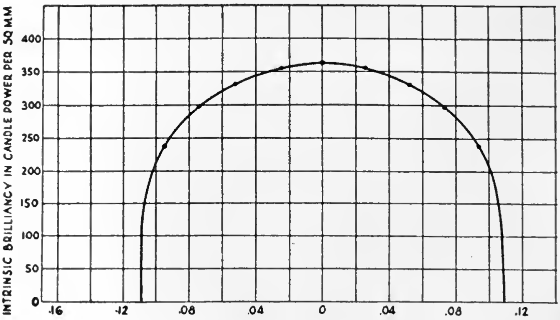

FIG. 4. Intrinsic brilliancy across crater face: 8-mm. a-c. high-intensity carbons; 80 amperes, $25^1/_2$ volts.

If the arc length is decreased it will hold essentially the same arc shape, if the operating conditions are favorable, until it reaches approximately 0.23 inch (5.8 mm.), or 24 volts. Fig. 5(*A*) illustrates the arc just before that point, with a good burning condition; and Fig. 5(*B*) the arc just after that point, with a shorter arc length and poor burning conditions. When the arc length is 0.23 inch (5.8 mm.) the arc stream begins to be turbulent. The two tail-flames and the highly luminous portion of the arc close to the electrodes lose their identity, and the whole arc assumes a boiling and seething appearance. There is rapid flicker; the arc voltage and current are erratic; and in addition, at such very short arc lengths there is a noticeable shadowing effect from the electrodes themselves.

If the length of the arc is increased beyond that shown in Fig. 3, the form of the arc will be sustained if the operating conditions are suitable, until the length is approximately 0.35 inch (8.9 mm.). Fig. 6(*A*) shows the arc immediately before, and Fig. 6(*B*) after, such a point has been reached. At and beyond that length the arc has a tendency to be swept upward, so that the lower part no longer bows down appreciably and the upper part and the tail-flame become greatly extended. The highly luminous portion close to the electrode likewise becomes distorted, as shown in Fig. 6(*B*). The arc is unstable to such an extent that it will repeatedly jump back and forth between the positions shown in Figs. 6(*A*) and 6(*B*).

Another arc condition that must be considered and, if encountered, corrected, is shown in Fig. 7. The arc is of medium length, and would ordinarily have the appearance of Fig. 3, but is disturbed by external forces so that it appears very much like Fig. 6(*B*), and has the tendency to snap back and forth between that position and the one shown in Fig. 3, causing variation of the current and voltage, flicker, and uneven light distribution. This condition may be caused by too strong a draft in the lamp, or by an unbalanced magnetic effect due to a poor arrangement of the current leads; or by other means that would tend to distort the arc.

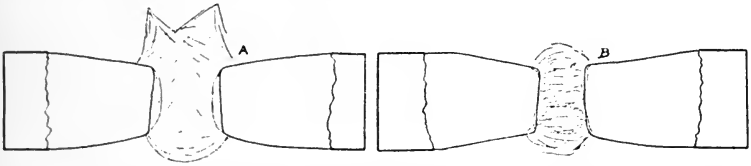

FIG. 5. 8-mm. a-c. high-intensity carbons: 80 amperes, 23 to 24 volts; (*A*) short arc length, good operating conditions; (*B*) short arc length, poor operating conditions.

If we assume that the design of lamp house, the draft, and the arrangement of leads are such as to avoid the above conditions, the 8-mm. high-intensity a-c. carbons at 80 amperes will exhibit good burning characteristics for arc lengths between 0.23 inch (5.8 mm.) and 0.35 inch (8.9 mm.), and from approximately 24 to 29 volts. There will, however, be a noticeable change of light intensity between those extreme limits, so that the permissible range of variation in arc length and voltage from moment to moment is much less than the complete range of satisfactory performance. This is discussed in greater detail in a later paragraph. The limits of arc voltage, as ordinarily measured at the incoming leads, will vary slightly depending upon the length of spindle of the carbons, the lengths of the carbons in the holders, and the resistance of the holders themselves

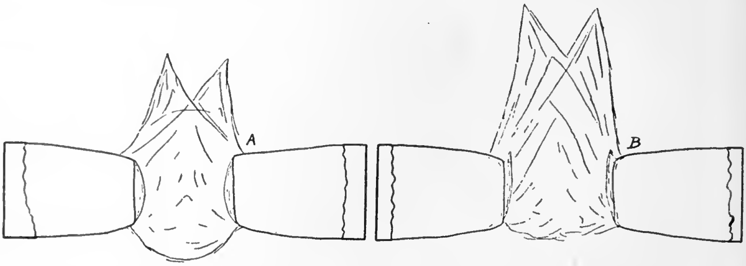

Fig. 6. 8-mm. a-c. high-intensity carbons: 80 amperes, 28 to 29 volts; (*A*) long arc length, good operating conditions; (*B*) long arc length, poor operating conditions.

At 75 amperes the arc lengths that will give good burning characteristics with the 8-mm. carbons are essentially the same as those for 80 amperes, and the arc voltage is approximately one volt lower. The 7-mm. high-intensity a-c. carbons are rated from 60 to 65 amperes. The corresponding conditions for good operation are an arc gap of 0.21 inch (5.3 mm.) to 0.31 inch (7.9 mm.), and an arc voltage of approximately 23 to 26 volts.

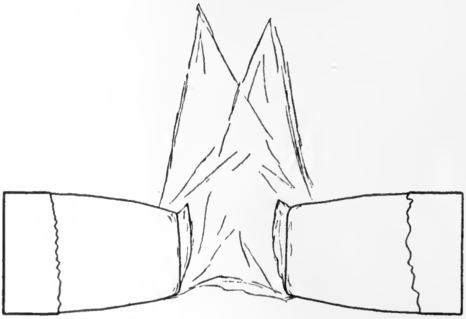

Fig. 7. 8-mm. a-c. high-intensity carbons: 80 amperes, 26 volts; medium arc length, arc disturbed by external forces.

The action of the high-intensity a-c. arc under various conditions has a direct bearing on the limitations of the mechanism for feeding the carbons. From the considerations discussed above it is apparent that such a mechanism must be able to feed the carbons at a rate up to 5.5 inches per hour; depending, of course, upon the current passing through the arc. It must also prevent the arc gap from varying more than 0.10 inch (2.5 mm.) or 0.12 inch (3.0 mm.); or, in terms of voltage, it must prevent the arc from varying over a range greater than 3 or 5 volts for the 7-mm. and 8-mm. carbons, respectively. These are the outside limits, for in order to utilize the total ranges the mechanism would have to be adjusted so that the average position of the carbons would be exactly at the center of the permissible variation. It must also be borne in mind that if the arc length varies in either direction much beyond the limits of good operation, the current and voltage become erratic and swing through a considerable range. If the feeding mechanism is controlled by either the current or the voltage the above action causes a sudden change in the rate of feeding that is not desirable.

It is not practicable to adjust the feeding mechanism so that it will operate exactly at the center of the permissible range, nor can it be expected that other conditions might remain sufficiently constant to keep it exactly in that position. It is therefore necessary that the mechanism be designed to feed the carbons within a variation much less than the theoretically allowable limits. The narrower the range, the easier it is for the projectionist to maintain the lamp adjustment within the limits of satisfactory arc operation, and maintain a uniform intensity of screen illumination.

These narrow limits for maintaining the arc length presented a real problem, but through close coöperation between the National Carbon Company and the manufacturers of projection equipment the desired results have been accomplished.

In the paper[1] previously cited, it was mentioned that the high-intensity a-c. arc can be operated in series with a suitable resistance unit from the power line, but that for practical reasons a resistance is never used. A transformer and reactor are used instead. The transformer gives an electrical efficiency of 90 per cent or more, a figure that can not be equaled when ballast resistance is used. The reactor is usually the leakage reactance of the windings of a "high-reactance" transformer. It is desirable that the reactance be kept comparatively low, in order to maintain a reasonable power factor. On the other hand, it must be high enough to assure sufficient stability so that the arc may not be extinguished by ordinary drafts at the longest desirable arc length. Tests have shown that a 40-per cent reactance will afford sufficient stability to the arc. In other words, if the no-load voltage on the secondary of the transformer is about 40 per cent higher than the load voltage, there will be sufficient stability of the arc for ordinary applications. Additional reactance would improve the factor of safety, but above a no-load voltage of about twice the load voltage, the effect would not be noticeable. A lower reactance could be used and the results might be satisfactory in most cases, but any advantage achieved in reducing the reactance would not be worth the risk of an "outage."

Another important factor in the design of a transformer for use with the high-intensity a-c. arc is the possible variation of line voltage on different installations. The transformer should be provided with suitable taps, or other means, so that it can be adjusted for the average line voltage of the theater in which it is installed. If the line voltage at the theater should vary appreciably, convenient means should be provided for the projectionist to change the transformer taps and so regulate the secondary voltage.

(*The discussion of this paper at the Spring, 1934, Meeting at Atlantic City, N. J., was held simultaneously with that of the supplementary paper by the same authors, published also in this issue of the* JOURNAL. *The reader is referred to p. 47.*)

REFERENCES

[1] Joy, D. B., and Downes, A. C.: "A New Alternating-Current Projection Arc," *J. Soc. Mot. Pict. Eng.*, **XXI** (Aug., 1933), No. 2, p. 116.

[2] Joy, D. B., and Downes, A. C.: "Direct-Current High-Intensity Arcs with Non-Rotating Positive Carbons," *J. Soc. Mot. Pict. Eng.*, **XXII** (Jan., 1934), No. 1, p. 42.

[3] Joy, D. B., and Geib, E. R.: "The High-Intensity A-C. Arc in Relation to the Light upon the Projection Screen," *J. Soc. Mot. Pict. Eng.* **XXIII** (July, 1934), No. 1, p. 35.

THE RELATION OF THE HIGH-INTENSITY A-C. ARC TO THE LIGHT ON THE PROJECTION SCREEN*

D. B. JOY AND E. R. GEIB**

Summary.—*The effect on the amount and uniformity of light on the projection screen of changing the position of the arc with respect to the reflector, varying the arc length, decreasing the current, and irregular feeding of the carbons is measured and discussed. The importance of proper draft conditions in the lamp house is emphasized. The comparatively low temperature at the film aperture for a given amount of light on the projection screen from this type of arc is demonstrated.*

The unique wave-form of the screen light from this high-intensity alternating-current arc is compared with the wave-form of the screen light from the low-intensity alternating-current neutral cored carbon arc and the rectified neutral cored carbon arc. A logical explanation is furnished by a consideration of these wave-forms for the comparative freedom from light beat or fluctuation with this type of alternating-current arc. It is pointed out that this arc gives no greater light fluctuation on the screen than the arc from rectified current. Other causes of fluctuation of the screen light are cited and suggestions are given for minimizing their effects.

The new high-intensity a-c. arc has already been compared with other types of arcs used for projection.[1] Since that time further data on details of operation have been accumulated which will enable the industry to use the arc to better advantage. The preceding paper[2] in this issue of the JOURNAL furnishes some of those details, describing the appearance of the arc, specifications for correctly operating the arc, and the general requirements concerning the reactance transformer and the feeding mechanism. The present paper, continuing the subject, discusses the high-intensity a-c. arc in relation to the light on the projection screen.

One of the objectives of good projection is to maintain a light of uniform intensity and good distribution on the screen at all times. As has been pointed out in the case of other types of arc, the light on the projection screen is dependent upon both the arc itself and the position of the arc in relation to the optical system. This applies also to the new high-intensity a-c. arc.

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

** National Carbon Co., Cleveland, Ohio.

The lamps using this carbon ordinarily have a horizontal trim with the carbon tip facing the back of the lamp, in focus with an elliptical reflector that projects the light picked up from the carbon and arc to the aperture and film. These lamps are provided with a device that throws an image of the arc on a white card, on which the correct arc length and arc position with respect to the mirror are indicated. They also have a method of feeding and adjusting the arc that keeps the carbons in the proper position with respect to each other and the optical system, provided the lamp is operated properly and the projectionist pays a reasonable amount of attention to the arc image.

The following illustrations show what happens to the light on the screen when the arc is not kept in the correct focal position, and indicate the leeway that the projectionist has in that respect in maintaining a reasonably uniform light on the projection screen. The curves were made by using one of the latest types of high-intensity a-c. projection lamps with an optical arrangement as shown in Fig. 1. If the magnification of the mirror, the size of the carbon, or the objective lens is changed, the shapes of the curves will remain essentially the same, but the relative values will be altered.

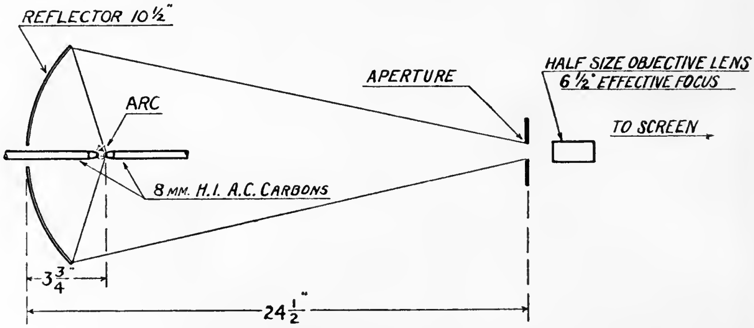


FIG. 1. Diagram of optical arrangement used in the test.

Fig. 2 shows the effect on the screen light of keeping the arc length and the current constant but changing the position of the arc with respect to the mirror. As the arc is moved from the position of maximum screen light (*C*) toward the reflector, the total light on the screen decreases rapidly, the light at the corners of the screen increases in intensity, and the light at the center of the screen decreases in intensity; until, at the position *A* the light at the sides and corners of the screen is actually brighter than at the center, and the center appears yellow. As the arc is moved from the position *C* away from the reflector, the total light on the screen decreases at a slower rate and the distribution of the light on the screen remains practically constant.

The curve of average screen light was constructed from the readings of nine Weston photronic cells placed at points on the screen that afforded a representative average of the total screen illumination. The ratio of the light at the sides to the light at the center was obtained by comparing the average of the readings taken at positions *1* and *3*, Fig. 2, with that taken at position *2*. The lower curve of Fig. 2 shows the change in this ratio for various positions of the arc.

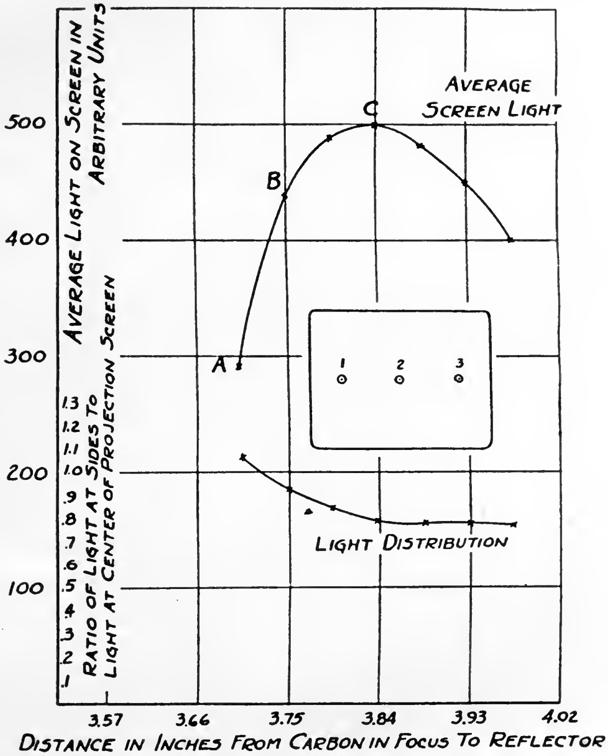


FIG. 2. Light on projection screen *vs.* position of the arc; 8-mm. high-intensity a-c. carbons: 80 amperes, 0.29-inch arc length.

It is apparent from the curves that, with the particular optical system used, the arc can be moved a distance of approximately 0.20 inch without allowing a variation in the total light on the screen of more than ± 5 per cent, and with the distribution of light maintained within a reasonable range of uniformity. It should be remembered, however, that unless the lamp is so adjusted that the position of the arc, as indicated by the arc image, is at the center of the allowable range, a small movement one way or the other might cause a considerable change in the light on the screen. For example, if the lamp had been set so that the arc was in the position *B* with respect to the optical system, a movement of 0.10 inch of the arc toward the reflector would cause an undesirable change both in the quantity of light and its distribution on the screen. If the magnification of the optical system or the size of the light source were increased, the arc would have a greater latitude of motion for the same change in the light on the screen.

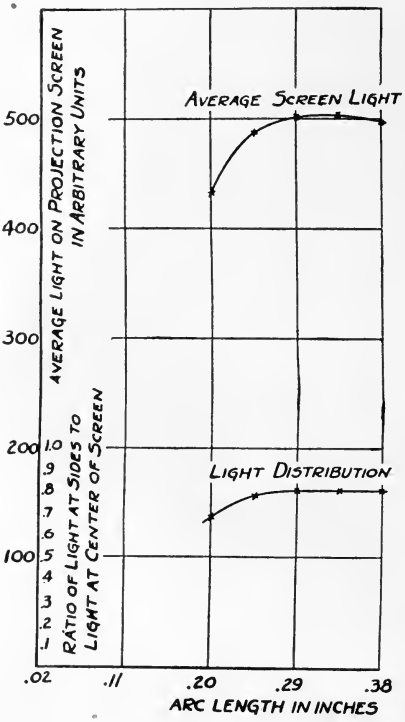


FIG. 3. Light on projection screen *vs.* arc length; 8-mm. high-intensity a-c. carbons: 80 amperes, carbon in focus 3.84 inches from reflector.

The appearance of the high-intensity a-c. arc gives the impression that there is an appreciable quantity of useful light cut off by the carbon facing away from the reflector. A practical demonstration is given in Fig. 3, which indicates that at the minimum recommended arc length of 0.23 inch,[2] there is only a very small loss of light due to the shadowing of the carbon, and it is not until an arc length of 0.20 inch has been attained that the loss becomes serious. It is also shown by the lower curve of Fig. 3 that this short arc length results in a poorer distribution of light on the screen. In addition, the arc tends to become unsteady,[2] and the arc feeding erratic. It should be noted in connection with Fig. 3 that the current was held constant for the various arc lengths by adjusting the transformer.

If the arc length and the position of the carbons with respect to the mirror are held constant, but the current varied, the light on the projection screen changes as shown in Fig. 4. The light, of course, decreases as the current through the arc is decreased, but the distribution of the light on the screen remains practically unchanged. If the current at the arc is decreased very much below the minimum recommended current of 75 amperes, the arc will fail to fill the ends of the carbons and will cause a variation of the distribution of the light[2] not shown by the curves.

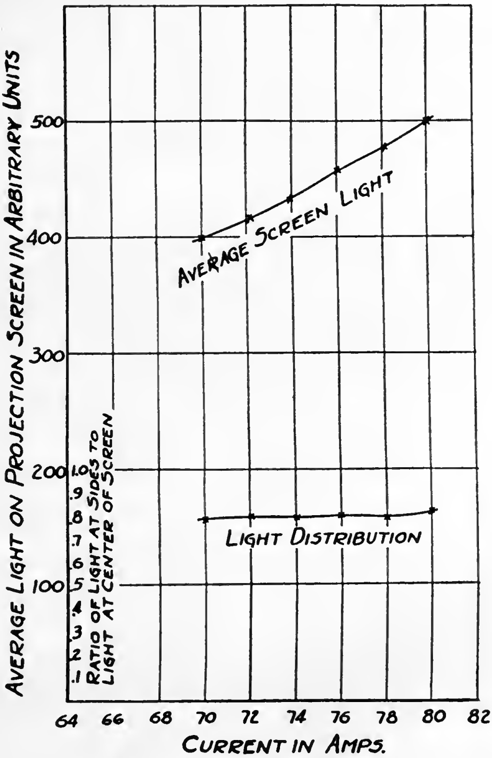


FIG. 4. Light on projection screen *vs.* current; 8-mm. high-intensity a-c. carbons: arc length, 0.29 inch.

If the carbons are not fed together at such a rate as to maintain the arc length approximately constant, the position of the arc with respect to the mirror, the arc length, and the current will all change at the same time. In other words, the changes illustrated in Figs. 2, 3, and 4 all occur simultaneously, and the result on the screen light is a composite of all the curves. Such a composite curve can be calculated for a given set of conditions, but actual measurements are given for one case in Fig. 5.

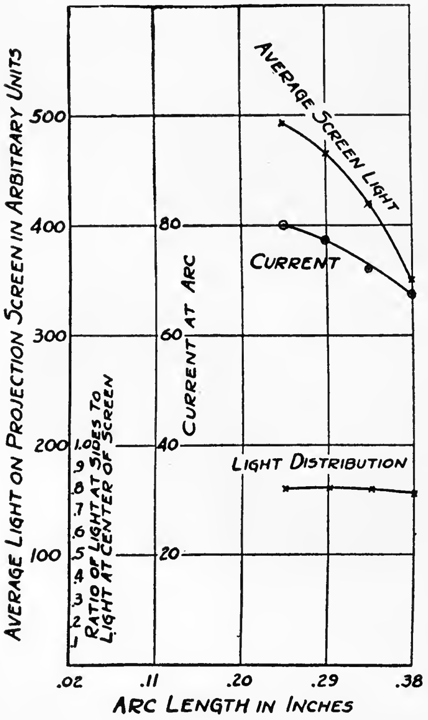


Fig. 5. Light on projection screen *vs.* arc length; carbons not feeding; no adjustment of transformer or arc position: 45 volts, no load on transformer.

Fig. 5 shows the change in the total light on the screen, the fluctuation of the light, and the change in the current as the arc is allowed to burn from a 0.245-inch length to a 0.58-inch length, without adjustment of the transformer or the arc controls. The focal position of the carbon for the 0.245-inch length was 3.84 inches from the reflector, corresponding to position *C* in Fig. 2. The light on the projection screen decreases rapidly because of the cumulative effect of the decrease in the current and the change in the position of the carbon with respect to the reflector.

Besides the rapid decrease of light, the lower current causes unsteadiness of the arc, which is discussed in detail in a previous paper.[2] Also, if the carbons are allowed to burn apart and are then suddenly adjusted to a much shorter arc length, the sudden change of current and arc length causes a disturbance in the arc which, of course, is transmitted to the light on the screen. It is therefore essential, both from the standpoint of steadiness and total light on the screen, that the arc length be held within as close limits as is practicable by the feeding mechanism, and that this feeding mechanism be kept in adjustment by the projectionist.

In addition to the foregoing factors, which are directly related to the control of the arc, certain other conditions may affect the steadiness of the screen illumination. It is assumed that any magnetic fields which might cause the arc to burn unsteadily have been taken care of in designing the lamp. Therefore, if blowing of the arc is observed, evidenced by a fluttering of the light on the screen, the drafts in the lamp house should be given some attention. It was noted in one theater installation that the rear shutter was so designed as to draw the air from the projection lamp through the light shaft of the lamp. This caused a blowing of the arc around the forward carbon and a noticeable disturbance in the light on the screen.

A characteristic of the high-intensity a-c. arc which, although not directly connected with the light on the screen, is a distinct advantage, is the comparatively low temperature at the film aperture. Table I compares the relative screen illuminations obtained with a low-intensity d-c. mirror arc and the high-intensity a-c. arc, and the corresponding temperatures at the film gate. The temperature was recorded by a thermocouple placed at the aperture. No shutter was used between the lamp and the projector, and the projector was not running. Although producing almost twice as much light on the screen as the low-intensity d-c. mirror arc, the high-intensity a-c. arc caused a temperature at the film gate of only 630°C. as compared with 525°C for the d-c. arc. In order to compare film gate temperatures for a given screen illumination, a wire grating was placed between the high-intensity a-c. lamp and the aperture. The openings in the grating were of such size as to allow the same amount of light to fall upon the projection screen as from the unscreened low-inten-

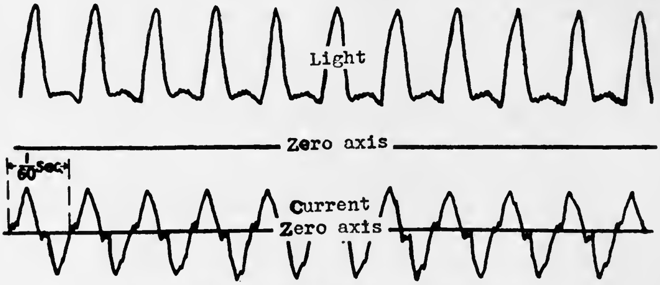
TABLE I

Thermocouple Temperature at Film Aperture

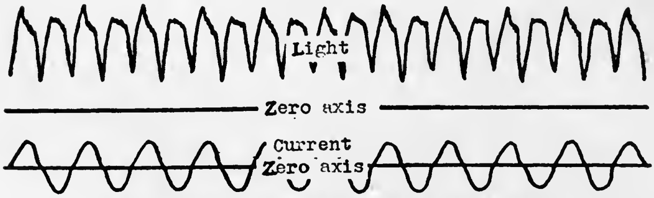
Carbons and Lamp	Light on Screen (Relative)	Temp. in °C. at Aperture
12-mm. × 8-mm. S.R.A. d-c. Carbons 30 Amps. in Mirror Arc Lamp	56	525
8-mm. H.-I. a-c. Carbons 80 Amps. in H.-I. Mirror Arc Lamp (Full light)	100	630
8-mm. H.-I. a-c. Carbons 80 Amps. in H.-I. Mirror Arc Lamp (Light and heat reduced by wire screen between lamp and aperture)	56	425

sity d-c. arc. In this case the temperature at the film gate was 100° C. lower for the high-intensity a-c. arc than it was with low-intensity d-c.

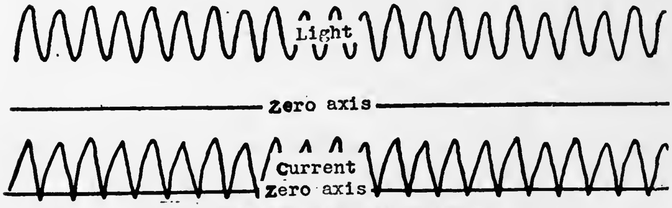
There has been considerable discussion concerning the possibility of a beat or fluctuation in the light on the projection screen from the high-intensity a-c. arc. This idea is based on the results that were formerly obtained when the low-intensity a-c. arc was used for projection. It will be shown that the present high-intensity a-c. arc is not the same as the old type low-intensity a-c. arc with neutral cored carbons, but is a new type of arc producing a light on the screen



Low-Intensity 60-Cycle Alternating-Current Arc



High-Intensity 60-Cycle Alternating-Current Arc



Low-Intensity Rectified Current Arc

FIG. 6. Oscillograms of arc current and instantaneous light on projection screen; projector shutter not running.

more comparable in wave-form to the light from the low-intensity d-c. arc operated by a rectifier.

Oscillographic pictures of the current and light on the screen without the shutter running are shown in Fig. 6 for the low-intensity a-c. arc, the new high-intensity a-c. arc, and the rectified low-intensity arc. The instantaneous light on the screen was measured by means of a photoelectric cell and an amplifying system that allowed a linear relation between the cell current and the output current, which was, in turn, recorded on the oscillograph coincidentally with the instantaneous value of the arc current.

The curves, of course, represent the fluctuations of the light over very short periods of time—less than one-fifth of a second—as indicated. A high-intensity a-c. lamp and transformer unit, which is typical of the equipment on the market at the present time, was used to obtain the curves for the a-c. high-intensity arc. A common type of ordinary low-intensity reflecting arc lamp was used with low-intensity neutral cored carbons for both the rectified current and the alternating current arcs. In other words, the same kind of optical system was used with all three varieties of arcs. The rectifier is the same as is now used with low-intensity mirror arc lamps in hundreds of theaters.

The direction of the current in the low-intensity a-c. arc changes every half cycle in the usual manner. The light emanating from the arc, as indicated in Fig. 6, rises to a peak when the carbon that is in focus is positive, and decreases and remains at a low value as the direction of the current changes and the carbon in focus becomes negative for half a cycle.

With the low-intensity d-c. arc operated by a rectifier, the current is unidirectional, but decreases to a zero point during each half cycle. The light on the screen rises to a peak at the middle of each half cycle, but decreases to about half that value as the current approaches the zero point, rising again to a peak, which is not quite so high as that in the first half of the cycle, and decreasing to a low value again. In other words, there is a fluctuation, but the light during each half cycle rises to very nearly the same level.

The current in the a-c. high-intensity arc, of course, changes its direction in the usual way, but the light on the screen is considerably different from the light of the low-intensity a-c. arc. Instead of remaining at a low value while the carbon in focus is negative, the light rises to approximately the same value as it does when the carbon in focus is positive, but the shape of the light curve is slightly different. In other words, except for certain differences in the shape of the curve, the light projected by the high-intensity a-c. arc approximates that of the rectified current arc much more closely than it does the light of the low-intensity a-c. arc.

The effect of the light-wave is very noticeable when the shutter mechanism is operating. The speed of the shutter is fixed at 1440 rpm. by the standard film speed of 90 feet per minute. On the other hand, the current from the ordinary 60-cycle circuit, or from a single-phase rectifier placed in the circuit, goes through a characteristic change 3600 times per minute. In other words, the time of opening of the shutter does not correspond to an even number of changes in the current or the light on the screen. This is illustrated very clearly by the oscillograms in Fig. 7, which show the variation of the light intensity on the screen for the three types of arc with the shutter running at approximately 1440 rpm. If it were possible to run the shutter at 1800 rpm., which would correspond to a film speed of 112.5 feet per minute, the shutter openings of the ordinary two-bladed shutter would correspond to one-half a cycle in the current and light curves, and would give the same amount of light on the screen for each shutter opening. Theoretically and actually, with a two-bladed symmetrical shutter operating at a speed of 1800 rpm., there would be no fluctuation of the light on the screen that could be detected by

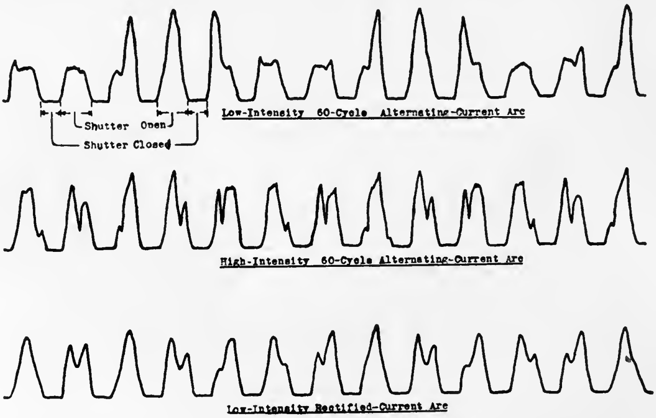


FIG. 7. Oscillograms of instantaneous light on projection screen; two-bladed shutter, 1440 rpm., corresponding to film speed of 90 ft. per min. [These oscillograms are of same magnitude as those in Fig. 6, although reduced in reproduction.]

the eye, even without film in the machine. In other words, the more nearly identical in amount and wave-shape the light on the screen is during each shutter opening, the less discernible would be the fluctuations or beats in the light on the screen.

It can be seen in Fig. 7 that the amount of light on the screen from one shutter opening to the next varies enormously in the case of the low-intensity a-c. arc. This is due directly to the fact that, as illustrated in Fig. 6, during the half cycle that the carbon in focus is negative, the light remains at a comparatively low value. On the other hand, the light from the high-intensity a-c. arc, although of irregular wave-form, is much more nearly constant for each shutter opening, and corresponds much more closely to the curve of the light obtained from the d-c. arc operating on rectified current with the shutter running.

This is the reason for the very decided improvement in steadiness over the low-intensity a-c. arc, and for the practical elimination, under favorable conditions, of noticeable fluctuation in the light on the screen from the high-intensity a-c. arc. In other words, the light-curve of the high-intensity a-c. arc, being of nearly the same intensity during each half of the current cycle, has practically the same fluctuation characteristic as that of the low-intensity d-c. arc operated by a rectifier. The practical proof of this is obtained by observing the projection of the same amount of light from the three types of arcs with the shutter running. This has been done in the laboratory with a very high degree of illumination on the screen and without film in the projector. Observation under such conditions agrees with the conclusions arrived at from the oscillograms: namely, that the light beat or fluctuation of the high-intensity a-c. arc is very much less than that of the low-intensity a-c. arc and of essentially the same magnitude as that of the low-intensity d-c. arc using neutral cored carbons and operated by a rectifier.

From the standpoint of practical projection, the beat or fluctuation of light is so small that under reasonable conditions it can not be considered detrimental to the quality of the picture. This was demonstrated at a recent meeting of the S. M. P. E. Projection Practice Committee, when pictures were projected by a high-intensity a-c. arc. One member of the Committee remarked at the time that if he could not see the light-beat or fluctuation, it was not there so far as he was concerned.

Factors other than the light source itself exert an influence on the fluctuation of the light and, if properly taken into consideration, will produce the favorable condition referred to before. For example, the design of the shutter is very important. It has been found experimentally that a three-bladed shutter of the unbalanced type, one blade of which is considerably larger than the other blades, causes noticeable beat of the light on the screen. It was also noticed that in a two-bladed shutter, when one of the blades is larger than the other, the beat of the light is more pronounced. In other words, lack of symmetry in the shutter will, of itself, introduce a beat with any arc. It has been reported that in cases where fluctuation is noticed, it can be decreased by stopping down the objective lens and cutting down both blades of the two-winged shutter to the point just before the appearance of shadow-ghost. The average shutter speed is fixed at 1440 rpm., but in some cases the speed fluctuates considerably because of worn gears or parts in the projector mechanism. This variation of the speed tends also to produce a beat in the screen light.

The use of a projection screen that has a highly directional reflection characteristic with the very efficient high-intensity a-c. lamps now available tends to make the beat more noticeable than when a flat white screen is used, which reflects the light evenly in all directions. This is probably a function of the light intensity, for in observations made in the laboratory with no film in the machine, the light beat is noticeable on the directional screen when viewed at a direct reflecting angle from the projector, but decreases as the angle of observation increases, until it entirely disappears.

From these practical and theoretical considerations it is believed that with a reasonable amount of care in the design of the lamp, in the operation of the arc, and in the choice of the light intensity, shutter, and type of screen, the high-intensity a-c. arc will find a definite place in the projection field in the same manner as other new types of arcs, such as the low-intensity mirror arc and the conventional high-intensity d-c. arc, which have appeared on the market during the past few years.

REFERENCES

[1] JOY, D. B., AND DOWNES, A. C.: "A New Alternating-Current Projection Arc," *J. Soc. Mot. Pict. Eng.*, **XXI** (Aug., 1933), No. 2, p. 116.

[2] JOY, D. B., AND GEIB, E. R.: "Operating Characteristics of the High-Intensity Alternating-Current Arc for Motion Picture Projection," *J. Soc. Mot. Pict. Eng.*, **XXIII** (July, 1934), No. 1, p. 27.

[3] JOY, D. B., AND DOWNES, A. C.: "Some Causes of Variations in the Light and Steadiness of High-Intensity Carbons," *J. Soc. Mot. Pict. Eng.*, **XVI** (Jan., 1931), No. 1, p. 61

[4] JOY, D. B., AND DOWNES, A. C.: "Properties of Low-Intensity Reflecting Arc Projector Carbons," *J. Soc. Mot. Pict. Eng.*, **XVI** (June, 1931), No. 6, p. 684.

DISCUSSION

MR. RICHARDSON: Will you please describe your observations on the effect of shutter speed variation on the screen illumination?

MR. JOY: Our observations in a theater were as follows: We used a tachometer to measure the shutter speed and found in one machine that it varied from 1420 to 1450 rpm. periodically, several times a minute. There was probably something worn in the mechanism to make it do that. The periodic change of speed made a noticeable variation in light on the screen.

MR. HARDY: What is the brightness of the effective area of the arc? Have you considered the possibility of supplying the arc possibly by means of a thyratron; from a source having a frequency the same as that of the shutter, so that the dark period of the arc would correspond to the dark period of the shutter?

MR. JOY: The brightness of the effective area of the arc is given in Fig. 1 of the paper[2] entitled "Operating Characteristics of High-Intensity A-C. Arcs for Motion Picture Projection." The maximum intrinsic brilliancy at the center of the crater was 360 candles per sq. mm., tapering off to lower values at the edges of the effective area.

The suggestion of supplying the arc by a thyratron from a source having frequencies the same as the shutter, so that the dark period of the arc would correspond to the dark period of the shutter, should have very interesting possibilities. A machine has been developed for changing the 60-cycle alternating current to a current of higher frequency. Such a machine is on the market at the present time, and does practically eliminate any flicker that may be due to the alternation of the current, even with no film in the machine.

MR. PALMER: How much of the light comes from the crater, and how much from the flame? That question has a bearing on the efficiency of the whole set-up. It seems to me that the light coming from the carbon that does not face the mirror is entirely lost. How much light is lost from the crater of that carbon?

MR. JOY: The light at and around the carbon not at the focus of the reflector is equal to the light at and around the carbon at the focus. The carbons are identical in composition. Of course, if the light from the carbon not at the focus could be directly utilized we should have a more efficient system. According to the oscillograms in Figs. 6 and 7, when the carbon at the focus is negative the light still rises to almost as high a value as it does when the carbon at the focus is positive, so that we may be indirectly using some of the light from the carbon not at the focus.

We have no data on the proportion of the useful light that comes from the incandescent carbon or from the concentrated flame close to the carbon. The intrinsic brilliancy curve shows a maximum of 360 candles per sq. mm. at the center of the curve. The intrinsic brilliancy of the low-intensity d-c. positive carbon—that is, incandescent carbon—is approximately 160 candles per sq. mm. What we probably have in this arc is the light from the gases that lie close to the carbons themselves superimposed on the light from the incandescent carbon and core material.

AN IMPROVED SYSTEM FOR NOISELESS RECORDING*

G. L. DIMMICK AND H. BELAR**

Summary.—*A new system of noisless recording that makes it possible to increase the volume range considerably without introducing distortion has been developed. The sound waves are amplified and split into two halves by a special mask in the recording optical system. The two half-waves are recorded 180 degress out of phase on separate parts of the sound track. The reproducing system utilizes a photoelectric cell having two cathodes connected in push-pull. Ground noise is reduced to a minimum because only the area occupied by the the recorded waves is transparent, and when there is no modulation the track is completely back.*

The reduction of ground noise in film recording has engaged the attention of engineers for many years. The incentive has been to increase the range of volume capable of being recorded, and to suppress the extraneous background noise to a level below the threshold of hearing. Both these factors are tremendously important in creating the illusion of reality, which, of course, is the ultimate objective of any reproducing system. Several methods have been devised for reducing ground noise to a limited extent. It is the purpose of this paper to describe a practical variable-width sound recording system that permits the reduction of ground noise to an absolute minimum, without introducing distortion. The system does not require auxiliary recording equipment, nor does it require special care in recording or processing.

The two principal causes of extraneous noise in film records are the film grains in the exposed portion, and foreign particles or scratches in the clear portion. Because of the random distribution of silver grains and groups of grains, the transmission through the dense part of the sound track varies at audible frequencies, producing a high-pitched hiss that sounds very much like the hiss due to "thermal

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

** RCA Victor Company, Camden, N. J.

agitation" in resistors, or "shot effect" in vacuum tubes. At the recommended print density for variable-width records, the hiss is of extremely low amplitude; foreign particles and scratches on the

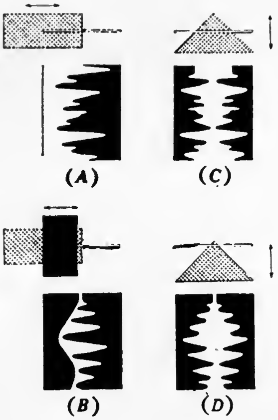

FIG. 1. Four types of variable-amplitude sound track.

transparent portion of the sound track form the most annoying cause of ground noise. The photoelectric cell is unable to distinguish between the reduction of light due to a decrease of width of the transparent portion of the track and the reduction of light due to opaque particles in the clear track.

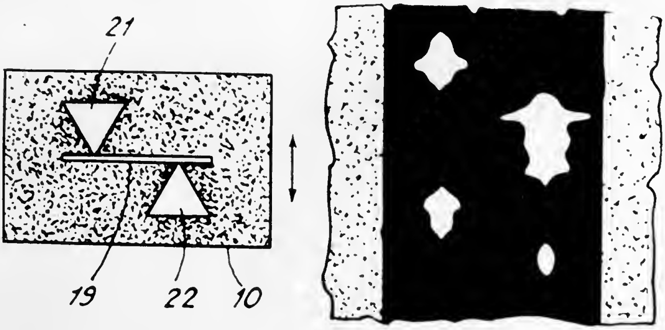

FIG. 2. A new type of push-pull track.

The average width of the clear portion in either of the variable-width tracks *A* or *C*, Fig. 1, is constant and equal to half the track width. Since the ground noise remains constant, the ratio of noise to signal increases as the signal is reduced. Tracks *B* and *D*, Fig. 1, were made with the biasing system of noise reduction. In that system a portion of the signal is rectified, and is caused to operate either a shutter vane or a biasing winding on the recording galvanometer in such a way that the clear portion of the track is reduced to a width that will just accommodate the modulation. When there is no modulation the clear track shrinks to a width of about four mils. The system affords a considerable reduction of the ground noise, and is a considerable improvement over previous systems. The biasing system is, however, inherently limited in the extent to which it can reduce film noise without introducing distortion. If the biasing current were allowed to actuate the galvanometer freely, without a timing circuit, an audible distortion would be superimposed upon the signal, because the envelope of many sounds occurring in nature is a wave of audible frequency. If the timing circuit should not act quickly enough, the narrow track could not accommodate the beginnings of sounds that occurred suddenly, thus causing the first part of the sound to be distorted. In practice, the biasing system is utilized to reduce ground noise only to such an extent that the accompanying distortion is negligible.

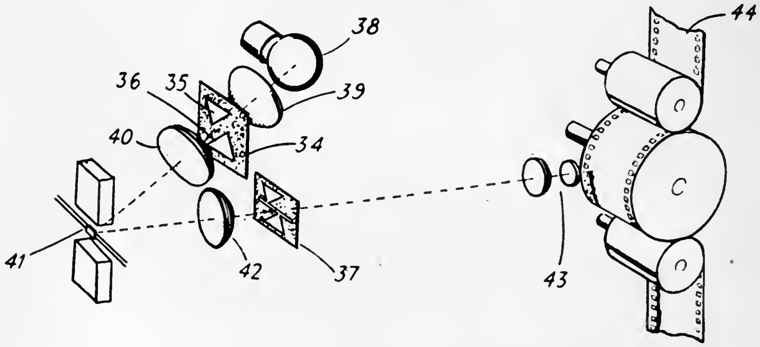

FIG. 3. Recording optical system.

A new type of sound track, which permits the reduction of ground noise to the theoretical minimum, is shown in Fig. 2. Only the area actually occupied by the sound record is transparent, which means that the ratio of the ground noise to the signal is constant, regardless of the amplitude. The recording optical system used in making the track is shown in Fig. 3. The only change that has been made in the standard Photophone recording optical system is the replacement of the single triangular mask by a mask having two triangles. An optical image of two opposing triangles is formed at the slit after being reflected from the galvanometer mirror, as shown in Fig. 2. The apexes of the triangular images are coincident with the center of the slit and are spaced apart half the length of the slit. When a signal is impressed upon the galvanometer the triangular light beams vibrate in a vertical plane and record two symmetrical tracks, one of which carries the positive half, the other the negative half, of the sound waves. The axes of the two component tracks are located a quarter of the total width of the track from each edge. The purpose of this is to assure proper scanning with low modulation and the proper separation of the two halves of the reproducing light beam in case of either a slight weaving of the film or a slight misalignment of the track.

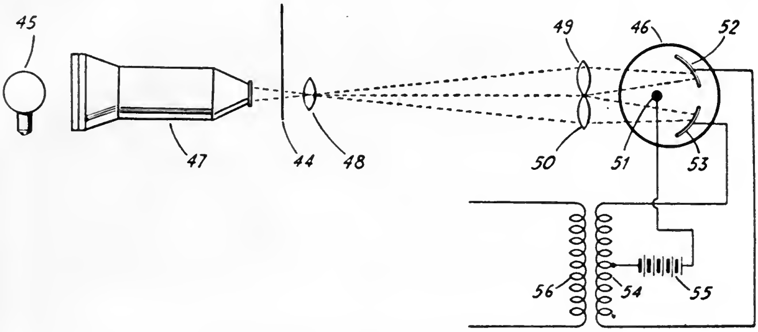

FIG. 4. Reproducing optical system.

The axes of the two half-tracks might be made to coincide at the center of the track, but it would be practically impossible to separate them later. The axes might also be placed at the two outside edges of the track, but then there would be less assurance of proper scanning with low modulation.

In practice, the recording system is quite simple to operate and adjust. The points of the two triangles may be made to lie upon a line parallel to the slit by a rotary adjustment of the barrel containing the aperture. The points are brought to the center of the slit by a vernier adjustment of the galvanometer about its horizontal axis. If, for any reason, the latter adjustment were either made incorrectly or accidentally spoiled, no distortion would be introduced. The only effect would be a slight increase of ground noise.

Both the optical and the electrical systems for reproducing this type of sound track are shown in Fig. 4. A beam of light 0.084 inch long and 0.001 inch wide is projected on the film *44* by means of a standard reproducing optical system *47* and a 10-volt, 5-ampere lamp *45*. A cylindrical lens *48* forms an image of the width of the sound track upon the two cylindrical lenses *49* and *50*. In the other plane, light from the reproducing optical system is allowed to expand to a height of about an inch. Lenses *49* and *50* each form an image of lens *48* upon the two cathodes *52* and *53*, of the photoelectric cell *46*. By means of such an arrangement the two images of lens *48* are separated, each containing the light transmitted through half the track, since the center of the track coincides with the dividing line between the two adjacent cylindrical lenses. The system produces variations in the intensity of the light striking the cathodes, corresponding to variations in the width of the clear portion of the sound track. As shown in Fig. 4, the cathodes are connected to the primary terminals of a transformer. The anode is connected through a battery to the center of the transformer. The secondary is connected to the reproducing amplifier. It is obvious that the two halves of the sound waves, which were recorded 180 degrees out of phase, are recombined in the proper phase by the push-pull transformer.

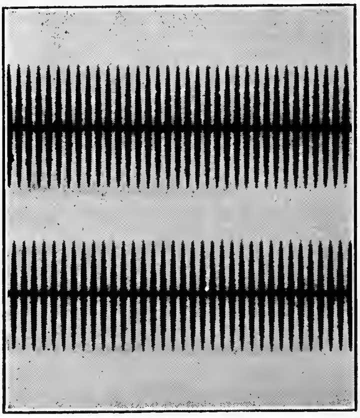

FIG. 5. A 9000-cycle negative made with the push-pull system.

In addition to its inherent freedom from ground noise, the push-pull sound track has other advantages of equal importance. The finite width and the spreading of the photographic image of the recording light beam are responsible for filling in the valleys and reducing the density of the peaks of the high-frequency waves. The push-pull track improves the condition in two ways. As shown in Fig. 5, the negative is composed only of peaks that are separated from each other by clear spaces equal in width to a half wavelength. In order to make a good print it is necessary to make the peaks quite dense. In the conventional system of variable-width recording, a compromise between light peaks and dense valleys must determine the density of the negative. Elimination of the valleys from the negative makes it possible to increase the negative density and thereby obtain better prints.

Another important advantage of the push-pull sound recording system is the elimination of a kind of distortion that results from improperly processing the variable-width films. When high frequencies recorded on a sound negative are attenuated because of the finite width of the slit and the limited resolution of the film, a reduction of the average transmission also results. If this condition were allowed to persist, a certain amount of distortion would accompany all high-frequency sounds that varied in amplitude at audible frequencies. The distortion would be of the form of an extraneous noise produced by the envelope of the high frequencies, as shown in Fig. 6. By properly determining the negative and print density it is possible to avoid such distortion in any type of variable-width track. The push-pull system completely eliminates all the distortion that is not already printed out. The reason may be seen in Fig. 6. The

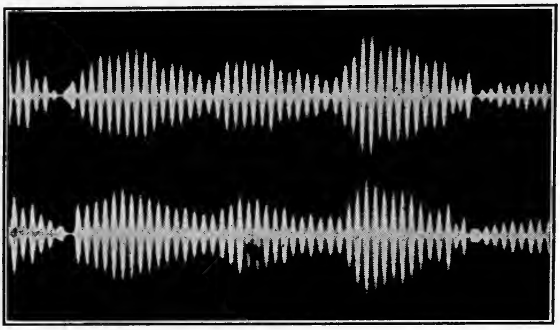

FIG. 6. Push-pull recording of keys jingling.

positive and negative waves of the high frequencies are 180 degrees out of phase, and so are added in the push-pull transformer; but the envelopes of amplitude for the two tracks are in phase, thereby cancelling the distortion in the transformer.

Acknowledgment is due Messrs. E. W. Kellogg and L. T. Sachtleben for their contributions to the development of the new system for noiseless recording.

DISCUSSION

MR. WENTE: How much free area is there between the two sound tracks? When there is no free space the method would appear to impose severe requirements with regard to weaving during reproduction. How much weaving can you tolerate with the records you have made?

MR. DIMMICK: The axes of the two sound tracks are half the width of the whole track, or 35 mils apart; therefore, for low modulation they are spaced 35 mils apart. However, for 100 per cent modulation the tracks just come together at the center, but do not overlap.

The triangles are so made that the tracks can not overlap; but in the record that you have just heard, there was no space between the half-tracks when the modulation was 100 per cent.

MR. WENTE: That is at 100 per cent modulation; if there were any weaving you would have "spilling over" from one side to the other, would you not?

MR. DIMMICK: Yes.

MR. KELLOGG: It should be understood that the fact that there was no clearance between the two half-tracks in this film, or, in other words, no margin to allow for weaving, means simply that this particular record happens to have been made that way. There is nothing inherent in the system that precludes a reasonable allowance for weaving.

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BOOK REVIEWS

Movie Making Made Easy. W. J. Shannon. *Moorfield & Shannon,* Nutley, N. J. 219 pp.

The preface of this handbook for the cine amateur states: "It has been estimated that there are some 300,000 home movie camera owners and 400,000 projector owners in this country alone. Serial numbers on equipment produced by leading manufacturers of cine equipment confirm this estimate." With these facts in mind, the author has attempted to compile into one book information that would interest not only this group but others contemplating joining it. The booklet is a compilation of tersely written chapters covering a very wide range of subject matter. In some cases it seems as though the brevity is too great even though this quality is most distinctly a virtue in any modern book. Some of the subjects treated are: The Home Theater, Amateur Movie Clubs, Making Up for the Camera, Photochemical Reactions, Reversal Process Explained, Aerial Photography, and Backyard Science with a Movie Camera. Practice and theory are somewhat mixed together in the text, and a more logical arrangement of subject matter might have been possible.

G. E. Matthews

Filming with the Cine Kodak Eight (Filmen mit Cine Kodak Acht). A. Stuhler. *W. Knapp,* Halle, Germany.

This little book contains an excellent discussion of the working characteristics of this 8-mm. camera, including many interesting illustrations and self-explanatory diagrams. In addition to general directions for use, information is given on the following subjects: artificial illumination, the use of teleobjectives, titling, making a picture story, editing, and splicing.

G. E. Matthews

Signals and Speech in Electrical Communication. J. Mills. *Harcourt, Brace & Co.,* New York, N. Y., 1934. 281 pp.

Without a diagram, an equation, a formula, or a chart, this book nevertheless portrays the discoveries, inventions, and principles that underly the many forms of communication of which the talking motion picture is but one.

"Twenty years ago a telegram was an event in the ordinary household, and the telephone was not the universal necessity it is today. Phonographs ground out a canned music all their own; motion pictures were silent, and there was no radio broadcasting. One couldn't telephone across America, much less across the Atlantic. There were no radios to ships at sea and airplanes in flight; no transmission of pictures by wire; and no prospect of television."

Intending his work for the interested but untechnical layman the author employs a number of unusually effective similes that tend to compensate for occasional obscurity resulting from inadequate editing.

H. G. Tasker

SOCIETY ANNOUNCEMENTS

STANDARDS COMMITTEE

At a meeting held at the Hotel Pennsylvania, New York, N. Y., on June 6th, the preliminary proofs of the revised Standards Booklet were carefully studied and corrected. New proofs are in process of being made for distribution to the members of the Committee for final vote on their acceptability for publication in the JOURNAL and subsequent recommendation to the Board of Governors for validation and submission to the American Standards Association.

Further attention was given to the comments of the German standardizing body on a number of the proposals of the S. M. P. E. Standards Committee with the thought of reconciling as many of the divergent opinions as possible in the revision of the Standards Booklet.

AMERICAN STANDARDS ASSOCIATION

At the last meeting of the Board of Governors, at Atlantic City, N. J., April 22nd, provision was made and the necessary funds appropriated to enable the S. M. P. E. to become an Associate Member of the American Standards Association. This is a new grade of membership in the A. S. A., created for the purpose of enabling organizations like the S. M. P. E. to participate more intimately in the work of the Association. Members in the Associate class are entitled to all the privileges of Member-Bodies except representation upon the Standards Council.

BOARD OF GOVERNORS

The next meeting of the Board of Governors will be held on July 16th, at the Westchester Country Club, Rye, N. Y. Among other items on the agenda, the nominations for officers for 1935 will be completed and plans will be initiated for the Fall Convention to be held at the Hotel Pennsylvania, New York, N. Y., October 29th–November 1st.

The Society regrets to announce* the deaths of
C. Francis Jenkins
Honorary Member of the Society
June 6, 1934
and
J. Elliott Jenkins
June 9, 1934

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* A full account of the contributions of Mr. C. Francis Jenkins to radio, motion picture engineering, and television will be published in a forthcoming issue of the JOURNAL.

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JOURNAL
OF THE SOCIETY OF
MOTION PICTURE ENGINEERS

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Published monthly at Easton, Pa., by the Society of Motion Picture Engineers
Publication Office, 20th & Northampton Sts., Easton, Pa.
General and Editorial Office, Hotel Pennsylvania, New York, N. Y.

Entered as second class matter January 15, 1930, at the Post Office at Easton, Pa., under the Act of March 3, 1879. Copyrighted, 1934, by the Society of Motion Picture Engineers, Inc.

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ON THE REALISTIC REPRODUCTION OF SOUND WITH PARTICULAR REFERENCE TO SOUND MOTION PICTURES*

H. F. OLSON AND F. MASSA**

Summary.—*The criteria for realistic reproduction of sound are discussed, showing how directional sound-collecting and dispersing systems may be employed to give results comparable with those of an ideal binaural system of reproduction. The use of a directional sound-collecting system, together with a directional sound-dispersing system, establishes: a "center of gravity" of the action; an illusion of depth or perspective; an acoustical or reverberation characteristic compatible with the picture; a large ratio of direct to reflected sound in the theater, emphasizing the acoustical properties of the theater; in musical reproduction, a correct balance and reverberation characteristic by the use of the two parameters.*

INTRODUCTION

To achieve realism in a sound-reproducing system, three conditions must be fulfilled: first, the frequency range must be such as to include all the audible components of the various sounds to be reproduced; second, the volume range must be such as to permit distortionless reproduction of the entire range of intensity associated with the sounds; third, the reverberation and binaural characteristic of the original sound must be preserved. It is only natural that most of the developments during the past decade have been concerned with the first two conditions, as it is quite obvious that those conditions should be satisfied before attempting a solution of the last condition.

During the past few years, the frequency and volume ranges of sound recording and reproducing equipment have been improved to such an extent as to permit serious thought on the problem of binaural reproduction. A brief discussion will be given of several methods now available for lending added realism to reproduced sounds, keeping in mind the particular requirements that must be fulfilled in sound motion picture reproduction. It must also be understood that from an acoustical point of view there are, fundamentally, two different and distinct types of scenes to be considered. First

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

** RCA Victor Co., Camden, N. J.

are those in which the action and sound are intimately related; and second are the scenes in which the sound effects are incidental. The first group, of course, includes the great majority of motion pictures; whereas the latter includes such pictures as are concerned with scenic views in which the orchestral accompaniment has no direct relation to the scene, but serves only to create a suitable mood in the audience.

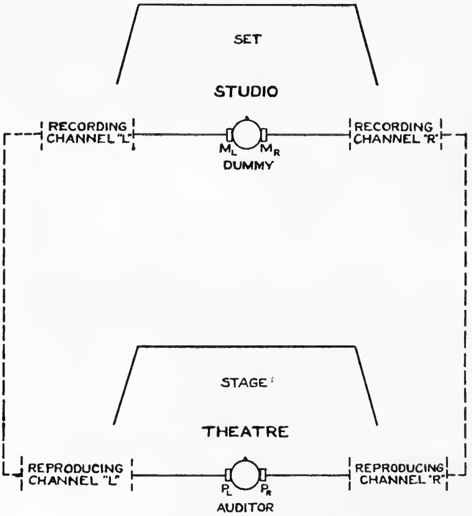

FIG. 1. Schematic arrangement of an ideal binaural sound-reproducing system.

(*A*) *Ideal System of Reproduction.*—An ideal binaural sound-reproducing system is shown schematically in Fig. 1, which indicates that the desired objective is attained by effectively transferring the auditor to the point of scenic action through the intermediary of a double recording and reproducing channel. Two microphones M_R and M_L simulate the ears of a dummy, each receiving the component of the original sound that would normally be received were the dummy a human being. Each component is recorded on a separate sound track and reproduced through a separate audio channel, each channel terminating in a high-quality telephone receiver. Each of the receivers is placed on the proper ear by the auditor, and the sound produced in each of his ears will be identical to what would have been produced at the original set had he been there at the time.

The advantages of this system are quite obvious; the binaural effect is practically perfect, and the reverberation characteristic of the set (which should be designed to conform to the scene) is transferred unadulterated to the listener.

There are two serious disadvantages to this ideal system in addition to the requirement for a double channel. In the first place, a set of ear phones is required for each member of the audience, which must be worn throughout the performance, and would not be tolerated by most persons. Second, each listener should be in the same position relatively to the scene as the dummy was relatively to the original set. Such a condition is obviously quite impossible of realization, and consequently those members of the audience who are somewhat removed from the screen will recognize a binaural effect not in accord with their distances from the scene. It appears, therefore, that the practical limitations of the ideal system render it undesirable for commercial application.

(*B*) *Approximation to Ideal System* (*Multi-Channel System*).—It has been stated that in an ideal binaural reproducing system the ears of the auditor must be effectively transferred to the original scene of action. A system for effectively transferring the original sources of sound from the studio to the theater stage is shown schematically in Fig. 2. A large number of microphones (M_1, M_2, ...) cover the entire area over which the action is taking place. The sound picked up by each microphone is recorded on a separate channel, each channel later feeding a separate loud speaker (S_1, S_2, ...).

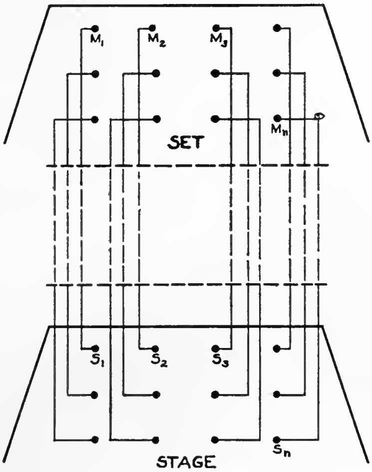

FIG. 2. Effective transfer of sound sources to a theater stage.

The loud speakers are arranged on the stage in the same positions as the microphones on the original set.*

The best application for such a system would be in those productions in which music is the essential part of the entire sound. In particular, a symphonic arrangement in which the picture accompaniment serves only to depict the meaning of the selection is admirably adapted to such a system. The orchestra would, figuratively, be transported bodily to the stage of the theater, and the location of each instrument of the group could be easily detected. The large number of channels required is the most serious handicap of the system. Attempts to reduce the number of channels have been made, and at a recent demonstration at New York City, Dr. Harvey Fletcher[1] of the Bell Telephone Laboratories showed the improvement over a single-channel system that could be attained by using only three channels.

The application of the multi-channel system to the theater will require drastic changes in the present technic of sound motion picture reproduction. If several sound tracks are to be recorded on the same film it is obvious that a wider film will become necessary, and it is improbable that such a change will be made.

In addition to the objections that arise from the need of several channels, two other conditions tend to operate against the ideality of the system. The first arises from the fact that the acoustical characteristic of the theater is superimposed upon that of the set. That may not be serious in some cases, but in others, particularly outdoor scenes, the reverberation of the theater may detract considerably from the naturalness of the sounds. Another objection arises from the necessity of requiring that the sound sources be spread far apart for the best effect. That means that the picture that is being reproduced should be spread out to cover the same distance occupied by the sound sources; otherwise the sounds will appear to come from "off stage" instead of from the picture.

(*C*) *Approximation to Ideal System* (*Single-Channel System*).—The

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* Another system of stereoäcoustical reproduction has been suggested by J. E. Volkmann. The stage should be made ideal for the collection of sound, and the auditorium should be made ideal for the dispersion of sound. For stereoäcoustical reproduction, the collecting microphones and the corresponding loud speakers should be located in the imaginary plane separating the two sections. This concept is different from the ordinary ones in which the auditor is transported to the scene of action, or the action transported to the auditorium.

most practical solution of the problem would obviously be one in which a single channel is employed for recording and reproducing. To what extent can a single-channel system be made to approach a solution of the problem? First, consider what happens when both ears are used in listening. In the first place, the auditor is able to judge the direction and apparent distance of the source and, second, to focus his attention upon the main source of sound and subconsciously attenuate the incidental noises that may be present. The latter characteristic of binaural hearing is perhaps the more important of the two, as it acts to enhance intelligibility, which is undoubtedly the most important factor of the ability to understand. The discrimination against undesired sounds that can be realized with a binaural reproducing system may be attained with a single-channel system by employing a directional pick-up; and it will be shown later how the apparent distance of the source of sound is preserved by using a directional pick-up. By employing a directional dispersion system in the theater, the acoustical characteristic of the auditorium will not mask the reverberation characteristic of the recording to such an extent as a non-directional reproducing system.

The advantages of directional systems for collecting and dispersing sound will be outlined more in detail in the sections that follow, and the discussions will indicate the extent to which they enhance the artistic quality and naturalness of sound motion picture reproduction.

COLLECTION OF SOUND

(*A*) *Collection of Sound in Reverberant Rooms; Direct and Generally Reflected Sound.*—When a source of sound is caused to act in a room, the first sound that strikes a collecting system placed in the room is the sound that comes directly from the source without reflection from the boundaries. Following that comes sound that has been reflected once, twice, and so on; meaning that the energy density of the sound increases with the time, as the number of reflections increase. Ultimately, the absorption of energy by the boundaries equals the output of the source, and the energy density at the collecting system no longer increases; this is called the steady-state condition. Therefore, at a given point in a room there are two distinct sources of sound: namely, (*1*) the direct, and (2) the generally reflected sound. For rooms that do not exhibit abnormal acoustical characteristics, it may be assumed that the ratio* of the reflected to the direct sound represents the effective reverberation[2] of the collected sound.

(*B*) *Performance of Directional and Non-Directional Collecting Systems in Reverberant Rooms.*—Consider a sound-collecting system, the efficiency of reception of which may be characterized as a function of the direction with respect to some reference axis of the system. (The non-directional collecting system is a special case of the directional system in which the efficiency of reception is the same in all directions.) The output of the microphone may be expressed as

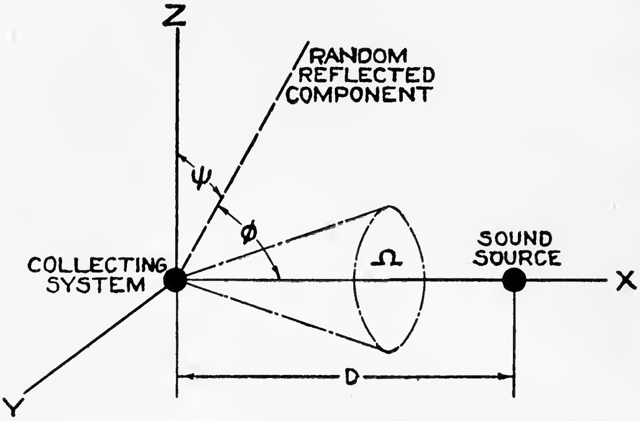

FIG. 3. Directional sound-collecting system.

$$e = Qpf_1(\psi)f_2(\phi) \tag{1}$$

where e = voltage output of the microphone.
p = sound pressure.
Q = sensitivity constant of the microphone.
ψ and ϕ are the angles shown in Fig. 3.

If the distance between the source of the sound and the collecting system is D, Fig. 3, the energy density at the microphone due to the direct sound is

$$E_D = \frac{E_0}{D^2 4\pi c} \tag{2}$$

where E_0 = power output of the sound source.
c = velocity of sound.

---

* The ratio of reflected to direct sound has been referred to as the "recorded" or "collected" reverberation.

To simplify the discussion, assume that the effective response angle of the microphone is the solid angle Ω. The direction and phase of the reflected sound are assumed to be random. Therefore, the reflected sounds available for actuating the directional microphone are the pencils of sound within the angle Ω. The response of the directional microphone to generally reflected sound will be $\Omega/4\pi$ that of a non-directional microphone. The generally reflected sound to which the directional microphone is responsive is therefore given by

$$E_{\mathrm{R}} = \frac{4E_0\ \Omega}{caS\ 4\pi}\left[1 - \epsilon^{cS\,[\log_\epsilon (1-a)t]/4v}\right](1 - a) \tag{3}$$

where a = absorption per unit area.
S = area of absorbing material.
V = volume of room.
t = time.

The ratio of the generally reflected sound to the direct sound is a measure of the recorded reverberation:

$$\frac{E_{\mathrm{R}}}{E_{\mathrm{D}}} = \frac{4D^2\Omega\left[1 - \epsilon^{cS\,[\log_\epsilon (1-a)t]/4v}\right](1 - a)}{aS} \tag{4}$$

If the sound continues until the conditions are steady, equation (4) becomes

$$\frac{E_{\mathrm{R}}}{E_{\mathrm{D}}} = \frac{4D^2}{aS}\,\Omega\,(1 - a) \tag{5}$$

From (4) and (5), it will be seen that the received reverberation can be reduced by decreasing the distance D, by increasing the absorption aS, or by decreasing Ω.

Fig. 4 compares a non-directional microphone with a directional microphone in which $\Omega = 4\pi/3$ (*i. e.*, the velocity microphone). The output of the microphone due to direct and generally reflected sound shows less frequency discrimination due to the absorption characteristics of the studio.

This discussion shows that, for the same room, the recorded reverberation in a directional system will be $\Omega/4\pi$ that of a non-directional system; or, for the same room and the same recorded reverberation, the directional microphone can be operated at $\sqrt{4\pi/\Omega}$ times the distance of a non-directional microphone.*

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* A fundamental requirement of any microphone is a directional characteristic independent of frequency. A system that does not possess such a characteristic will introduce frequency discrimination. The directional characteristics of the velocity ribbon microphone are independent of the frequency.

(*C*) *Use of a Directional Sound-Collecting System for Discriminating against Sounds Incidental to the Action.*—When one listens normally with both ears he is able to focus his attention on the main source of action and subconsciously attenuate incidental noises that may be present. In single-channel sound reproduction, it is important that the same emphasis be placed on the main action and a

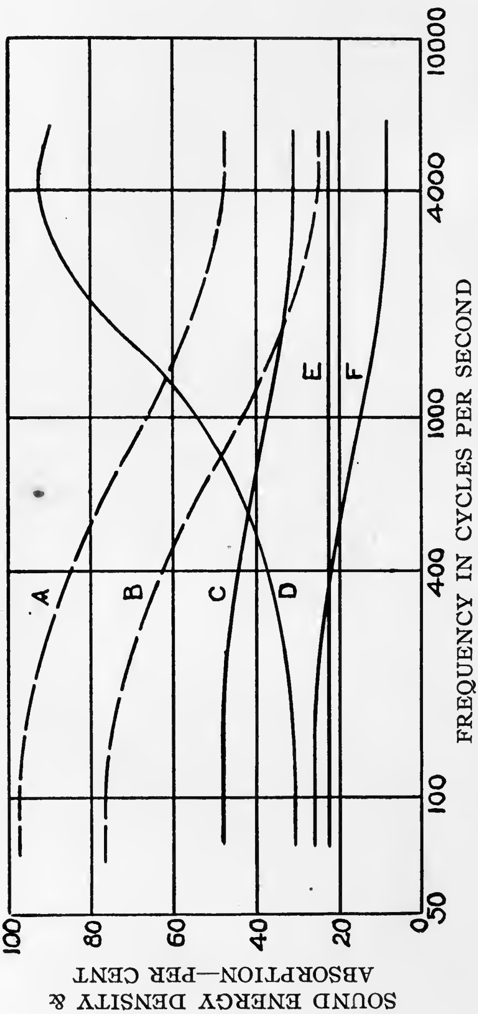


FIG. 4. Curves showing the absorption characteristic of a room and the various components of sound received by both a directional and non-directional sound-collecting system: (*A*) total sound picked up by a non-directional system; (*B*) reflected component of sound picked up by a non-directional system; (*C*) total sound picked up by a directional system; (*D*) absorption characteristic of the room; (*E*) direct component of sound picked up by both directional and non-directional systems; (*F*) reflected component of sound picked up by a directional system.

corresponding discrimination be made against the incidental sounds. In those respects the directional collecting system possesses distinct advantages. Fig. 5 illustrates. The action centers about the characters seated at table *2*. To achieve the correct artistic effects as regards distance, the pick-up distance must be comparable with the camera distance. As a consequence, the distances from tables *1*, *2*, and *3* to the microphone are nearly the same. Therefore, in order to concentrate the attention upon table *2*, the only alternative for attenuating the sound from the tables *1* and *3* with respect to *2* is

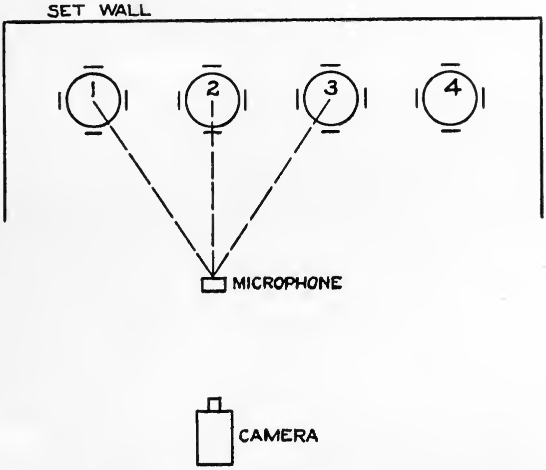


FIG. 5. Arrangement employing a directional collecting system for emphasizing the action and discriminating against incidental sounds.

to use a directional collecting system. Furthermore, the relative ratio of the intensities of the sounds from tables *1* and *3* can be adjusted to what one would actually hear were he located at the "distance" of the camera. This example illustrates how a "center of gravity" of the recorded sound can be established comparable with the "center of gravity" of the action.

(*D*) *Use of a Directional Sound-Collecting System in Locating the Action with Respect to the Environs.*—When we listen normally with both ears we are able to localize the azimuth of the sound by means of binaural triangulation. In the preceding section, it was shown that an illusion of azimuth of the action can be gained in a single-channel system by adjusting the relative intensities of the various sounds in accordance with the way in which one would normally hear when viewing the action first-hand. In listening normally the source of sound is further localized, as regards distance, by the time relations between the direct sound and the sound reflected from the boundaries, as illustrated in Fig. 6. If a directional sound-collecting system is employed, the pencils of sound reflected from the walls *1* and *3* will be attenuated more than the pencils of sound reflected from wall *2*, corresponding to the relative intensities of the sounds perceived by a person located at the microphone position. The relative time-intervals and intensities of the direct sound and the sound reflected from wall *2* determine the perspective of the sound. To accomplish an illusion of depth successfully under the conditions described, it is important that the first reflections from the boundaries should overshadow the succeeding reflections. The reverberation-time of sets is generally relatively short, which means that the boundaries are highly absorbent and that the first reflections predominate. Furthermore, the geometry of the sets is usually such that the reflected sound is directed into the studio proper. This example illustrates how an illusion of depth or perspective of the recorded sound can be established by the time-interval and intensity of the direct and reflected sounds reaching the microphone, and by excluding or attenuating sounds that would not normally contribute to the perspective.

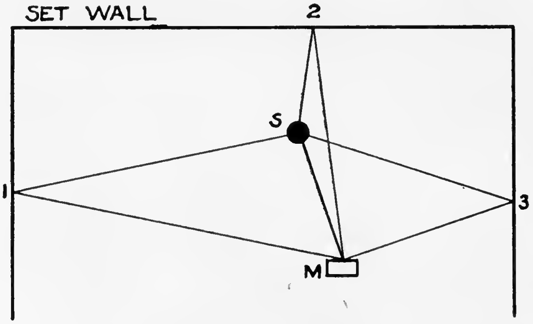


FIG. 6. Arrangement employing a directional sound-collecting system for creating an illusion of the position of the source of sound, by utilizing the relative times and intensities of the direct and reflected sounds.

(*E*) *Sound-Collection Distance Commensurate with Camera Distance.*—In the preceding sections means have been outlined for establishing perspective in a single-channel system by employing a directional sound-collecting system. In order further to enhance the artistic effect of the collected sound, it is important that the apparent distance of the sound source, as perceived in the reproduced sound, be commensurate with the apparent distance of the projected picture as perceived on the screen by the eye. In order that the realistic effects outlined in sections (*C*) and (*D*) be enjoyed to their utmost, it is important that the reflected sounds capable of actuating the microphone shall not be large compared with the direct sound.

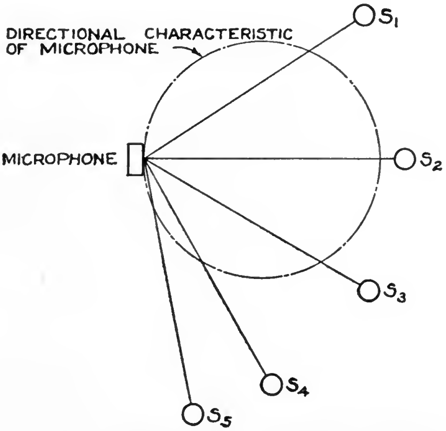


FIG. 7. Arrangement employing a directional sound-collecting system to secure the correct balance and reverberation characteristics of the instruments of an orchestra.

In section (*B*) it was shown that the ratio of the direct to the reflected sound was inversely proportional to the square of the distance and directly proportional to the effective angle of the collecting system. Obviously, since the collecting distances commensurate with the picture distance are in general relatively large, a directional collecting system is required to maintain a tolerable ratio of direct to reflected sound.

(*F*) *Use of a Directional Collecting System for Adjusting the Relative Intensities and Reverberation Characteristics of a Group of Recorded Sounds.*—The recording of an orchestra is a salient example of the value of a directional sound-collecting system. In musical sound reproduction there are two important factors, namely; the "correct balance" or relative intensities of the instruments, and the correct reverberation characteristics of the reproduced sound. In a non-directional system only one parameter, the distance, is available for controlling the intensity and effective reverberation of the recorded sound. However, in a directional sound-collecting system, two parameters are available. A plan view of a directional sound-collecting system (a velocity microphone) and a group of sound sources is shown in Fig. 7, which is self-explanatory. In this particular case the sound source S_2 is to be emphasized, and it is consequently placed upon the axis of the sound-collecting system and quite close to it. This results in a relatively high recorded intensity and low recorded reverberation. Sound source S_4 is placed at an angle of 60 degrees, in which case an attenuation of the direct sound of 6 db. results, due to the directional response characteristic of the microphone. In other words, practically any value of loudness, as well as of effective rever-

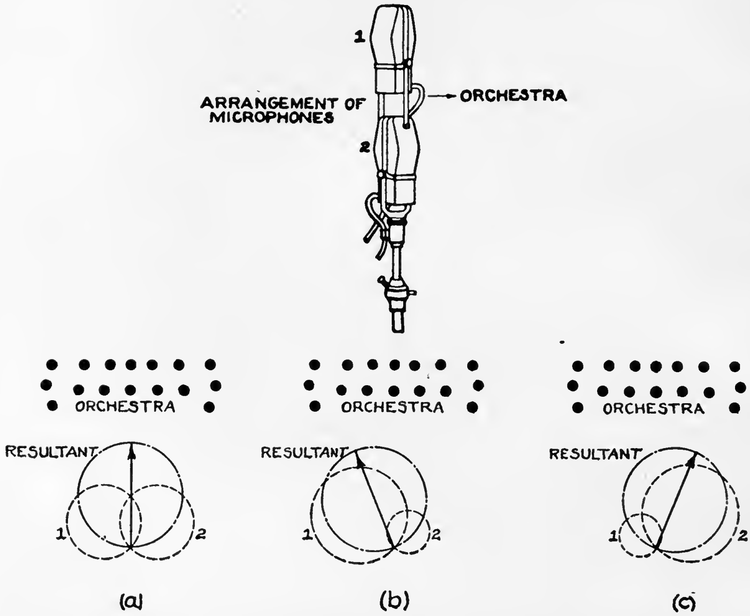
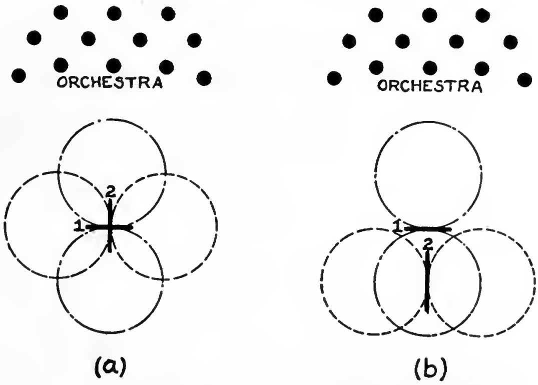


FIG. 8. Use of two directional microphones mounted at right angles for varying the "balance" of an orchestra.

beration, can be attained by orienting and positioning the sources with respect to the microphone.

The preceding discussion shows how the correct balance and reverberation characteristics of musical reproduction may be effected by employing a velocity microphone. In certain musical recordings it is desirable to change the balance or relative intensities of the instruments during the course of a single selection. This may be accomplished by employing two velocity microphones, one placed above the other, with the axes of the ribbons in the same line and the planes of the ribbons intersecting at right angles. A plan view of such an arrangement is shown in Fig. 8. In Fig. 8(*a*) the mixers of microphones *1* and *2* are adjusted so that the outputs of the two microphones are equal. In this case the vector of maximum pick-up passes through the center of the orchestra. In Fig. 8(*b*) the mixers of microphones *1* and *2* are adjusted so that the output of microphone *1* is several times that of *2*. In this case, the vector of maximum pick-up passes through the left-hand portion of the orchestra and, as a consequence, the left portion of the orchestra is emphasized relatively to the right-hand portion. Similarly, in Fig. 8(*c*), the right-hand portion of the orchestra is emphasized relatively to the left-hand portion.



(a) (b)

FIG. 9. Arrangement of two directional microphones for controlling the recorded reverberation of an orchestra.

By employing three velocity microphones, two placed as described above and the third at right angles, the resultant vector can be shifted from side to side in order to emphasize certain portions of the orchestra, and shifted up and down to control the collected reverberation.

Fig. 9 shows another variation of the use of two microphones. In Fig. 9(*a*) the axis of microphone *1* passes through the center of the orchestra, microphone *2* being at right angles. If microphone *2* is used alone, practically all the recorded sound is reflected sound. The reflected or reverberant sound decreases as the relative recorded output of *1* with respect to *2* increases.

Fig. 9(*b*) is another variation, in which the microphones are placed at right angles and separated in space. At low frequencies, when the distance between the microphones is small compared with the wavelength of the sound, the resultant collection diagram is a cosine function. At higher frequencies the diagram is complex.

The systems shown in Fig. 9 are valuable when it is desirable to introduce considerable reverberation or "liveliness" into the recording.

DISPERSION OF SOUND

(*A*) *The Action of a Reproducer in a Reverberant Room: Direct and Generally Reflected Sound.*—The resultant sound energy density at the position of the auditor in a theater depends upon the response, the directional and energy characteristics of the loud speaker, and the reverberation characteristics of the theater. From the standpoint of the auditor, it may be said that there are two sources of sound energy, namely: the direct sound, which travels directly from the loud speaker to the auditor, and the generally reflected sound, which is reflected from the boundaries before reaching the auditor.

In a theater free from acoustical difficulties, the energy density of the generally reflected sound is practically the same for all parts of the theater. Therefore, the solution of the problem of achieving uniform energy density is to employ reproducers that will yield the same direct sound energy to all parts of the theater. We shall illustrate by an example how that may be accomplished by employing a directional loud speaker.

(*B*) *The Distribution of Direct Sound Energy in a Theater, Employing a Directional Loud Speaker.*—An elevation view of a reproducer in a theater is shown in Fig. 10. The two extreme points to be supplied are indicated *1* and *2*. If the speaker were non-directional, the ratio of the direct sound energy densities at the two points would be inversely as the ratio of the squares of the distances from the reproducer. In this particular case, the difference in level is 13 db. Obviously, such a large variation in sound intensity precludes the possibility of satisfactory reproduction over the entire area to be supplied. Therefore, a compensating means must be provided to counteract the variation of intensity with the distance from the reproducer. The directional reproducer furnishes a solution of the problem.

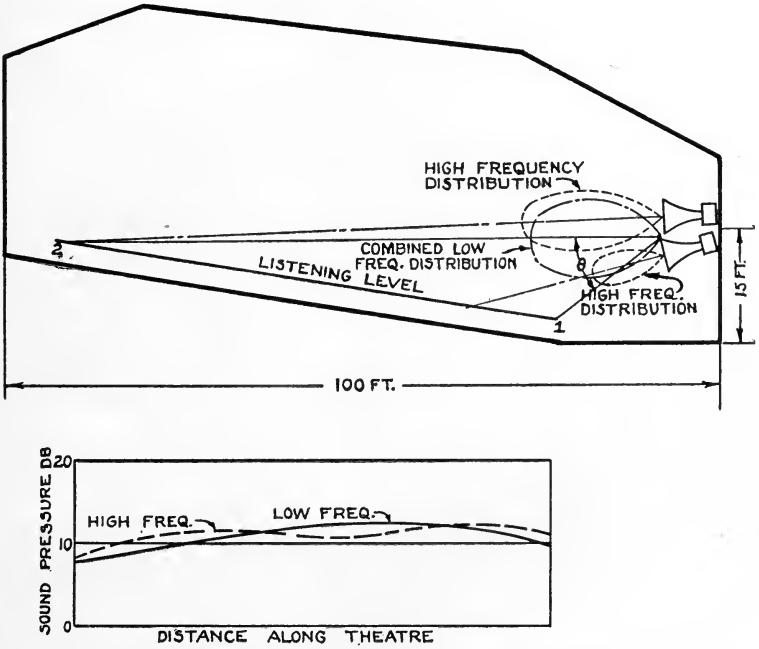


FIG. 10. Arrangement of a directional sound-radiating system in a theater, showing the uniform sound distribution attained.

The directional characteristics of the individual units in Fig. 10 vary with frequency, being somewhat sharper at the high frequencies, as compared with the low frequencies. The use of two or more loud speakers makes it possible to arrive at directional characteristics that are practically independent of the frequency. In this particular case, at low frequencies, the difference of level for a point 40 degrees from the common axis, as compared with the level at a point on the axis, is 13 db. The loud speakers are adjusted until the axis of the characteristic passes through the point *2*. Then the height is adjusted until the angle θ is 40 degrees. To render the distribution uniform at the higher frequencies, the horns are flared and the relative output of the loud speakers adjusted for uniform distribution. The distribution over the distance under consideration is shown in Fig. 10. In other words, the variation of the sound pressure with the angle between the axis and the line joining the observation point and the reproducer has been employed to compensate for the decrease of the sound energy with the distance.

The sound energy density, due to direct sound radiation from the loud speaker, may be defined as

$$E_{\mathrm{D}} = \frac{p_0^2 X_0^2 R_\theta^2}{r^2 \rho c^2} \qquad (6)$$

where p_0 = the sound pressure at a distance X_0.
r = the distance from the loud speaker to the observation point.
ρ = the density of air.
c = the velocity of sound.
R_θ = the ratio of the sound pressure at the angle θ to that at the angle zero.

To analyze the distribution of the direct sound over the area, the plan view of the theater and the directional characteristics of the reproducer must be considered. The number of reproducers will depend upon the angle subtended at the loud speaker by the area to be covered and the effective dispersion angle of the reproducer.

(*C*) *The Energy Density in a Theater Due to Reflected Sound.*—The sound energy density due to the generally reflected sound is a function of the absorption characteristics of the theater and the power output of the reproducer. The sound energy density due to the generally reflected sound is given by

$$E_{\mathrm{R}} = \frac{4P}{caS}\left[1 - \epsilon^{cS[\log_\epsilon (1-a)t]/4V}\right](1 - a) \qquad (7)$$

where a = the average absorption per unit area.*
S = the area of the absorbing material.
V = the volume of the room.
t = time.
c = the velocity of sound.
P = the power output of the loud speaker.

---

*The average absorption coefficient for a directional dispersing system in a theater in which the absorption of the boundaries depends upon the orientation of the axis of the system with respect to these surfaces.

(*D*) *Total Sound Energy Density: Effective Reverberation.*—The total sound energy density at any point in the theater will be the sum of the direct and the generally reflected sound, and may be expressed by

$$E_T = E_D + E_R \tag{8}$$

In section (*B*), a method was outlined employing directional loud speakers for achieving uniformity of the energy density of the direct sound. The energy density of reflected sound, as shown by equation (7), is independent of the observation point. As a consequence, by employing directional loud speakers, the sound energy density will be the same in all parts of the theater. Furthermore, the effective reverberation of the reproduced sound (the ratio of generally reflected to direct sound), due to the theater, is the same for all parts of the theater.

To gain the effect of greatest intimacy in the reproduced sound, it is important that the acoustical characteristics of the recording conditions be emphasized and those of the theater suppressed, an objective that will be attained by making the ratio of the direct to the reflected sound as great as possible.

A consideration of equations (6) and (7) shows that the effective reverberation due to the theater can be reduced by decreasing the reverberation time. There are, of course, limitations beyond which a further reduction of the reverberation time becomes impracticable. Further consideration of the equations shows that the effective reverberation can be reduced by means of directional loud speakers; that is to say, the generally reflected sound is proportional to the effective dispersion angle of the loud speaker. From the foregoing discussion, we may draw the following conclusion: the use of a directional loud speaker reduces the effective reverberation due to the theater and emphasizes the acoustics of the action by suppressing the acoustics of the theater; for example: outdoor scenes—practically no reverberation; cathedral scenes—much reverberation.

This paper has been concerned with creating the maximum degree of intimacy with the reproduced sounds by emphasizing the acoustics of the studio. In certain musical arrangements serving as accompaniments to the picture, there would be an advantage in employing a spread-out sound source, such as, for example, loud speakers spread across the entire stage, as contrasted to the cluster outlined in this paper.

DIRECTIONAL SOUND-COLLECTING AND DISPERSING SOUND SYSTEMS AS A UNIT

The use of a directional sound-collecting system, together with a directional sound-dispersing system, establishes: A "center of gravity" of the action by emphasizing the action and suppressing incidental sounds; an illusion of depth or perspective, by adjusting the time intervals and intensities of the direct and reflected sounds reaching the microphone and by excluding or attenuating sounds that would not contribute to the perspective; a reverberation characteristic compatible with the projected picture, by employing collection distances comparable with the camera distance; a large ratio of direct to reflected sound in the theater, emphasizing the acoustics of the action and suppressing the acoustics of the theater; in reproducing music, a correct "balance" or relative ratio of intensities of the instruments, and a correct reverberation characteristic of the reproduced sound by adjusting the two parameters in the directional collecting-system that control those factors. Then by the careful application of a directional sound-collecting and dispersing system, a new and powerful means of controlling sound reproduction becomes available for enhancing the illusion of reality and heightening the acoustical character of the performance.

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DISCUSSION

MR. DAVEE: Are the data given in the paper actual or theoretical? How were the sound pressures measured, if the data are actual?

MR. OLSON: In the case of the theater, we have made sound energy measurements. To obtain the direct sound energy density the measurements are made outdoors, or in free space. Then measurements are made indoors, giving a combination of direct and generally reflected sound.

In the case of the collection of sound, the data which we have shown were results of observation rather than of direct physical measurements. Of course, the microphones were calibrated, and we also made measurements showing the discrimination against sound coming from off the axis; but in the final analysis, it is the results that count in case of recording, rather than the measurements.

MR. FRITTS: Please state the elementary differences of construction and principles of the velocity microphone as compared with the other types? What other styles of construction can be used to make the microphone directional?

MR. OLSON: The directional characteristic of the velocity microphone is a cosine characteristic—the same as a loop antenna. The efficiency of pick-up is a function of the cosine of the angle with respect to the axis, which is normal to the ribbon. Such a characteristic results from the fact that the ribbon of the velocity microphone is actuated by the difference of pressure between the two sides of the ribbon, which is a function of the cosine of the angle. For example, if a sound originates in the plane of the ribbon, the same pressure occurs on both sides of the ribbon. The maximum difference of pressure between the two sides occurs when the source of sound is in a line normal to the ribbon.

This microphone has a uniform directional characteristic with respect to frequency. The combination of a pressure and a velocity microphone is another example of a directional microphone.

MR. SHEA: With respect to using a number of ribbon microphones for recording, can you notice the interference due to the fact that the microphones are not in exactly the same location? Analogously, in theaters where one loud speaker is directed toward the rear and another toward the front of the theater, is the interference noticeable at the center of the theater?

MR. OLSON: When using two or three microphones, the microphones are placed in line normal to the floor. In this case there would be practically no interference, because the distance from the source to each microphone is practically the same.

When the microphones are separated, there are interference effects, of course, at the higher frequencies, and the combined characteristic is quite complex; but, apparently, if the distance is not too great, it is noticeable in some instances, but not in others.

In the case of the two loud speakers, interference does not occur because the distance from each unit, at the point where the two feed a certain portion of the theater, is the same. In other words, at the overlap point in the theater, the distance from the unit to the point of observation is the same; and therefore there is no phase shift, and, consequently, no interference. Of course, there would be interference at the front of the theater, but there is no sound at this point from the upper loud speaker. The same is true at the rear of the theater where there is no sound from the lower speaker.

SIXTEEN-MILLIMETER SOUND PICTURES IN COLOR*

C. N. BATSEL AND L. T. SACHTLEBEN**

Summary.—*The nature of a variable-width sound track on longitudinally lenticulated color films is discussed, and the optical reduction of 35-mm. subtractive color subjects to 16-mm. film by the Kodacolor process is described.*

It is the purpose of this paper to present a brief account of work done in the development laboratory relative to the production of 16-mm. sound films in full color. The medium selected was the well-known Kodacolor process of color photography and projection, a true three-color additive process,[1,2] by which excellent pictures may be made and projected in full natural color.

Following extensive development in the 16-mm. sound picture field, during which means were worked out for producing 16-mm. sound films of good quality, both by direct recording and by re-recording from 35-mm. sound films, some attention was given to the matter of producing 16-mm. sound records on Kodacolor film. It was thought at the time that some peculiar effects might arise if the sound recording beam were passed through the longitudinally lenticulated base of the film before the final formation of the image on the emulsion, as in the case of the picture. The lenticular film base would no longer permit the formation of a true optical-slit on the emulsion, but would produce a series of images, each separated from the other, formed by the several cylindrical lenses in the path of the beam. For instance, if a recording optical system images an optical slit upon an emulsion through a longitudinally lenticulated film base, the image that results will be a true image of the slit in the longitudinal plane, and a series of more or less sharp images of the exit pupil of the system in the transverse plane. And as the cutting edge of the recording beam advances and recedes across the cylindrical lenses there will be produced a series of more or less fully illuminated images of the exit pupil of the system in the transverse plane, according to the extent to which the individual lenses on the film base are filled

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*Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

**RCA Victor Company, Camden, N. J.

with light. Thus, in recording in this fashion by the variable-width process, the recording image consists of a series of more or less brightly illuminated image elements, rather than a uniformly illuminated image of continuously varying length. Fig. 1 shows the comparison between variable-width recording on standard film and on Kodacolor film when the emulsion is in the reverse position.

It is seen that the blackened portion of the variable-width negative will comprise a series of longitudinal strips of density, rather than a continuous field of density, and that the boundary between the clear and the blackened portions of the track will not be a smooth curve, but will comprise a series of more or less fully exposed images of the exit pupil, in the transverse plane. Or, more simply, the boundary presents a serrated or step-like appearance where it crosses the lenticulations. This was a situation quite different from that encountered in usual variable-width practice, and it was felt that distortions of a more or less troublesome nature might arise from it.

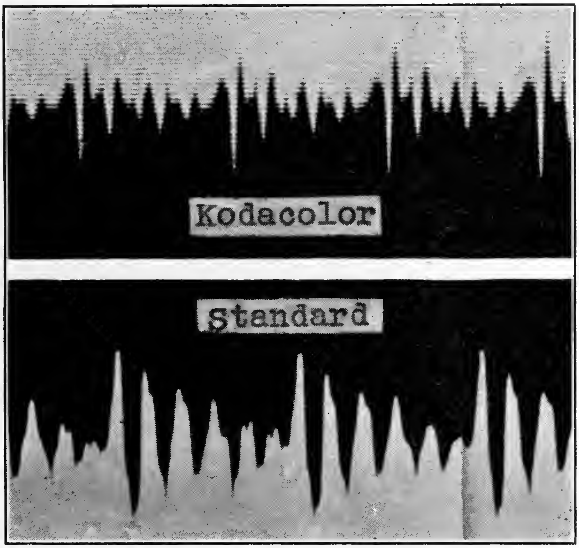

FIG. 1. Comparison of variable-width sound tracks on Kodacolor film and on standard film.

A single-film, 16-mm. sound camera was chosen to test the feasibility of recording sound on Kodacolor film. The camera was constructed for normal black-and-white picture work with the recording system focused directly upon the emulsion in the obverse position. With Kodacolor film the emulsion was in the reverse position, making it necessary to refocus the recording system before a recording could be made. The original test recording was made on August 9, 1932. The sound record was very successful, and definitely demonstrated the feasibility of recording sound on this film by the variable-width process, with the emulsion in the reverse position. It was found that no distortion of a serious nature occurred due to the use of Kodacolor film with longitudinal lenticulations.

Pursuant to the successful recording of sound on Kodacolor film in the single-film, 16-mm. sound camera, it was believed that subtractive color subjects on 35-mm. film should be optically reducible to 16-mm. film by the Kodacolor process, using an optical system similar to that employed in Kodacolor photography with the 16-mm. camera. The first test was made in a crude way using a projector fitted with a two-inch Kodacolor projection lens as a camera. The projector was mounted in a light-tight box and focused on a white card, upon which was projected an image of a frame from a 35-mm. Technicolor print. A strip of raw Kodacolor film was placed in the projector, exposed and reversed, with the result that a fairly promising image was obtained when the film was reprojected.

Following this, an optical-reduction step-printer was equipped with the necessary optics to permit printing directly from a 35-mm. Technicolor film to 16-mm. Kodacolor film. This optical system was essentially the one used in Kodacolor projection, with a three-color filter in front of the printing lens, and a negative lens at the 16-mm. film to produce a virtual image of the filter of the proper size at the proper distance from the film. The first system was improvised from such optics as were available in the laboratory, and the pictures obtained exhibited marked color dominants at the margins, due to the insufficient speed of the printing lens and the consequently diminished size of the filter image. Nevertheless, the results were remarkably promising. Later, a lens of sufficient speed was obtained to permit the required 3:1 ratio between the distance from the film to the filter image, and the total width of the filter image; with the result that a great improvement was effected in the color-balance, and the color dominants at the edges of the picture were practically eliminated.

The sound track of the 35-mm. Technicolor print was transferred to the 16-mm. Kodacolor film by continuous optical reduction printing, with the 16-mm. emulsion in the obverse position.

Summarizing, it has been shown in the laboratory that 16-mm. Kodacolor sound films can be successfully produced without introducing serious sound distortions due to the peculiar character of the film base. Such films can be produced by either of two methods: by recording with a 16-mm. single-film sound camera at the time the picture is taken, or by optical reduction printing of the picture and sound track on the Kodacolor film from a 35-mm. subtractive sound film.

Acknowledgment is due Mr. A. C. Blaney for his suggestion that 35-mm. subtractive color pictures be optically reduced to 16-mm. film by the Kodacolor process.

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DISCUSSION

MR. HOLSLAG: Do I understand that the first portion of the film that was projected was made on a direct single-system sound camera?

MR. SACHTLEBEN: Yes.

MR. HOLSLAG: Then I don't quite understand how the emulsion could be turned around so it would face the recording light. It seems to me that it would be out of focus, because in the Kodacolor process it is necessary to photograph through the film base.

MR. SACHTLEBEN: It was necessary to refocus the recording optical system.

MR. HOLSLAG: You would have to have a special focusing adjustment for the recording light.

MR. SACHTLEBEN:—or some means of pushing the image forward optically. That could be done quite simply.

MR. RICHARDSON: It seems to me the principal fault with color pictures is the constant predominance of certain colors. What, if any, progress is being made in bringing out the finer shades of color and differentiating between the vast number of possible shades.

MR. BATSEL: In respect to this paper, we are not trying to develop new color processes.

MR. RICHARDSON: Well, do you know whether there is any possibility of reducing the preponderance of red, or other colors, and bringing out the more delicate shades?

MR. BATSEL: Yes, if there is too much red you can change the filters, or the illumination of the subject. We used the filters that were supplied to us. We may have more red than we should have had if the subjects had been illuminated by sunlight.

MR. RICHARDSON: When there is a predominance of one or two colors the picture on the screen doesn't look natural. Occasionally we see a picture that apparently has a wonderful assortment of shades that appear naturally, and theater patrons comment on the beauty of the picture. If there is any possibility of making such pictures it ought to be done.

Mr. Crabtree: Most of the color pictures shown to date have been produced by the two-color processes, in which, as you say, the reds and browns, greens and bluish greens predominate. In order to reproduce the original colors faithfully a three-color process is necessary. The only three-color processes that have been developed commercially to date are the Spicer-Dufay; the Gaumont, which requires special projectors; the Technicolor process, exemplified by the *Silly Symphony* cartoons; and the Kodacolor process, which to date has been shown only in 16-mm.

I think that the fidelity of reproduction of color in the three-color processes is quite remarkable. In the case of some of the color sequences that we have seen perhaps the choice of colors in the set was not very appropriate, so that with some subjects the colors have been rather glaring. However, I want to assure Mr. Richardson that processes are now available that are capable of reproducing colors faithfully. So far Technicolor has restricted its pictures to cartoons and indoor sets. I expect that within the next six months you will see outdoor pictures by Technicolor that will probably meet with your approval.

Mr. Blaine: I might mention that the Technicolor camera has been used out-of-doors along the coast of Europe. We have recently received some of the most beautiful negatives and prints that we have ever seen, and I believe they reproduce exactly the natural colors of the scenes.

Mr. Faulkner: I have seen some of Technicolor's out-door scenes taken in the last thirty days, and there is a vast difference between them and the two-color pictures with which we are all acquainted.

Mr. Edwards: I believe a great deal of the trouble with the color pictures we see in the theaters nowadays is due to the make-up man in the studio. He has the same idea that he had in the old Kinemacolor days, that if he wanted to get a peach bloom on a girl, he had to paint her in ocher red. Besides, not enough care is taken in selecting the colors in their sets. They are so anxious to get color that the color is overdone.

Mr. Kellogg: I don't think it is quite fair to this demonstration to center attention on the imperfections of the colors. The men that made the film and projected it are interested primarily in showing that the sound system that we have been working on for the Victor Company is applicable to pictures made by the Kodacolor process. For that purpose they have used the standard Kodacolor system, and have taken a few pictures in colors, recording sound on the same film. The work happened to be done in the winter, when good outdoor color subjects were not abundant. Enough shots were made to show that sound can be satisfactorily recorded on Kodacolor film. The pictures were in color, and that is as far as the authors of the paper attempted to go—not to give a demonstration of pictorial art.

A 16-MM. SOUND RECORDING CAMERA*

C. N. BATSEL, L. T. SACHTLEBEN AND G. L. DIMMICK**

Summary.—*A discussion of some of the problems encountered in the development of a 16-mm. sound recording camera, and a description of the most important features of such a camera developed for the use of amateurs.*

The rapid transition of the professional movies from silent to sound pictures convinced those engineers who had followed the development and expansion of 16-mm. pictures that unless sound were added, the field of application of that type of moving picture would rapidly narrow and become practically extinct. Consequently, work was carried on for several years in developing means of obtaining and showing sound-on-film 16-mm. pictures. Most of the earlier efforts were expended in developing re-recording, printing, and projection equipment that would fulfill the needs of the commercial users. It was realized, however, that perhaps the largest consumers of 16-mm. film and equipment were the amateurs; and while the projection equipment developed for commercial use was so designed that it could serve the amateur exceedingly well, it was felt that his interest in pictures was largely held by the fact that he could make as well as show his own pictures. If this interest were to be maintained it would be necessary to provide the appropriate film and equipment.

The problem of providing a means of permitting him to take the pictures and record the sound presented some very difficult and unsolved problems, not only as to the simplicity and dependability of the design, but as to size also.

Consequently, in developing such a camera, the primary considerations were dependability, size, weight, and simplicity of operation; so that the person using it could make good sound movies with very little more effort than when taking a silent picture, and with as much assurance of good over-all results as could be experienced with his silent camera. The size and weight should be such that it could be

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

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carried and operated inconspicuously and with ease; and, finally, there must be a minimum number of controls to be manipulated during operation.

Although the camera described in this paper is in an advanced stage of development, it is still a laboratory product. However, so much of the preparatory work has been accomplished that we hope to be able to make such equipment commercially available in compact, fool-proof, and inexpensive form within the near future.

Fig. 1 is a general view of the camera. Its dimensions are $7^1/_2$ inches high, $8^7/_{16}$ inches long, and $5^1/_{16}$ inches wide. It weighs $8^1/_2$ lbs. when loaded with one 100-ft. roll of daylight-loading sound recording safety film and with three No. 2 dry cells for supplying the current for the recording lamp. The electrical equipment is somewhat heavier, due to the amplifier and microphone.

FIG. 1. General view of camera.

Extreme care was taken in designing the case to give it a neat appearance as well as to fulfill its function of housing the working parts of the camera. It is finished in a neat, durable gray, crinkle finish, with chromium plated trimmings, and is equipped with a padded leather strap handle securely attached to the top.

The door, or cover, and the telescopic view-finder are made in one piece. The view-finder is so placed that when taking shots with the camera held before the face in the operating position it is directly before the left eye. It is also very convenient when using the tripod. The front lens of the finder is ruled into squares to represent the field covered in using 1-, 2-, and 4-inch photographic lenses. It produces an upright image, is corrected for parallax for distances greater than 35 feet, and has an adjustment on the eyepiece for distances less than 35 feet.

Fig. 2 is a view with the door removed, showing the arrangement of the main assembly plate. The reels are located in the top of the case, the one at the left being the supply reel. The footage indicator at the back of the camera is actuated by an arm that rides on the surface of the film on the supply reel. This type of indicator never needs resetting, and is calibrated to indicate the unused footage of film. The reel at the right is the take-up reel. Driving torque is supplied to it through gears and a slipping clutch, thereby insuring a positive, never-failing, take-up action.

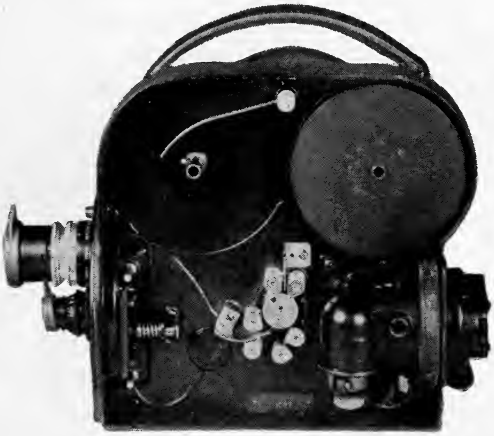

FIG. 2. Main assembly plate showing location of reels and optical system.

The single sprocket serves three functions: (1) as a pull-down from the feed reel; (2) as the hold-back for the take-up reel; and (3) as a recording sprocket. All movable pad-rollers are eliminated, and threading is made much easier by placing stationary rollers about the sprocket in such a manner that the natural stiffness of the film serves to keep it in contact with the sprocket surface. It is very essential that the film stay snug against the sprocket at the recording point, yet pass on and off freely. Experiment showed that sufficiently good sprocket action for recording could be effected by properly dimensioning the sprocket drum and teeth and by flexing the film about properly placed stationary rollers so that the stiffness of the film would hold it snugly in contact with the drum over approximately a 90-degree wrap. As a precaution against jamming, a metal stripper was inserted at the point where the film leaves the sprocket.

Torque is supplied to the sprocket by a spring motor capable of running 25 feet of film through at the proper speed with one winding. The running time can be made longer by installing a longer spring, but experience has proved that 25 feet of film will be sufficient for practically all shots. This is particularly true of the autophone type. The operator of the camera rewinds after each shot, using the winding crank permanently attached to the rear of the case. However, lest he should forget, the spring motor is equipped with an automatic stopping device, which prevents the camera from operating after 25 feet of film have passed. This feature prevents the spoiling of recordings resulting from the motor's running down and the consequent reduction of the speed.

Extreme care has been taken in designing the spring motor to make it capable of unwinding freely during its entire run and consequently exerting a constant pressure on the train of high-quality spur gears that drive the sprocket. Uniformity of the recording speed is achieved by connecting a flyball governor of the type used in phonographs to the sprocket-shaft driving gear through an extra-high-quality pinion gear. The friction pad against which the governor disk runs is provided with two stops, one for a speed 16 frames per second, and one for 24 frames per second. The single-claw, cam-operated intermittent movement is driven by a crown gear freely mounted on the sprocket shaft, and driven by the shaft through a damped spring. This form of drive effectively prevents reaction of the intermittent load back through the gear-train to the sprocket. The shutter is mounted on the intermittent cam-shaft, and is open for picture exposure during 240 degrees of the revolution. The gate is doweled to the center-plate at exactly the correct distance to focus the picture image properly on the film. The pressure-shoe can be quickly and easily removed from the camera to permit inspection and cleaning of the gate surface.

For picture taking the standard equipment is an *f*/3.5 1-inch focal length lens. However, the camera is equipped with a self-locking rotating turret that will accommodate three lenses. The wear-resisting locking device will always insure perfect centering of the lens on the picture area. In connection with the variable-focus lens used in turret jobs, it is sometimes advisable to check the focus of the image. A critical focusing device is supplied for installation behind the lens opening opposite the picture aperture. The desired lens can then be focused in this position and turned over to the picture aperture for use.

The recording optical system occupies a space just behind the sprocket and beneath the take-up reel, as shown in Fig. 2. It is of the variable-width type, and records the sound track along the edge of the film according to the accepted dimensions. The requirements of space and weight were kept forcibly in mind during the development and design of the optical system, with the result that it is only $2^1/_4$ inches in diameter by $3^7/_8$ inches long, and fits into the camera without destroying the symmetry of the case.

The optics of the system are extremely simple. Essentially it comprises a 4-volt, 3-watt lamp with a small coiled filament, a condenser lens, an aperture, a bi-convex spherical lens, and a cylindrical lens, arranged in the order given. The system is folded in the horizontal plane. The bi-convex spherical lens is in the form of a lens mirror, and is attached to the vibrating member of the system.

In forming the recording image, the condenser focuses the lamp filament on the lens mirror, and the cylindrical lens in turn focuses the filament on the film in the vertical plane. In the horizontal plane the lens mirror focuses one edge of the aperture (at the condenser) on the film for the recording edge of the light beam. The image on the film is $^3/_4$ of a mil high, and permits a maximum sound-track width of 58 mils.

The recording unit carries an adjustable pin abutting against a boss on the main center-plate, which is machined accurately with respect to the surface of the sprocket drum. Before assembling the optical system into the camera, it is placed in a jig, adjusted, and focused. The adjustable pin is fixed against a boss in the jig corresponding exactly, as to location, to the one on the camera center-plate. Every camera is alike in this respect. Consequently, all recording units are interchangeable, and their installation merely requires placing them upon the plate and pushing them forward until the pin abuts against the boss, before locking into place with the screws provided for the purpose.

The recording unit is supplied in two types—the newsreel and the galvanometer, the difference between the two lying in the means employed in actuating the mirror. In the newsreel type the driving unit is a metal diaphragm coupled mechanically to the mirror by a system in self-equilibrium; and by properly choosing the material from which it is constructed, no strain is imposed upon the diaphragm due to changes of temperature. The chamber that houses the diaphragm is located between the mirror and the back of the camera case. Part of the chamber extends through the case, forming a mouthpiece. The mass and stiffness of the mechanical parts, assisted by the properties of the properly designed acoustical circuits, afford a response covering the range from 200 cycles to 3000 cycles, which is sufficient for recording intelligible speech.

FIG. 3. Rear view showing newsreel mouthpiece and battery compartment.

Inasmuch as this type of unit depends upon the sound waves of the voice to operate the diaphragm and mirror, it is essential that the speaker place his mouth fairly close to the mouthpiece. The newsreel camera is, therefore, so designed that when the operator holds it before his face in order to take pictures, the mouthpiece is directly in front of his mouth. A double-layered wire wind-screen and perforated metal guard placed in the mouthpiece effectively protect the diaphragm from blasts of wind and physical damage. The mouthpiece of the newsreel recording unit and the lamp battery compartment are shown in Fig. 3.

The galvanometer is essentially the same as the one used in 35-mm. recording.[1] It is of the dry, permanent magnet, vibrating-reed type, with the lens mirror mounted on a tiny grooved plate resting upon the sharp end of the vibrating reed and held in place by a flexible strip of phosphor bronze. It is small in size, and is completely interchangeable with the newsreel unit. The mirrors in both units are made adjustable in the horizontal plane, in order to set the light beam to the null position by means of a screw protruding through the back of the case.

Power is supplied to the galvanometer, and current to the recording lamp by a cable from the extremely portable amplifier and battery-box. The amplifier is extremely high-gain, and contains two tubes, one *232* and one *233*. It is equipped with a glow-tube monitoring device, which warns the operator when serious overshooting of the sound track occurs. Additional assistance in monitoring can be gained by using the headphones and by observing the deflection of the light beam through the window in the side of the case. The battery-box contains a complete set of *B* batteries and two sets of recorder lamp and *C* batteries. The amplifier and the battery-box measure $7^1/_2 \times 6 \times 2^3/_4$ inches over-all, and are designed to be mounted on the tripod by a "unimount" suspension as shown in Fig. 4.

FIG. 4. Camera mounted on tripod, with amplifier mounted on the unimount suspension.

The microphone is of the magnetic type, and is not sensitive to jars and wind as is the carbon microphone. It is ruggedly constructed and sufficiently sensitive to record speech of amplitude equivalent to the complete width of the sound track when placed 6 feet from the loud speaker. The over-all response of the electrical equipment covers the range 150 to 3000 cycles.

Before closing, it should again be emphasized that the models described in this paper were made in the laboratory, and that they are not yet in their final form for the commercial market. A point of development has been reached, however, which seems to indicate that within a few months apparatus incorporating such desirable features of convenience, simplicity, portability, and appearance may be made available on the market.

Acknowledgment is due to E. W. Kellogg and I. J. Larson for many helpful suggestions during the development of the camera, and to H. Belar and A. Shoup for the design of the compact and efficient amplifier.

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DISCUSSION

MR. GOLDEN: What is the approximate cost of the entire outfit?

MR. WEST: We do not yet have a final list price. I believe that the camera by itself will sell for less than $300. The attachment shown in the last illustration will probably sell for about $200.

MR. KELLOGG: During the earlier development of 16-mm. sound films, the thought of making good amateur sound movies seemed to be a forlorn hope; there were enough difficulties in making good 35-mm. recordings. With 16-mm. films on which the sound waves had to be compressed to 40 per cent of their former size, the problem of obtaining adequate resolution was many times greater; and those who were following the sound-recording work were not overly optimistic about attempting to get good sound with extremely light and portable equipment, using picture negative and without either the technic or the facilities that were available in making commercial 35-mm. sound pictures. We felt that in order to record good-quality sound on 16-mm. film, all the refinements of the very best laboratory equipment would be essential. Mr. C. N. Batsel, the author of the paper, is the one to whom we are profoundly indebted for the vision to realize fully the possibilities of the much wider field for 16-mm. sound pictures that would be opened when people could make their own movies, photograph their own families, and be amateur picture producers, rather than simply motion picture audiences.

In working with some of the earlier laboratory equipment, one of the very happy surprises we had (perhaps not a 100 per cent surprise, but at least it was a great comfort to have it checked) was that there is available to every amateur a sound stage acoustically superior, probably, to the best stages in Hollywood. In other words, if you want a good sound stage you can find it out-of-doors. You may have to motor a mile or two to the woods, or to some quiet place away from too many neighbors, but when you find such a place, without too much wind (the wind used to bother more than it does now), you will have almost ideal conditions. The microphone distance at which the recording can be done is limited principally by the gain of the amplifier, and the great loss of sound quality that comes into play at quite small distances indoors is not bothersome. So there were no difficulties, acoustically, in taking a number of what we considered very successful amateur movies, without having the microphone in the picture.

Of course, one may wish to take movies indoors. In that case, he will have to endure whatever acoustical difficulties the surroundings impose; but whenever it is desired to have the microphone comparatively well away from the subject, the problem can be solved by going out-doors. It is fortunate that it is within the means of every amateur to get this ideal sound stage without spending a million dollars on concrete, sound proofing, and sound absorption.

MR. CRABTREE: What is the weight of the total equipment?

MR. BATSEL: The weight, including the amplifier, is approximately 30 pounds—$8^1/_2$ pounds for the camera alone.

MR. PALMER: Was the picture that was shown a print from a 16-mm. negative, or was it a reversal?

MR. BATSEL: Reversal.

MR. PALMER: Was it the original film on which the picture was taken?

MR. BATSEL: Yes; the same as the amateur film used for silent pictures. The picture is made on the film and it is returned to the Eastman Kodak Co. for processing. The original film that was exposed in the camera is returned to you for projection.

CONTINUOUS OPTICAL REDUCTION PRINTING*

A. F. VICTOR**

***Summary.**—Referring to his early experimentation in continuous optical reduction printing, the author discusses briefly the state of the art and present practices.*

At the Fall Meeting of the Society, at Pittsburgh, in 1919, the author presented a paper dealing with the continuous reduction printer.[1] Since that time, many things have changed. Sound, then a vague possibility, has come to stay and has revolutionized the motion picture. The continuous reduction printer, then a variant of the reduction step printer, has now become an essential necessity. Quoting from another paper,[2] in 1918, on the subject of portable projectors:

> Following the introduction and adoption of the safety standard film, the next logical step of progression was the creating of a supply of this film, adequate for the needs of the field it has to safeguard. The most immediate and richest source of film subjects would naturally be the thousands of standard negatives already in existence. Only one bit of apparatus was required to bring this treasure trove into immediate service of the home, school, and church: a satisfactory reduction printer was the essential thing.

With the advent of sound the continuous reduction printer has come into its own. By its means sound tracks already registered on standard negatives or positives may be expeditiously and accurately transferred to film of smaller or larger dimensions.

At the present moment interest is centered in the reduction of sound from 35-mm. to 16-mm. film. Film of the latter width, since its introduction in 1923, has steadily developed in usefulness and quality. Finer emulsions, better development, and greater illumination in projectors have brought a larger and more brilliantly illuminated screen image. Twelve-foot pictures are now a reality, and the simplicity and safety of 16-mm. film apparatus recommend their use where such advantages are important.

Several 16-mm. projectors equipped with sound reproducing appa-

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

** Victor Animatograph Corp., New York, N. Y.

ratus are now being manufactured and marketed. Needless to state, the manufacture and sale of such projectors have aroused a demand for 16-mm. sound film. "The immediate and richest source would be the thousands of standard negatives already in existence," so that the problem is the reduction of this standard supply to 16-mm. film. There are two ways of doing this: by means of electrical re-recording, or by optical reduction.

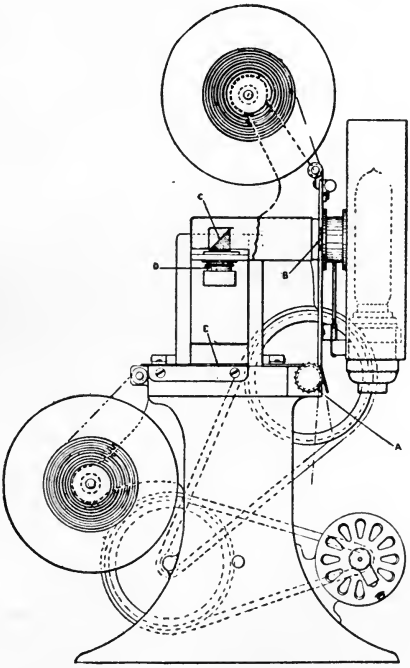

FIG. 1. Original design of continuous reduction printer.

In re-recording, the standard negative is passed through an apparatus similar to a reproducer. A light beam passing through the already recorded track is varied according to the photographic densities (in variable-density records) or to the areas of light transmission (in variable-width records) of such a track, and the resultant electrical impulses cause an oscillator or a glow-lamp to record a new sound track on the smaller film. In principle the system does not differ greatly from original recording.

Regardless of the fact that the writer was the inventor of continuous optical reduction, he does not believe that re-recording is inferior to optical reduction, as has been claimed by a number of persons lately. On the contrary, he believes that re-recording has possibilities that optical reduction does not possess; especially as regards the facility with which sound from mediums other than the standard track may be interpolated and changes made during reduction if required.

The particular reduction printer used and manufactured by the author at the present time closely resembles the machine designed in 1919, illustrated in Fig. 1. A single sprocket carries the two films on different diameters, the small film on the inside. Both films travel on a single shaft and are turned together about a common center. There is no need of reversing the travel of the films; both travel in the same direction, the prism serving to reverse the image.

There can be no greater simplicity, no fewer parts. Experience has shown that the work produced by this machine is equal to the best yet produced by this method of reduction printing. The only limitation to the quality appears to be imposed by the graininess of the photographic emulsion. However, up to a frequency of 8000 cycles, according with usual practice, the result is commercially acceptable and perhaps all that may be ever required. The average 16-mm. projector-reproducer does not reproduce frequencies higher than 6000 cycles, although 7000 may be possible, with interference from film noise.

A continuous reduction printer requires perfect sprockets and superior optics. The tendency to flare in the final line image is considerable, and care must be taken in selecting the condensing as well as the objective lenses; otherwise the harmonics are lost. Focusing is best accomplished by projection: a fine surface screen is located near the floor, and a projection lens is placed beneath the 16-mm. track for the purpose of observing the projected line image.

Referring to Fig. 1, the mount *B* supports the condenser, the first objective, and the slit. The light beam passes through the prism *C* and is directed downward at an angle of ninety degrees, the objective *D* forming an image of the sound track, at *E*, on the 16-mm. film. The sprocket *A* carries both films, having two sets of teeth and two diameters. For simplicity, the drawing does not show the take-up spools or the feed and take-off sprockets.

A possible variant of the principle of optical reduction is found in the use of the light valve. With such a type of reduction printer, no attempt is made toward achieving sharp optical definition, as only variations in the quantity of light are demanded. The result is a variable-density track, of course; but in this form of printer pictures may be reduced from variable-width as well as from variable-density recordings.

The reason for suggesting such a scheme is based on the possibility of increasing the speed of printing. The printing light may be increased considerably when no well-defined image is demanded, an especially valuable feature when the reduction is directly to 16-mm. positive instead of to a negative track. The present tendency is to reduce directly from standard negative film to 16-mm. positive. The main disadvantage is that the negatives wear out. The writer believes that the practice is due to the lack of better contact printers, and that when better equipment becomes available the results from 16-mm. negatives will be quite satisfactory. It is recommended that efforts be made toward designing contact printers so that 16-mm. negatives may be employed.

As regards the development and processing of 16-mm. sound tracks, the laboratory plays a very important part in this work. The most perfectly reduced track may be ruined by faulty development. Great precision is demanded; the striations at a frequency of 8000 cycles are equal in fineness to those at a frequency of 24,000 cycles on standard film, and the high tones are easily lost when over or underdevelopment occurs. Furthermore, the graininess should be reduced as much as possible; reversal prints have indicated what splendid results can be attained with finer grains, and the best sound the writer has heard has been obtained by that means.

In closing, the writer should like to point out that neither the continuous reduction process nor the type of machine designed for that purpose by the writer in 1918 was patented, and is therefore open to use or manufacture by anyone.

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[1] VICTOR, A. F.: "The Continuous Reduction Printer," *Trans. Soc. Mot. Pict. Eng.*, III (1919), No. 9, p. 34.

[2] VICTOR, A. F.: "The Portable Projector: Its Present Status and Needs," *Trans. Soc. Mot. Pict. Eng.*, II (1918), No. 6, p. 29.

A NON-SLIP SOUND PRINTER*

C. N. BATSEL**

Summary.—*The improvement of sound negatives and the extension of the frequency range have made the printing of the sound negative onto the final print much more difficult. This paper deals with a printer that assures positive contact and no slipping between the two films at the time of printing. The principle upon which it operates is discussed, and improvements to be gained in making prints upon a machine of this type are shown.*

In making sound-on-film records the first requirement is a good sound negative. Much has been done to improve the recording machines, optics, and film in order that good negatives can be made with frequencies up to 10,000 cycles. The second requirement is to make high-quality reproductions of the recordings; usually by contact printing. Most contact printers today make use of a split sprocket or a curved gate to carry or support the film as it passes the light aperture. The sprocket or gate is usually so designed as to correct for a fixed value of shrinkage of the negative.

It is physically impossible for all negatives to bear the same relation to the raw stock as to length at the time of printing. Consequently some slippage must occur. There is also evidence of poor contact between the two films at the printing aperture, particularly in the sprocket machines. At a frequency of 10,000 cycles, corresponding to a wavelength of 1.8 mils on the film, a slippage of 0.001 inch will cause considerable blurring and make it impossible to produce a good print regardless of how good the negative may be.[1]

The need for a continuous contact printer that would be consistent in its performance and accommodate various values of film shrinkage became increasingly apparent as other improvements were made in sound recording. A principle on which a contact printer that meets those requirements might be based, was proposed some time ago by A. V. Bedford, who also constructed a laboratory contact

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

** RCA Victor Company, Camden, N. J.

printer embodying the same idea.[2] The same principle as applied to printers has also been described by R. V. Wood.[3]

The principle employed for avoiding slippage, on the basis of which the printer described in this paper was designed, is briefly as follows: Two belts differing in length may be made to travel past a given point without slippage between the two, provided the belts are held in contact around rollers in such a way as to prevent slippage along the line of contact. This statement is based on the fact that when bending a belt around a pulley or roller, the mean length of the belt remains always the same; whereas the concave side, contiguous to the roller, is compressed and the convex side stretched, in proportion to the curvature of the roller. Thus, if the short belt (or shrunken negative) is bent around a roller of the proper diameter, the outer surface will become longer than the mean length of the film. Then, if the longer, unshrunken raw stock is passed over the same roller, tangent to the outer surface of the negative film, assuring good contact and, consequently, traction, between the two by means of a pressure roller at the point of contact, the concave surface or compressed side of the long film will make contact with the stretched side of the short film only along the line of tangency.

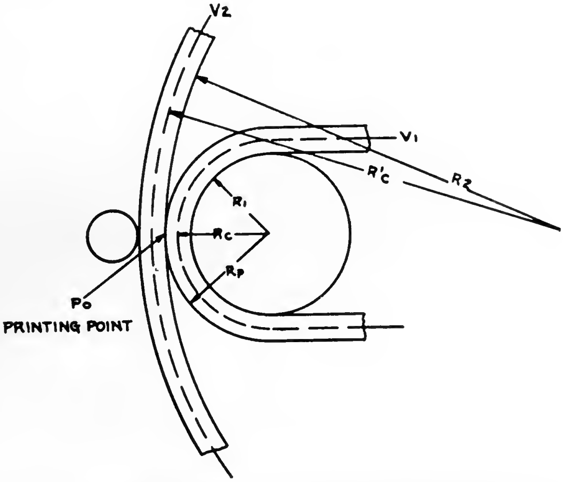

Fig. 1. Diagram illustrating principle of non-slip printer.

Printers employing sprockets or curved gates fulfill such a requirement only under one condition: when the negative or raw stock happens to have exactly the proper length, so that the flexing around the sprocket or gate results in making the length of the inner surface of the raw stock exactly the same as that of the stretched outer surface of the negative—a rather remote possibility.

Referring to Fig. 1 and assuming that the pitch (or the number of sprocket holes per unit length) of the shrunken film is P_1 and that of the raw-stock is P_2, the shrinkage factor is P_1/P_2. The condition for maintaining synchronism between corresponding particles of the two films is $P_1/P_2 = V_1/V_2$, in which V_1 is the mean velocity of the shrunken film and V_2 that of the unshrunken film. The condition under which no slippage occurs (referring to Fig. 1) at the line of tangency is

$$V_1 \frac{R_p}{R_c} = V_2 \frac{R_2}{R_c'} \qquad (1)$$

whence

$$R_2 = R_p \frac{R_c'}{R_c} \cdot \frac{P_1}{P_2} \qquad (2)$$

Therefore since the two films are held in non-slipping contact at the tangent line or printing point the outer surface of the inner or shrunken film will be on the radius $R_p = R_1 + T$, T being the thickness of the film; and at the line of contact (P_0), the outer surface of the inner film will carry the inner surface of the raw stock past the line at its own velocity. As contact is assured and no slippage occurs at P_0, the raw stock automatically assumes at the line of contact the radius of curvature given by equation (2) which is a function of the lengths (or pitches) of the two films.

It is readily seen that if no exterior forces are brought to bear upon the raw stock, it will travel past the line P_0 at the proper rate to compensate for the difference between the mean lengths of the two films; and if allowed to form a free loop as it approaches P_1, it will form about the radius $R_p \dfrac{R_c'}{R_c} \cdot \dfrac{P_1}{P_2}$ and remain so formed until all the film has passed P_0.

From this it is evident that the principle depends entirely upon the choice of the film path and the size of the rollers. The film path must be so arranged that a small change in the length of the upper loop of the raw stock will cause a large change in the angle at which the film approaches the contact line at P_0. The size of the rollers tangent at P_0 must be such that for any required correction of shrinkage, the film will not pull taut over the pressure roller. This means of control can be used until the difference between the lengths of the two films becomes so great that R_1 becomes too small to permit flexing the negative around it.

Fig. 2 is a photograph of the model, showing the various rollers and the film path. The diameters of the printer rollers have been so chosen that the control is effective over a range in which the length of the negative may have any value from about 0.2 to 1.0 per cent greater than that of the raw stock. The curve assumed by the raw stock as it approaches the contact point is controlled by the loop between the feed sprocket and the main drum, which is adjusted to provide sufficient range with a change of approximately one frame in the length of the loop. The average condition requires, of course, less than one frame, and does not interfere with the synchronism between the sound and the picture. Immediately before passing over the main drum the raw stock passes over a movable roller, which follows up the loop and acts also as a guide roller. After passing the printing drum the raw stock forms a loop, and passes over a hold-

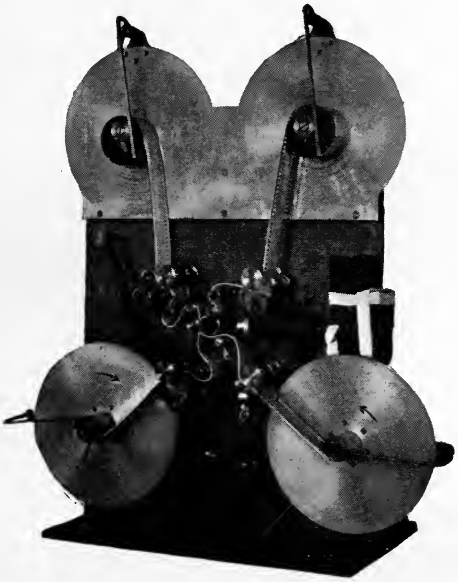

FIG. 2. Model of non-slip printer, showing film path and various rollers.

back sprocket to the take-up reel. The negative film is fed down from the supply reel over a feed sprocket, then over a guide and pressure roller, over the drum, and then over a pull sprocket to the take-up reel. The negative is in contact with the printing drum and is used as a means of driving the drum. To assure steadiness of motion at the printing point and prevent variations of density in the sound track due to irregularities of speed, a speed-regulating mechanism has been attached to the drumshaft.

To achieve the best results it is important that the printing light strike the films at the point at which they are in contact. If the light should cover the films before and after contact there would be an apparent slippage and a consequent blurring of the printed image. In order to prevent this the height of the printing light beam has been restricted to approximately 0.0025 inch, by imaging an 0.005-inch mechanical slit on the film reduced in the ratio of two to one. Light control and stopping and starting devices are installed on the model to make it operative on a commercial basis.

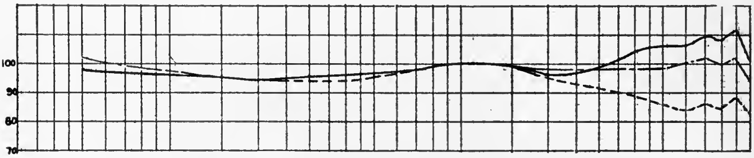

FIG. 3. Output curves, showing improvement obtained with new printer at the high frequencies: solid curve, neg.; dashed curve, commercial print (restricted light aperture); dot-and-dash curve, non-slip printer.

Test prints of the "Service Reel" have been made with this printer. The output and the variation in output were measured and compared with prints of the same negative made on a popular commercial printer, the height of the printing aperture of which had been reduced to $^1/_8$ inch. The curves of Fig. 3 show the improvement in the output at the higher frequencies, which is apparently entirely due to better printing as the same care was taken in processing and the same density produced in both cases.

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[1] CRABTREE, J.: "Sound Film Printing," *J. Soc. Mot. Pict. Eng.*, **XXI** (Oct., 1933), No. 4, p. 294.

[2] U. S. Pat. 1,754,187; granted 1927. (This type of drive was applied also to sound-film printers in 1929.)

[3] WOOD, R. V.: "A Shrinkage-Compensating Sound Printer," *J. Soc. Mot. Pict. Eng.*, **XVIII** (June, 1932), No. 6, p. 788.

DISCUSSION

MR. KELLOGG: The fact that the radius of curvature at the driving point affects the linear speed of a belt, has long been recognized. The selection of suitable curvature to minimize slippage has also been applied in designing contact printers. The novelty in the Bedford printer consists in making the film select its own curvature, and in the very simple expedient by which that is accomplished. The manner in which the device operates is not obvious. Even if one conceded the soundness of the general principle it was not at first clear that the curvature at the point where the film is pinched between the rollers could be varied sufficiently to compensate for extremes of shrinkage. But Mr. Bedford's simple model settled the point. The principle of operation might have been somewhat more clearly explained if Fig. 1 had shown the film approaching the driving point between the rollers from several angles. You will notice in Fig. 2 that the new stock is fed from a sprocket above and to the left of the friction rollers, and that the path between is so arranged that when the loop is excessively long, the film makes a swing to the right and approaches the driving point from the right. With a shorter loop the film approaches from directly above; whereas with a still shorter loop, it approaches the driving point from the left. It should also be borne in mind that the left-hand roller may revolve at any speed (it simply serves to hold the raw stock against the negative at the driving point), that the raw stock is drawn through the rollers entirely by the friction between it and the surface of the negative (which you may regard as moving at constant speed), and that the friction between the two films is exerted only at the line of contact where the rollers pinch them together. So we are concerned only with the curvature of the raw stock at that one point.

If the concave side of a bent film is propelled at a specified velocity, more feet of film per minute (measured after it is straightened) would pass than if the convex side were propelled at the same velocity. Therefore, by flexing the film so that the driven side is convex or concave, the speed of the film as a whole can be altered. Another way to look at it is this: Imagine that we could stretch or shrink the film as desired. We might adjust each piece of raw stock to exactly the same length (for a given number of sprocket holes) as the negative, and then print without slippage. Fortunately, we do not need to stretch or shrink (compress) the film as a whole. It is sufficient to stretch or compress one of its surfaces, the one that is in contact with the negative, which stretching and compressing are very easily accomplished by simply bending the film.

Because of the arrangement of the loop, the accumulation of a little additional film between the sprocket and the rollers will result in the raw stock's entering the driving point with its concave side toward the negative, which automatically speeds up its passage through the rollers. In a few seconds equilibrium is attained, and the speed at the rollers becomes identical to that at the sprocket. On the other hand, suppose that the raw stock has been in storage a while and has shrunken abnormally. It will then approach the rollers from the left, bending around the left-hand roller and presenting a convex surface to the negative at the driving point. That is the condition required to feed fewer linear feet of raw stock through for a given length of negative.

One of the problems in designing the printer was to obtain the necessary changes of curvature with the smallest possible differences in loop length. This required a careful experimental study of roller sizes, and of determining the best loop arrangement. In the model that has been described, sufficient variation in the angle of approach (and therefore in the curvature at the driving point) was attained to accommodate all degrees of shrinkage normally encountered, with a small enough change in loop length to remain well within tolerances of synchronism with the picture.

In experimenting with printers of this type it is easy to be fooled by slippage. Thus, with a short loop the raw stock tends to be placed in tension, causing a slight slipping which would work in the same direction as the curvature changes, and therefore make the printer appear to be working properly when it is not. Low loop tension for all working positives, good contact pressure, and a speed control by curvature that really works, are the necessary conditions to prevent the slipping.

Any printer for synchronous sound must, of course, control the speeds of both the negative and the raw stock by sprockets geared together, or by running both over one sprocket. Most present contact printers print on a sprocket. There is one important point about sprockets that has not been recognized as generally as it should be, and that is that there is only one length of film (for a given number of sprocket holes) that can run on any particular sprocket without slippage on the surface. Probably the easiest way to visualize that is to calculate how fast a film would run in the absence of teeth if it did not slip. Obviously, it could be calculated simply by multiplying the number of revolutions per minute by the circumference in feet (making proper allowance for the thickness of the film in estimating the diameter). But on the basis of the number of teeth on the sprocket there is another way of calculating the film speed. Multiply the number of teeth on the sprocket by the revolutions per minute, and divide that by the number of sprocket holes in a foot of film (not the nominal number 96, but the exact number, to a couple of decimal places), and the two calculations will almost always result in a slightly different answer. Which is correct? The teeth will control, and if friction between the film and the body of the sprocket should give a different speed, then slipping must occur. If, as in a printing sprocket, there are two films on the one sprocket, the effect is equivalent simply to increasing the body diameter for the outer film. There is still a surface that must be moving at a certain speed; and the raw stock that runs over the surface, engaged by teeth, in all probability requires a different speed, and slippage between the two surfaces is practically inevitable. The slippage is, to be sure, generally small; but so are the waves to be printed.

MR. TERRY: Do you not lose loop or gain loop if the differences between the films are exactly figured?

MR. KELLOGG: Whatever gain or loss of loop occurs, takes place in the first few seconds, and amounts to not more than about an inch of film. Thereafter the loop remains constant, whether we print 50 feet or 1000 feet of film. The curvature control makes it possible for both films to travel the same number of sprocket holes per minute, and at the same time to run past the printing point in contact without slipping and with no accumulation of gain or loss in the loop. For two films to run in contact without slipping it is not necessary for them to have identical lengths, but only that the two surfaces that are in contact shall have the same length, and the convex surface of the shrunken film can be made to have the same length (for a given number of perforations) as the concave side of an unshrunk film.

MR. MITCHELL: Have pictures been printed with this type of printer? What is the extent of asynchronism due to a change in the length of the loop?

MR. BATSEL: In this particular printer the loop will change about one frame, and will compensate for a shrinkage of about 1.2 per cent.

MR. MITCHELL: There seems to be a great tendency to pay more attention to the parent film and to maintain shrinkages within certain tolerances; with the proper humidity in the printing and stockroom that can be done.

We also find that as the sprocket teeth curve away from the base to the tip, there is a little compensation according to a somewhat similar principle, due to the fact that the film rides up and down on the teeth.

MR. BATSEL: It is true that proper storage reduces shrinkage. In running vault-stored films through the printer I noticed quite a bit of change in the loop, indicating that even those films that were stored under the proper conditions differ somewhat in length. It seemed that even regardless of storage some type of printer is needed that will compensate for varying shrinkage. The sprocket will not do that.

OPTICAL REDUCTION SOUND PRINTING*

G. L. DIMMICK, C. N. BATSEL, AND L. T. SACHTLEBEN**

Summary.—*The optical reduction sound printer was developed to provide a simple and direct means of transferring sound tracks from 35-mm. film to 16-mm. film, and its use resulted in the production of 16-mm. sound tracks of superior quality. The mechanical and optical requirements of the printer are discussed, and features of the process that led to the improved record quality pointed out. An optical system is described that was built to convert a re-recorder into an optical reduction sound printer.*

The laboratory development of an optical reduction sound printer, by means of which high-quality sound tracks might be transferred from standard 35-mm. films to 16-mm. films by direct photographic printing, was originally occasioned by the desire to simplify the production of 16-mm. sound prints from standard films. In proceeding from the original standard sound negative to the finished 16-mm. sound print by the re-recording process, two printing operations and one recording operation are necessary. It is necessary to prepare a print of the standard negative from which to re-record on the 16-mm. film if the 16-mm. negative is to be of the highest quality; and it is also essential to produce the finished 16-mm. sound track by a final contact printing of the 16-mm. negative. These printing steps, when properly carried out, eliminate non-linear distortions occurring at the higher frequencies in variable-width negatives, due to the filling in of the valleys of the negative record. The investigations of Sandvik, Hall, and Streiffert[1] have shown that non-linear distortion becomes a minimum and modulation of transmission becomes a maximum in variable-width records when the print density is made equal to, or slightly less than, the negative density. The optical reduction sound printer provides for the direct production of a 16-mm. print from a standard sound negative by optically projecting an image of the moving standard sound track upon the moving 16-mm. positive emulsion, at the proper magnification.

Steps were taken in the laboratory in January, 1932, to construct

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

** RCA Victor Company, Camden, N. J.

a model optical reduction sound printer. The mechanical requirement of uniform motion of the two films in the proper speed ratio of 2.5 to 1 was fulfilled by properly gearing together two film-moving mechanisms, each incorporating the magnetic drive developed by Kellogg[2] to assure freedom from irregularity of the film speed. In this type of drive the film is propelled at the recording or scanning point by a magnetically driven drum, to which irregularities of speed arising in the train of driving gears can not be imparted. Also at the recording point the film is isolated from the sprocket by flexible loops of film, which render the uniformity of motion of the film at that point independent of the pitch of the perforations and the sprocket action. The normal vibrations of the film-driving system are effectively damped by magnetic means. The optical requirements of the printing system were peculiar in that the reduction ratio in the plane of motion of the film was 40 per cent; whereas in the transverse plane the reduction ratio was 85.7 per cent, necessitating the adoption of an optical system of the anamorphote or distorted-image-producing type employing a combination of cylindrical and spherical lenses yielding unequal reductions in the two planes. The optical system finally adopted comprised a pair of crossed cylindrical lenses with a standard 32-mm. achromatic microscope objective dis-

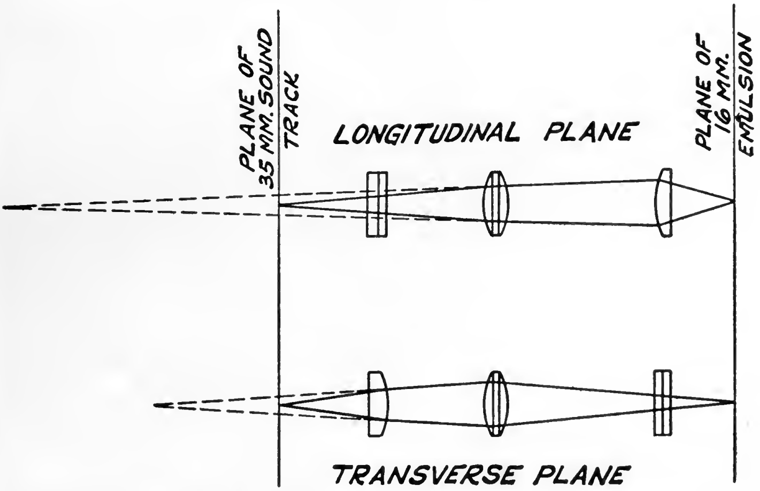

FIG. 1. Diagram of anamorphote optical system of model reduction sound printer.

posed between them, the image being formed independently in each of the two planes by the achromatic lens and one of the cylindrical lenses. An appropriate illuminating system was employed to scan the standard sound track, and to direct the light into the printing system in an efficient manner. Fig. 1 is a schematic diagram of the printing optical system proper.

Sixteen-mm. sound films were not only more easily produced on the optical reduction printer, but were at once noted to be superior in quality to any 16-mm. sound films previously produced. Fig. 2 compares the frequency response characteristic of a print produced by optical reduction with that of the negative from which it was made. The improved quality is partly attributable to the fact that no contact printing is involved, with its attendant dependence of print quality upon sprocket hole pitch, and upon the degree of fidelity of contact between the negative and the raw positive stock. The investigations of J. Crabtree[3] have shown that printer "slippage," arising from improper sprocket hole pitch in contact printing, or

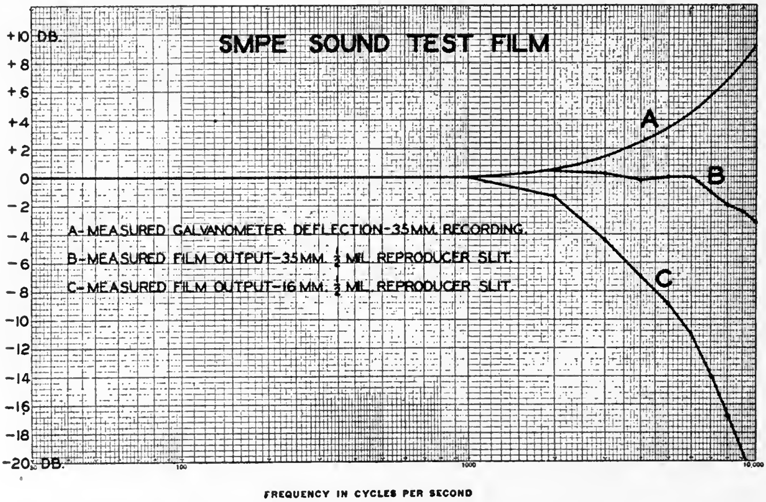

FIG. 2. Comparison of frequency characteristic of a print produced by optical reduction with that of the negative from which it was made: (*A*) 35-mm. recording galvanometer deflection; (*B*) measured output of print of 35-mm. frequency negative (0.5 mil reproducer slit); (*C*) measured output of 16-mm. optical reduction print of same 35-mm. negative (0.5 mil reproducer slit).

from inaccuracies in the sprocket pitch or tooth shape in the printer, gives rise to more or less periodic variations in the amplitude of a high-frequency print. Such high-frequency prints, when reproduced, are characterized by a "fuzzy" or "soft" quality, and are lacking in "cleanness" or "crispness." In the optical reduction printer, incorporating the magnetic drive to propel both the 35-mm. and 16-mm. films, uniformity of film speed at the scanning and printing points does not depend upon sprocket or sprocket hole pitch. In addition, the transfer of the sound track by optical reduction is wholly an optical-photographic process, allowing distortions of a photographic nature in the negative, such as filling in of the valleys, to be compensated for in printing and developing the 16-mm. positive.[1] Compensation for such distortions in re-recording can be effected only by preparing a print of the standard sound negative and re-recording from it, since non-linear distortions of a photographic origin can not be compensated for in any way, once they have been impressed upon an electrical circuit.

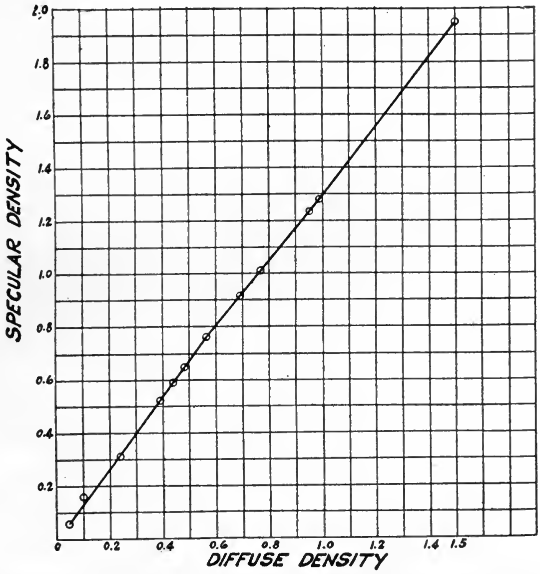

FIG. 3. Relation between specular and diffuse density of motion picture positive film.

Since the two films are not printed in contact, but an image of the standard sound track is projected upon the 16-mm. film by an optical system, the specular density rather than the diffuse density of the negative is the effective factor in optical reduction printing. The specular density of a developed image is determined by measuring the light transmitted through the layer of silver grains without change of direction; whereas the diffuse density is determined by measuring both the light passing through without change of direction and the light that is scattered or diffused by transmission through the silver grains of the developed image. Since less light is transmitted specularly than is transmitted *both* specularly and by diffusion, the specular density of an image is higher than its diffuse density. Fig. 3 is a curve obtained by Tuttle[4] showing the relation between the specular and diffuse densities of images on motion picture positive film. Thus, in optical reduction sound printing the effective density of the negative is greater than in contact printing, and therefore the effective contrast is greater. This permits greater contrast and better resolution to be obtained in the print, with a consequent increase in the high-frequency response of the print. Fig. 4 illustrates how the increased effective contrast of the negative arises in optical printing.

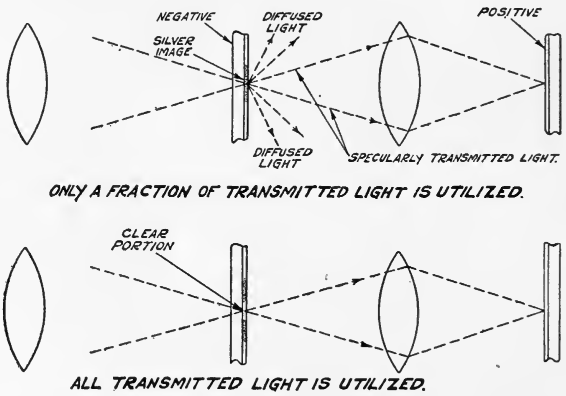

FIG. 4. Diagram illustrating the manner in which increased contrast of the negative arises in optical printing.

CONVERSION OF A RE-RECORDER FOR OPTICAL REDUCTION SOUND PRINTING

In response to the interest shown in the improved 16-mm. sound prints produced by direct optical reduction printing, the laboratory designed an optical system for converting a re-recorder[5] to an optical reduction printer. The film-moving mechanisms of the film phonograph and 16-mm. recorder heads of the re-recorder impart motion to the film of sufficient constancy for printing; and, in addition, permit the use of the simplest kind of optical system, since the two films are moving in opposite directions at the scanning and the printing points. The problem was therefore that of providing a simple optical system that would image the 35-mm. sound track upon the 16-mm. film at the proper ratios in the two planes.

The optical system adopted is of the anamorphote type employing two achromatic microscope objectives, with two uncorrected cylindrical lenses between them, and both working in the same plane. In the longitudinal plane, or the plane parallel to the direction of motion of the film, the achromatic objectives alone are employed in the formation of the image. The first achromatic lens forms a virtual image of the 35-mm. sound track, which is re-imaged upon the 16-mm. film by the second achromatic lens at an over-all magnification of 0.400, which is the ratio of the two film speeds. In the transverse plane, the two cylindrical lenses, acting together, modify the original virtual image of the 35-mm. sound track in such a manner that in the transverse plane the over-all magnification is 6/7, which is the ratio of the two sound track widths. Fig. 5 is a schematic representation of the printing optical system proper. Features of the system are that in the longitudinal plane, in which the greatest resolution is required in order that the shorter wavelengths may be successfully printed, the image is formed only by the achromatic lenses,

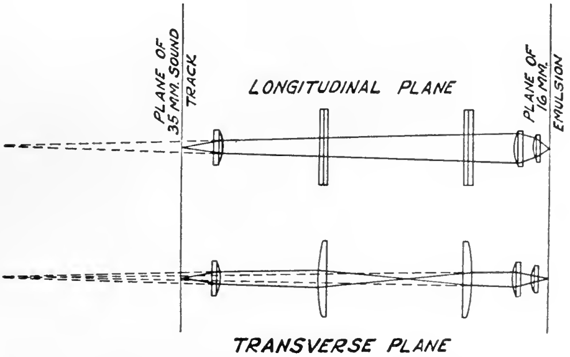

FIG. 5. Diagram of anamorphote optical system of rerecorder converted for optical reduction sound printing.

which in that plane work at about one-third their maximum aperture. The uncorrected cylindrical lenses act only in the plane in which the resolution requirements are not great. At the same time the magnification of the final image is practically independent of the position of the second achromatic lens, making it possible to adjust the focus of the system without changing the magnification.

The illuminating system comprises a standard 10-volt, 7.5-ampere lamp, a condenser system, and a lens that images a 0.010 × 0.115-inch optical slit on the 35-mm. sound track. This optical slit is in turn imaged by the printing system upon the 16-mm. emulsion at which point the image of the 35-mm. sound track is in focus and moving in the same direction and at the same velocity as the 16-mm. emulsion. The printer is equally adaptable to both variable-width and variable-density work, and fulfills the high illumination requirements attendant upon the production of a duplicate negative from a "noiseless recording" variable-density print without exceeding the rated wattage of the lamp. Variable-width work is carried on with the lamp current between 5 and 6 amperes, whereas the rated current is $7^1/_2$ amperes. The system is capable of producing a duplicate negative from a print, and a print from a negative, and a frame line mask is provided for use when printing from a combined print or from a negative that carries both picture and sound.

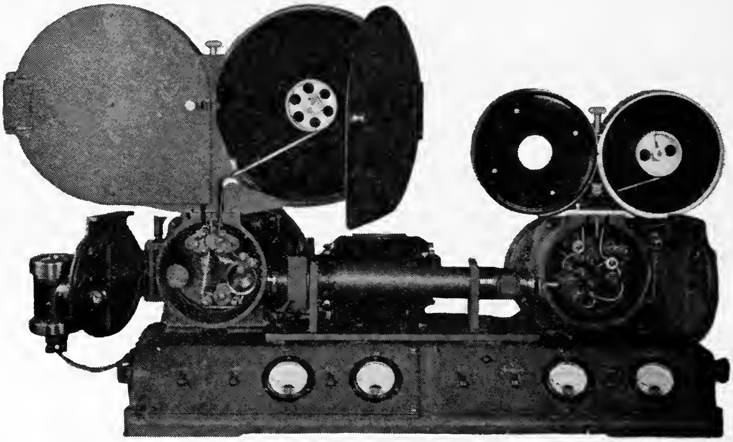

FIG. 6. Re-recorder converted for optical reduction sound printing; cover removed and doors open to show threading.

Some variation in the speed ratio of the two films will occur due to film shrinkage, since the films run at a constant number of frames per second. A relative shrinkage ratio of one per cent introduces a relative slip between the printing image and the 16-mm. emulsion of only $5^1/_2$ per cent of a wavelength at 10,000 cycles during the time that a given element of the sound track is illuminated. During operation of the printer the films run at standard speed, and the printer is suitable for either daylight or darkroom operation. Fig. 6 shows the appearance of the converted re-recorder.

Acknowledgment is due Messrs. E. W. Kellogg, E. Oeller, and R. Brady for their work in producing the first successful model of the optical reduction printer.

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DISCUSSION

MR. PALMER: Is any distortion introduced by reducing the 35-mm. sound track to 16 mm. laterally?

MR. SACHTLEBEN: No. There is a true image of the sound track in each of the two planes. However, the magnifications in the two planes differ.

MR. TASKER: At the time the development here described was begun the United Research Corporation had already done some months of work with reduction printers and had concluded that it was the one successful method, as contrasted with re-recording. I am happy to see that there is now general agreement in the industry to the effect that reduction printing is the best method of producing 16-mm. sound films.

MR. KELLOGG: On a one-to-one printing, for example, 35- to 35-mm., I doubt whether the increased contrast that is helpful in making prints of variable-width records would more than offset the slight loss due to lens flare and such optical defects.

The first experiments of which I have any knowledge seemed to indicate that contact printing would be somewhat better under such a condition; but in making 16-mm. film, the contact print would necessarily have to be made from 16-mm.

negative, whereas the optical print could be made from a negative of much larger scale. Owing to the better resolution of the larger-scaled negative the blacks would be blacker and the whites cleaner. That is, to my mind, the main reason why optical printing seems to work out so well in making 16-mm. reductions.

PRESIDENT GOLDSMITH: Is it not a fact in any case that the final preferred 16-mm. printing methods will not be definitely known until 16-mm. sound prints have been produced on a far larger scale? Certainly if only a small edition is required, one can take the 35-mm. negative and conveniently reduce it optically, particularly if there is no necessity for modifying tone quality or changing volume of sound. But if very large editions were required, say, thousands of 16-mm. prints, it would not be desirable to preserve the 35-mm. original negative, but to proceed rather by contact printing from 16-mm. negatives.

I do not propose or defend these measures at this time, but I think this is a subject that should be carefully studied. Probably the answer can not definitely be given until commercial practice in the field has been more nearly crystallized.

MR. BATSEL: Referring to Mr. Kellogg's discussion, even though we do improve our negative in optical printing we can not realize the full advantage of doing so unless we do have the proper film-moving mechanism. Most of our success in optical printing is due largely to the fact that we have eliminated slippage and poor contact, and similar defects. For that reason, I feel that we can put 10,000 cycles on the 16-mm. film.

MR. STRICKLER: Which would result in greater loss in reduction sound printing: to make a 16-mm. dupe negative and then from that a contact positive, or to make a dupe 35-mm. negative from which to make the reduction 16-mm. prints, assuming that the original negative were not used throughout?

MR. SACHTLEBEN: I am sure that the quality would be much better by direct reduction from the original or dupe 35-mm. negative than by making a 16-mm. negative from the 35-mm. positive and then printing by contact. You would lose many or all of the advantages of reduction printing if you were to make 16-mm. prints in that fashion.

MR. SANDVIK: You can make a somewhat better print from the 35-mm. dupe negative than from the 16-mm. There are optical, photographic, and mechanical reasons for that.

MR. REICHER: In my experience I find that the 35-mm. sound track does not wear in reduction printing as it does in contact printing. Therefore, if thousands of 16-mm. prints were demanded at some future time from the same negative, far fewer reproductions would be required than with 35-mm. I have made short loops of 8000-cycle negatives and have run them through the printer enough to account for thousands of prints without deterioration.

PRESIDENT GOLDSMITH: That was the reason why I raised the point that there was a necessity for crystallizing commercial practice before the preferred path of operations from the 35-mm. original negative to the final 16-mm. positive prints can be definitely specified. It might well be that the 16-mm. version would sometimes require special editing, as compared with the 35-mm. version. That again might profoundly modify the most desirable procedure for making 16-mm. prints.

MR. MITCHELL: Admitting that better results might be achieved by reducing from the duplicate of the 35-mm. negative, it must be remembered that in practice that involves a double printing operation, for the reason that the 16-mm. area occupies all the available printing space. It is quite a commercial problem to make a 16-mm. master negative, both picture and sound track, at one operation. Commercial considerations will in the long run decide the question.

MR. TASKER: Wouldn't it be better to make a 35-mm. master negative rather than a 16?

MR. MITCHELL: You still must consider the 35-mm. picture size as compared with the 16-mm., referring to printing the picture and sound on the 16-mm. In the 35-mm. negatives there is a separation between the pictures, whereas there is only a narrow frame line between the pictures in the 16-mm. The picture and sound can not be reduced to 16-mm. film in one operation. The picture must be reduced by step reduction, and the sound by continuous optical reduction.

MR. TASKER: In the course of preparing the 35-mm. dupe negative, the pictures could be magnified as desired.

PRESIDENT GOLDSMITH:—with a different reduction ratio for picture and for sound track.

MR. TASKER: A master 35-mm. negative could be made, properly pre-edited, as Dr. Goldsmith suggested, for the double sprocket hole standard and reduced in a single printing operation, which you suggest as being desirable. On the other hand, that can not be done very well for the single sprocket hole standard, in view of the fact that the transverse and longitudinal reductions of the sound track must be different unless a non-standard, 35-mm. (say, 38- or 40-mm.) dupe negative from which one row of sprocket holes has been omitted is provided for the purpose. That is a very obvious disadvantage, of course, for the double sprocket hole type of 16-mm. film.

MR. MITCHELL: With the 35-mm. master positive the space between the 35-mm. pictures must still be eliminated in the 16-mm. print, whether with one or two rows of sprocket holes. It would be commercially impracticable to consider 38-mm. or other off-standard film for the master negative.

BOOK REVIEW

The Complete Projectionist. R. H. Cricks. *Kinematograph Publications, Ltd.*, London, 1933, 231 pp.

Projectionists will undoubtedly welcome this new handbook for two reasons: (*1*) it represents a concise statement of the subject, and (*2*) it may be slipped into the pocket easily because of its small size. Both these characteristics should encourage wide reading of the book. The book contains 16 chapters and 7 appendixes as well as an index. A useful feature of the latter is that all matter related to troubles is set in bold-faced type. Numerous illustrations and diagrams aid in clarifying the text. The closing chapter deals briefly with forthcoming developments, such as color films, stereoscopy, non-intermittent projection, and television. Many useful tables are included in appendix sections.

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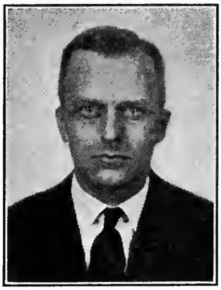
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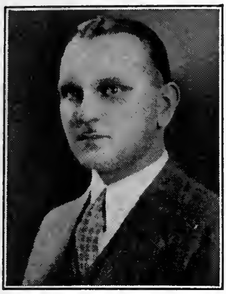

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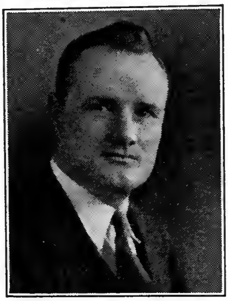

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SOCIETY ANNOUNCEMENTS

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At a meeting of the Board of Governors held July 16th, tentative plans for the Fall, 1934, Convention were formulated, as described below, and nominations for officers of the Society for the calendar year 1935 were completed. Voting ballots will be mailed to the Honorary Members, Fellows, and Active Members on or about September 19th, and the results of the election will be announced at the Fall Convention.

Various administrative and fiscal matters engaged the attention of the Board; and the Financial Vice-President, Mr. O. M. Glunt, reported that the Society was operating satisfactorily within its budget. Increased impetus is to be given to the membership campaign, which had shown signs of lagging during the summer months.

FALL CONVENTION

HOTEL PENNSYLVANIA, NEW YORK, N. Y., OCTOBER 29–NOVEMBER, 1, 1934.

The Fall, 1934, Convention will be held at the Hotel Pennsylvania, New York, N. Y., Oct. 29th–Nov. 1st, inclusive. Mr. J. I. Crabtree, Editorial Vice-President, with the assistance of Mr. J. O. Baker, Chairman of the Papers Committee, is arranging an interesting program of technical papers, presentations, and lectures; and Mr. W. C. Kunzmann, Convention Vice-President, is completing arrangements with the Hotel for most attractive accommodations for the members and their guests and facilities for the Convention.

Mr. H. Griffin will be in charge of the projection equipment; Mr. J. Frank, Jr., of the Apparatus Exhibit; and Mrs. O. M. Glunt will act as hostess, assisted by her Ladies' Committee.

The possibilities of arranging interesting trips or tours of inspection of studios or manufacturers' plants are being studied; and plans are being made to provide several outstanding figures of the motion picture industry as speakers for the Semi-Annual Banquet, to be held on Wednesday, October 31st, in the Grand Ballroom of the Hotel.

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Published monthly at Easton, Pa., by the Society of Motion Picture Engineers
Publication Office, 20th & Northampton Sts., Easton, Pa.
General and Editorial Office, Hotel Pennsylvania, New York, 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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C. Francis Jenkins

C. FRANCIS JENKINS

(*1867–1934*)

With the death of C. Francis Jenkins, June 6, 1934, our Society lost not only its founder, but also one of the inventors of the motion picture projector, around which the entire industry has been built up. Those of us who had the privilege of knowing Mr. Jenkins intimately knew him as a man of great imagination and boundless energy, evidenced by something over four hundred patents in his own name, both here and abroad.

On various occasions he had to leave his beloved laboratory and devote his attention to raising sufficient funds to carry on his prime work—research and invention. His indomitable will and faith can not be better indicated than by quoting a statement that he often made and evidently thoroughly believed, "If a thing is very difficult it is as good as accomplished; if it is impossible it will take a little time."

In his laboratory he surrounded himself with young men and young women because, as he put it, "If Jenkins tells them it can be done, they believe it." Once Mr. Jenkins hired a brilliant scientist from one of the great research laboratories of the country. The scientist did not last long because, as Jenkins said, "He spent too much time proving why it wouldn't work instead of figuring out how to do it."

Mr. Jenkins was a true and loyal friend; a hard fighter, loved by those who knew him well, and respected by even his business enemies, of whom he had a few—invariably the price of success.

In his home life I have never seen a more beautiful relationship between man and wife. Mrs. Jenkins was his sweetheart to the very end, and he treated her, both in private and in public, as a youthful lover. They had no children but were continually doing things for their nieces and nephews and the children of their friends. Jenkins was always trying to help young people to get a start finanically.

Just before the depression Jenkins sold his business. His manner of disposing of the tidy sum he received was very characteristic of the man. First he created a trust fund to take care of Mrs. Jenkins for the rest of her life. The remainder of the money he and Mrs. Jenkins gave away outright and unconditionally to poor relatives, friends, and servants whom they had had from time to time.

Like many inventors Jenkins was of a high-strung, nervous temperament. At times when he would get too fidgety and nervous to work, he would leave his laboratory and pilot his private plane up into the great blue reaches of the sky, where he found peace and quietness to rest his nerves. Often his wife, good sport that she was, would go with him on those flights.

About 1930 Mr. Jenkins' health began to fail. His heart made it necessary for him to drop most of his active work at his laboratory. The majority of his time thereafter was spent quietly, though restlessly, at his home in Washington.

Probably realizing that his years were numbered, he wrote his autobiography and published it in 1931 as a book entitled *The Boyhood of an Inventor* from which the following data are drawn largely.

A red-headed boy, C. Francis Jenkins, was born of Welsh-French parents—Quakers—near Dayton, Ohio, in 1867. When he was about two years of age his parents moved to a farm near Richmond, Indiana. His early boyhood was spent in the log cabin home on that farm. Like many other farm boys Jenkins learned various things by experience and hard knocks. He early began to show great interest in mechanical things. Hours were spent turning the hand-wheel of his mother's sewing machine and trying to puzzle out the mechanics of the sewing. Other lessons were learned from the spinning-wheel, the flax-break, the wool-carder, the butter-churn, the log-lever cheese press, the winnowing mill, and such early mechanical aids that have long since been superseded but that nevertheless utilized many of the principles of mechanics of modern machinery.

Probably his earliest invention was a bean-shelling machine which he made as a boy. Following that, he invented a jack to lift wagon wheels for greasing purposes. Some of them he painted bright colors, and in selling them he learned one important business principle, *i. e.*, that appearance goes a long way in selling an article.

Jenkins' early schooling was at the little country school to which he walked three miles from his house and three miles back again. This was followed by high school and Earlham College. Later in life his College gave him the honorary degree of Doctor of Science (1929). While at school the school board gave him a Leyden jar and a static machine, because nobody else knew how to work them. That was probably the start of his interest in electricity, which was to play so great a part in his success in later life.

Jenkins also learned that hydrogen gas made from sulphuric acid and zinc would fill paper bags and cause them to rise like balloons. Perhaps those experiments implanted in his mind the seed of a desire to fly. After he was fifty years old he bought his first aeroplane and received his pilot's license.

Parties in his youth usually furnished their own entertainment. The games played were those of mental skill, cleverness, quickness; tricks such as trying to blow a card from off a spool by blowing through the hole—involving a principle of aerodynamics; turning a tumbler of water upside-down on a card, and the like—far different from the hired entertainment furnished the present-day youth.

Jenkins' father was progressive, although not inventive nor particularly mechanical. He used machinery of the latest type on his farm, and it was Jenkins' particular job to keep all the mechanical gadgets operating and in repair. He proved so adept at the job that he built up quite a reputation in the neighborhood as a clever mechanic. The day he saw his first locomotive he ran off from his family, who were meeting friends at the rear of the train, and spent his time studying the engine. Later he found out enough about its operation so that he borrowed a locomotive and took his girl for a ride.

When he was a young man his desire to "go places and do things" took him to the Pacific Coast. There he worked in lumber camps, on a ranch, and down in Mexico in a mine. His first job in the lumber camp was riding logs. The first day was a series of spills into the water, but his persistence kept him at it all day long, even though soaking wet, and he soon learned the trick. His indomitable will and persistence were characteristics that contributed greatly toward his success.

As a result of a Civil Service examination he received an appointment as a clerk to Sumner I. Kimball, the founder of our life-saving service, which is now the U. S. Coast Guard. This position brought him to Washington, D. C., where a few years later he resigned to start on his real life work, inventing.

It was at Washington that he met and married Grace Love, of whom he writes in his book, "Perhaps the turning point came when he married that wonderful girl, 'Miss Grace,' who had endeared herself to everyone by her sympathetic understanding and unselfishness, winning the hearts and confidences of all who came in contact with her. It is to her kindly help and business widsom, rather than to any personal 'genius,' that this inventor attributes such success as has attended his efforts."

Jenkins built the first horseless carriage in Washington—a small steam car— and went broke trying to promote it. Later he developed the self-starter for automobiles, which proved to be a financial success.

Photography and the projection of motion pictures were really his life's great work. In addition to his work on the development of the motion picture projector, he made many contributions to the motion picture art. Notable among them are the first fire-proof projector—really the foundation of the home and school movies of today; a high-speed camera for showing in slow motion such things as the flight of a projectile, Bobby Jones' golf drive, *etc.* His Chronoteine camera takes 3200 separate exposures in one second; the film moves through it so rapidly that 400 feet of film can be shot up into the air before the first end falls to the ground.

Jenkins early recognized the need of standardization in the motion picture industry. The need was stimulated by the World War, and to meet the demand Jenkins founded the Society of Motion Picture Engineers in 1916 and became its first president. That organization is today international in scope. It is the outstanding organization in motion picture engineering, and its standards have attained worldwide recognition. Its *Transactions* and JOURNAL form the greatest technical library pertaining to motion pictures in existence.

In 1921, Jenkins set up his own research laboratory at Washington, D. C. It was in this laboratory that Jenkins developed the prismatic ring, a device for producing a smoothly oscillating beam out of a continuous beam of light. As time went on, Jenkins became interested in radio. By conducting tests with his own aeroplane he discovered that a radio "shadow" was cast behind a metal plane and that an antenna flown in that area could be used for two-way telephone conversation without interference from engine ignition.

Sending photographs by radio, and later by television, interested Jenkins greatly. I shall never forget the thrill of standing in his laboratory and having a photograph of my daughter transmitted over the regular telephone line to the U. S. Naval broadcasting station at Anascostia, Md. There it was broadcast by radio, picked up in the Jenkins laboratory, and reproduced at the side of the sending device. Jenkins established his own station for broadcasting motion pictures by radio. Nightly entertainment of that sort was transmitted from his station, *W3XK*. Relatively simple and inexpensive receivers had been developed by Jenkins and sold practically at cost to thousands of radio fans all over the country.

A more complicated machine for receiving weather bureau maps by radio was developed and installed on many of the Government ships. Jenkins had the fullest coöperation of the U. S. Bureau of Standards, the Army, and particularly the Navy, in testing out his many inventions, some of which were purchased by the Government and put into regular service.

As often happens to a man who works so intensively, his health began to fail. As a result, in 1930 he sold out his principal business, the Jenkins Television Corporation. A failing heart kept him more and more at home until his death in 1934. With his passing went one of the ten men in the United States having over three hundred patents in their own name. He was a man of great vision, with the courage of his convictions; a man of indomitable will and boundless energy; a man having great love for his fellow men, a fine Christian character respected by all who knew him and loved by those who had the opportunity of being associated with him. Perhaps the greatest monument to him is the continued success of the Society he founded and for which he worked so hard in its early struggle for recognition.

L. C. PORTER

THE BIPLANE FILAMENT IN SPOTLIGHTING*

GJON MILI**

Summary.—*The high degree of uniformity and source of brightness that have made the biplane filament so desirable for motion picture projection prove to be valuable also in spotlighting. The two parallel rows of coils placed so that the coils of one plane fill the spaces between the coils of the other provide a light source of greater uniformity and double the average brightness of the monoplane filament construction. Results are given showing the increased uniformity of the spot and the higher intensities attained with biplane filament lamps as compared with monoplane filament lamps of the same rating. The three types of spotlights most commonly used—namely, the lens spotlight, the shallow paraboloid, and the stereopticon spotlight—have been subjected to test to determine their operating results.*

The advantages of the biplane filament for motion picture projection were reported two years ago.[1] Like motion picture projection, spotlighting is a form of light projection, and the advantages of the biplane filament in the one field apply to a large extent in the other. Two types of filament construction are at present in common use as light sources for spotlighting: the barrel-shaped (*C-5*) and the monoplane (*C-13*). The latter predominates in the higher-wattage equipment designed for the studio and the theater, and it is with that type of spotlighting that the following analysis is chiefly concerned.

Light Source Characteristics.—Compared with the monoplane filament construction, in which the coils are all placed in one plane with intervening dark spaces, the biplane staggered-filament construction consists of two parallel rows of coils so placed that the coils of one plane fill the spaces between the coils of the other, thus providing a light source of greater uniformity and increased average brightness. For a given electrical rating the biplane source occupies approximately half the area and therefore is almost double the average brightness of the monoplane filament.

Fig. 1 illustrates the reduction of the size of the source and the increase in brightness and uniformity produced by the biplane

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

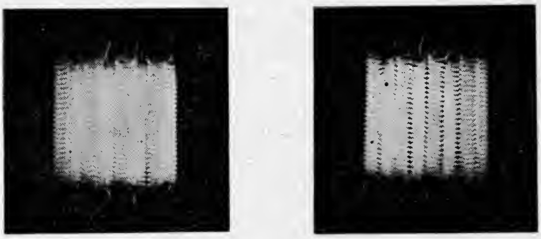
** Westinghouse Lamp Company, Bloomfield, N. J.

(*C-13D*) construction as compared with the monoplane (*C-13*) of identical electrical rating. Light sources rated at 2 kw., 115 volts, were photographed with and without a spherical silvered glass reflector.

Test Procedure.—A series of tests was conducted to determine the operating results obtained with the three kinds of spotlight most commonly used: namely, the lens spotlight, the shallow paraboloid, and the stereopticon spotlight. Candle-power measurements were made by means of a calibrated light-sensitive cell, the test distance being 60 feet for the lens spotlight and 100 feet for the paraboloid. Relative measurements of the light output of the stereopticon spotlight at various apertures were made with a 30-inch integrator pro-

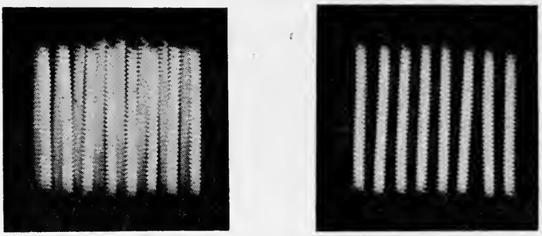
2-Kw. 115-Volt Biplane Filament

(*A*) With reflector (*B*) Without reflector



2-Kw. 115-Volt Monoplane Filament

(*C*) With reflector (*D*) Without reflector



Ratio	Source Area	Brightness
A/C	0.56	1.49
B/D	0.58	1.80

Fig. 1. Relative light-source area and uniformity of monoplane and biplane filament lamps of the same electrical rating.

vided with a circular diffusing glass window. The test unit was so placed that the projected beam came well within the circumference of the diffusing window.

Two-kw , 115-volt spotlight lamps of biplane and monoplane filament construction, such as shown in Fig. 2, were used in all tests. Lamp *A* has a monoplane filament; *B* and *C*, biplane filaments. Lamps *A* and *C* are designed to be operated with the base down; lamp *B*, with the base up.

The Lens Spotlight.—Where mobility and great variation of the size and intensity of the spot are required, a lens spotlight such as illustrated in Fig. 3 is most commonly used. In a unit of this type the intensity and spread of the beam depend upon the distance from the filament to the lens. The curves of Fig. 4 show the comparative beam spreads and the intensities at the centers of the beams of biplane and monoplane filament lamps for filament-to-lens distances ranging from 4 to 13 inches. It is apparent that when the lamp is positioned for a relatively small beam spread, the biplane filament provides much greater intensities than the monoplane. However, there is no appreciable difference of performance between the two types of filament when the lamp is drawn close to the lens in order to attain a wide spread. As may be noticed in the curves, maximum intensity occurs when the filament is focused sharply


(*A*) (*B*) (*C*)

FIG. 2. Two-kw., 115-v. spotlight lamps: (*A*) monoplane; (*B*,*C*) biplane.

in the plane of test. Such a spot, however, is hardly uniform enough to warrant its use. Instead, by drawing the filament to a point slightly behind the focus, a more uniform spot can be obtained without much loss in candle-power. This is the position marked as the plane of *minimum effective divergence.* The candle-power distribution of the beam, with the filament at the position of minimum effective divergence, is plotted in Fig. 5, the biplane showing a 90 per cent increase over the monoplane. Fig. 6, showing the beam patterns at the position of minimum effective divergence, brings out another advantage of the biplane filament when the unit is adjusted so as to produce a relatively small spot: namely, the marked uniformity of the spot. Actually, the striations shown in the beam pattern of the monoplane filament are even more objectionable to the eye than they appear in the illustration, because they represent not only a variation of intensity but also marked color fringes due to chromatic aberrations of the lens.

FIG. 3. Lens spotlight in operation.

The Shallow Paraboloid.—For such applications as require a highly concentrated beam with extremely high intensities, *i. e.*, several million cp., a projector equipped with a parabolic mirror of fairly large diameter (18, 24, or 36 inches) may be used to great advantage. In Fig. 7 are data obtained with biplane and monoplane filament lamps used with a silvered glass parabolic reflector (diam. = 25 in., f = 10 in.) with the projected beam focused in the plane of test. The superiority of the biplane type of filament over the monoplane both as to intensity and uniformity is again evident. While neither spot is perfectly uniform, experience has shown that a plain glass door or a slightly convex lens of the pressed type will completely smooth out the beam of the biplane filament lamp. The increase in the maximum candle-power attained with the biplane filament over the monoplane is about 50 per cent. The test projector and the method of measuring the intensities are illustrated in Figs. 8 and 9, respectively.

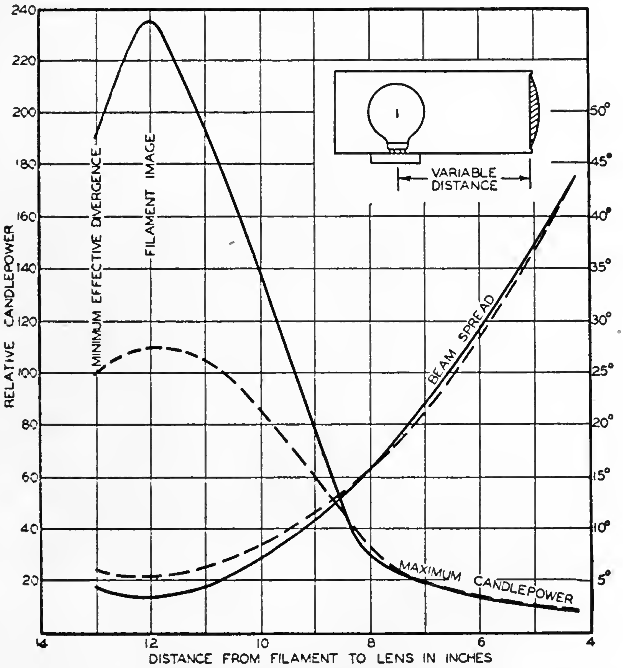


FIG. 4. Relative cp. and beam spread throughout range of lamp movement in lens spotlight equipped with biplane and monoplane lamps. [Plano-convex lens (dia. = 6″, f = 12″); 2-kw., 115-v. *G-48* bulb spotlight lamp.] Solid curves, biplane (*C-13D*); broken curves, monoplane (*C-13*).

The Use of an Auxiliary Reflector.—When employed with a shallow paraboloid or a lens, both monoplane and biplane filament lamps can be rendered more efficient by the addition of an auxiliary spherical reflector. The auxiliary reflector is so placed as to gather the light radiated in the direction opposite to the main optical element, whether lens or reflector, and is focused to produce an image in the plane of the filament. This is illustrated in Fig. 1. The reflected light filters through the interstices between adjacent coils, and also through the spaces between wire turns of the coils themselves, thereby increasing the quantity of light directed into the lens or paraboloid. As may be seen from Table I, an increase of illumination of 67 per

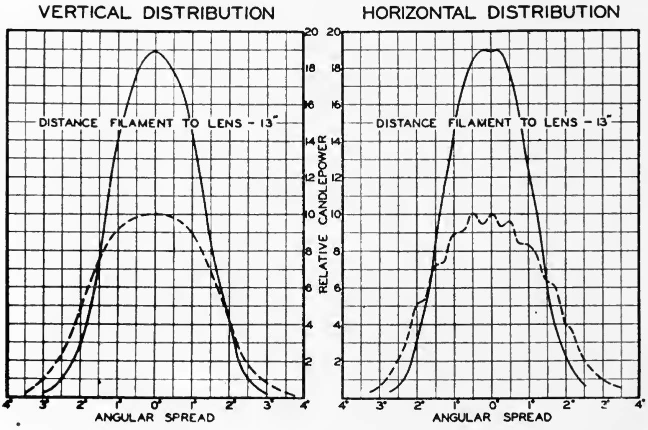
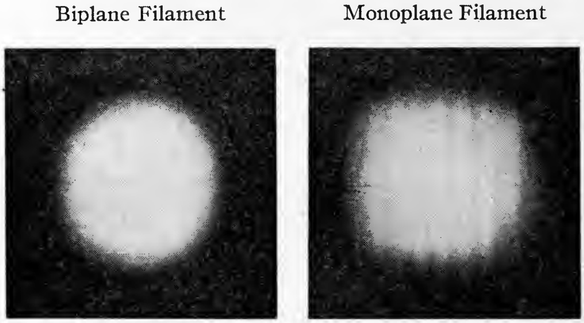


FIG. 5. In a lens spotlight, with the lamp at position of minimum effective divergence, a large increase of candle-power is possible by substituting a biplane for a monoplane filament lamp. [Plano-convex lens (dia. = 6", *f* = 12"); 2 kw. 115-v. *G-48* bulb spotlight lamp.] Solid curves, biplane (*C-13D*); broken curves, monoplane (*C-13*).


Biplane Filament

Monoplane Filament

FIG. 6. Appearance of spot at position of minimum effective divergence, showing increase of uniformity attained with biplane lamp. [Plano-convex lens (dia. = 6", *f* = 12"); 2-kw. 115-v. *G-48* bulb spotlight lamp.]

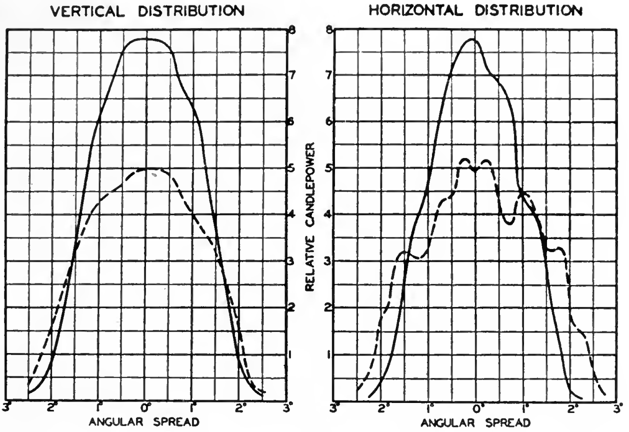


FIG. 7. In a parabolic projector greater candle-power and smaller beam spread may be attained by substituting for a monoplane filament lamp a biplane of equal electrical rating. [Commercial parabolic silvered glass reflector (dia. = 25″, *f* = 10″); 2-kw., 115-v. *G-48* bulb spotlight lamp.] Solid curves, biplane (*C-13D*); broken curves, monoplane (*C-13*).

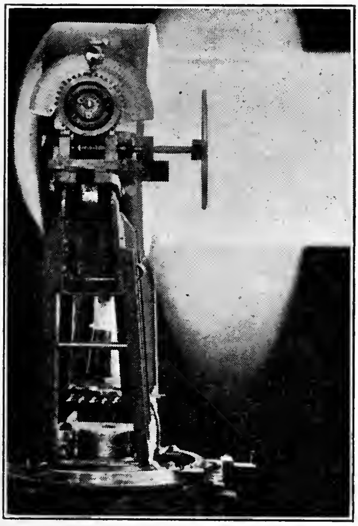


FIG. 8. A projector drum containing parabolic reflector, shown on test trunnion, which provides angular adjustment in vertical and horizontal planes.

FIG. 9. Candle-power measurements made with calibrated light-sensitive cell.

cent may be attained with the monoplane when the image from a silvered glass mirror is enmeshed between the coils; but the increase is only 39.6 per cent when the image is superposed on the coils themselves. Accordingly, to insure the best results and most uniform performance with the monoplane, the mirror must be reset accurately at each renewal of the lamp. With the biplane, where the mirror image falls upon the filament itself, only 35–40 per cent may be gained. But, on the other hand, the mirror setting is not so critical

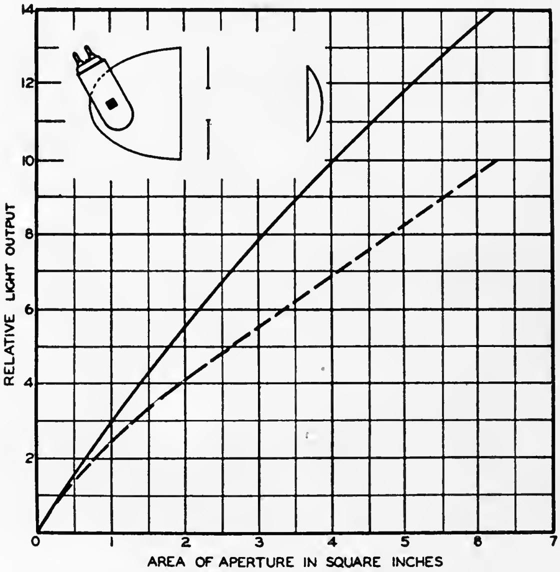


FIG. 10. The light output of a stereopticon spotlight is greater with a biplane than with a monoplane lamp throughout the range of operating apertures. [Stereopticon spotlight with deep ellipsoid, square aperture, and projection lens (dia. = 8″, *f* = 12″); 2-kw., 115-v. *T-32* bulb spotlight lamp.] Solid curve, biplane (*C-13D*); broken curve, monoplane (*C-13*).

TABLE I

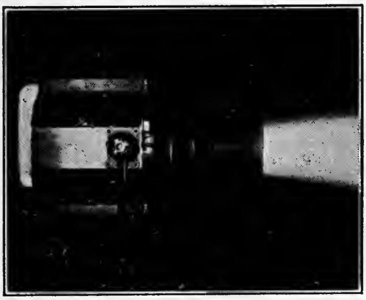
Effect of Spherical Mirror on Beam Illumination

Monoplane Filament Lamps Held at Constant Voltage

	Lamp Current	Illumination
No Mirror	100	100
Mirror Image between Coils	99.5	167.0
Mirror Image over Coils	98.7	139.6

as with the monoplane, and prefocus-base lamps perform satisfactorily without necessity of readjusting the mirror when a burned-out lamp is replaced by a new one.

The Stereopticon Spotlight.—Stereopticon spotlights may be divided into two groups, according to the optics employed in their design. The first group duplicates the optics embodied in a motion picture projector, except for the fact that the aperture size and shape may be varied. The advantages claimed for the biplane in motion picture projection[1] apply equally well to this type of spotlight. There remains the second group, in which the optical system consists, as a rule, of a lamp with the filament placed at the principal focus of a deep elliptical reflector, which acts as a light-gathering element; an aperture of varying size and shape at a suitable position near the conjugate focus; and a plano-convex lens that projects an enlarged image of the aperture in the plane of illumination. With a deep reflector the lamp should be mounted with the plane of the filament along the axis of the reflector.



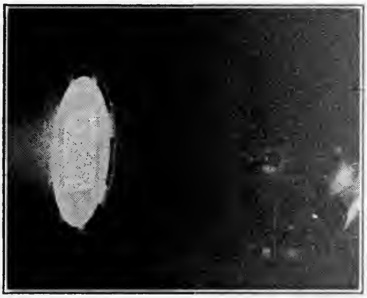


Fig. 11. Deep ellipsoid stereopticon spotlight.

FIG. 12. Integrating photometer used for measurements of light output in projected beam.

Two advantages may be claimed for the deep ellipsoid spotlight as compared with the lens spotlight: first, the higher efficiency; and, second, the sharpness and flexibility of outline of the beam spot. The intensity at the center of the beam is the same for all apertures, although the edge brightness decreases as the size of the aperture increases. Fig. 10 shows graphically, for various apertures, the total light output of a unit of this type equipped with biplane and monoplane filament lamps of equal electrical rating. The total light output with the biplane lamp is about 40 per cent greater than with the monoplane. The stereopticon spotlight used in the test, and the method of measuring the total light output by means of the integrating photometer, are illustrated in Figs. 11 and 12, respectively.

Conclusion.—The test results and photographs presented show the improvement achieved in the performance of the unit by substituting the biplane filament for the monoplane, in three types of spotlight: namely, the lens spotlight, the shallow paraboloid, and the stereopticon spotlight. With the first two types, in which the position of the filament may be varied, the advantages of the biplane are most marked when the filament is at or near the optical focus. With the stereopticon spotlight, in which the position of the filament is fixed, the advantages of the biplane are maintained throughout the range of operating apertures. The data presented and the conclusions reached will apply equally well to spotlights similar in design to the units tested, and to lamps of other wattages.

REFERENCE

[1] MILI, J. T.: "Biplane Filament Construction—A High-Intensity Incandescent Lamp Light-Source for Motion Picture Projection," *J. Soc. Mot. Pict. Eng.*, **XIX** (July, 1932), No. 1, p. 829.

DISCUSSION

MR. JOY: The speaker stated that the intrinsic billiancy of a tungsten filament is considerably increased by using a coil construction. How great is that increase?

MR. MILI: The intrinsic brilliancy of a 2-kw. filament such as that used in the test is about 1350 candles per sq. cm. on the outside and 3000 candles per sq. cm. on the inner surface of the coil. The temperature of the inner surface is at most only a few degrees higher than on the outside, and the increase of brightness is due almost entirely to the reflection of light made possible by coiling the filament. This increase of brightness by means of reflection occurs not only at the inner surface, but also at portions of the outer surface adjacent to another coil.

MR. MANHEIMER: Table I indicates that the lamp current is less when a spherical reflector is used, the voltage remaining unchanged. Is that due to an increase of the filament temperature?

MR. MILI: The resistance of tungsten wire increases with the temperature. Accordingly, a filament that is operated at constant voltage will draw less than the rated current when its temperature is raised above normal by some external means. As shown in Table I, the heat reflected by the spherical mirror will cause a larger decrease of current, and hence a greater increase of filament temperature, when the image falls on, instead of between, the coils. The increase of temperature due to the mirror image is compensated for when designing the lamp, in order that the life of the lamp may be maintained at the established figures.

MR. RICHARDSON: What, in ordinary service, is the rate of deterioration of the surface of the auxiliary reflector, and how easily can it be kept clean?

MR. MILI: In studio spotlighting we deal with lamps that consume power of the order of two, five, and ten kilowatts. The auxiliary reflector is placed only 4 to 6 inches away from the filament, and is subjected to the heat radiated by these lamps. On account of the heat, first-surface reflectors are likely to tarnish, at a rate that depends upon operating conditions and the kind of metal used. Silvered glass mirrors do not tarnish, because the reflecting surface is protected from atmospheric action, unless the backing chips off, although the glass may crack if strains are caused by the supporting mechanism. Metal reflectors may be cleaned with ordinary polishing compounds, whereas occasional wiping with a clean cloth will be sufficient to ensure good performance with glass mirrors.

MR. PALMER: Since the biplane filament is practically a full source of light, how is it possible to increase the illumination by using a spherical mirror with the biplane filament? Can the projected beam be rendered more uniform by placing the mirror image slightly out of focus?

MR. MILI: The increase of illumination resulting from using a spherical mirror with the biplane filament is due partly to the reflected light that filters through the coils between turns of the filament, and partly to the light that passes back between the coils, especially at lateral angles of 35 to 45 degrees on either side of the optical axis; and, finally, to the rise in filament temperature caused by the mirror image.

If the spherical mirror image is focused behind the plane of the filament, the reflected light will be localized at the center of the beam, sometimes resulting in disturbing filament images. If the image is focused ahead, the reflected beam will be wider than the direct beam, thereby causing a dim ring of light around the beam spot.

MR. PALMER: What would be a practical way of positioning a spherical mirror with a biplane filament lamp?

MR. MILI: If prefocus lamps are used, a very practical way would be to position the mirror with a monoplane lamp, and then to replace the monoplane with the biplane. A more accurate method would be to focus the mirror so as to produce an image equal in size to, and at one side of, the filament; and then, by revolving the mirror, to superpose the image upon the filament so as to fill the spaces between coils at lateral angles from the optical axis.

MR. TUTTLE: Why is the conventional type of relay system, using a condenser and a field lens, not used more in this sort of spotlighting equipment?

MR. MILI: Such a system has been suggested, since it would improve the uniformity of the spot. The field lens would, however, increase the cost of the unit, add weight, and make it appear more complex.

RECIPROCITY LAW FAILURE IN PHOTOGRAPHIC EXPOSURES*

LOYD A. JONES AND J. H. WEBB**

Summary.—*Reciprocity law failure is dealt with from the standpoint of its application to practical photographic exposures. Reciprocity failure and the manner of its portrayal are first briefly and simply described. It is then shown how the reciprocity failure diagram can be interpreted to show the behavior of time-scale and intensity-scale H&D curves, with regard to speed and contrast, for widely different ranges of intensity corresponding to those existing in certain definite classes of photographic work. Actual reciprocity curves for a number of commercial emulsions are included in the paper.*

INTRODUCTION

A perusal of the literature which has appeared during the past thirty or forty years relating to the scientific and theoretical aspects of photography reveals many references to the "failure of the reciprocity law." Much of the earlier investigational work on this subject was done by astronomers who were forced to make very long exposures with extremely low illuminations on the photographic material. It was quite evident from their experimental work that a much smaller photographic effect was produced under these conditions of low illumination than when exposures were made with higher illuminations, even though the product of illumination by the exposure time was kept the same in the two cases. It has been known for many years, therefore, that, at least under certain conditions, it is not justifiable to assume that the photographic effect produced by a constant exposure is independent of the intensity level at which the exposure is made.

In many fields of photographic work, such, for instance, as portraiture, landscape photography, and motion picture photography, the variations in the photographic effect resulting from equal exposures at the various practically available illumination levels are not

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J. Communication No. 531 from the Kodak Research Laboratories.

** Eastman Kodak Co., Rochester, N. Y.

sufficiently great to be of much importance. Workers in this field, therefore, have not paid much attention to the failure of the reciprocity law. The relation between the time and intensity factors of exposure are of great interest, however, to those investigators chiefly concerned with the theory of photographic exposure and latent image formation, and a study of the literature shows that many investigations of the reciprocity law failure have been made for the specific purpose of finding out more about the nature of the latent image.

During recent years developments in various fields of applied photography have necessitated the use of shorter and shorter exposure times at high illumination levels. A study of the data available on the reciprocity failure shows that as illumination levels are increased, reciprocity failure again becomes of considerable magnitude. It is becoming more and more evident that the failure of the reciprocity law is of importance in some kinds of work, and the primary purpose of this paper is to show how the available data can be interpreted and applied in the case of practical photographic exposures. As stated previously, the chief interest in the practical aspects of reciprocity law failure has been manifested in astronomical work where exposures must be made at very low illumination levels. However, under the conditions of high intensity which are now being used on certain types of motion picture photography, especially in the photographic recording of sound, the reciprocity law failure is coming to be recognized as an important factor at high as well as at low intensity.

The reciprocity law failure is an inherent and fundamental characteristic of all photographic emulsions, although the magnitude of the departure from the reciprocity relationship may vary considerably with different emulsion types. It is, of course, quite evident that the reciprocity characteristic of an emulsion must be known in order to predict precisely the performance of that emulsion when exposed at any particular illumination level.

HISTORICAL RÉSUMÉ

The fact that the magnitude of the chemical effect produced on a light-sensitive substance is not determined solely by the *total quantity* of energy absorbed, but is dependent also upon the *rate* at which the energy is absorbed, seems to have been known almost from the beginning of photography.[1] Since the first photographic materials made were extremely slow and this failure to integrate correctly the incident radiant energy over an exposure period of finite duration is accentuated with slow emulsions, it is natural that the effect should have been found and then more or less neglected as the speeding up of the emulsions made it less and less troublesome to the average photographer.

In 1876 Bunsen and Roscoe[2] formulated a general law for photochemical reactions, without specific reference to photography. Their statement was:

$$\text{Insolation} \propto \text{Exposure}$$
$$\text{Exposure} = \text{Intensity} \times \text{Time}$$

The term *insolation* was used by them in referring to the *effect*, the photochemical reaction, produced by the action of radiant energy on the photosensitive material. *Exposure* is defined specifically as the product of intensity by time, both factors of which are precisely measurable by appropriate physical methods. Exposure must therefore be regarded as of a purely *causative* nature of which the *effect* is referred to as insolation. From the reciprocal relation between time and intensity given by the Bunsen-Roscoe formula, it was called the reciprocity law, and the deviations from it have been known universally as "failure of the reciprocity law."

In 1892 Abney[3] worked on the problem using two different light sources, a candle and an electric spark. He found that when he decreased the illumination on the photographic plate, by increasing the distance between the candle and the photographic plate, the photographic effect (insolation) decreased faster than it should if the Bunsen-Roscoe equation were valid. On the other hand, with constant values of exposure ($I \cdot t$) when using the electric spark, an increase in the energy intensity incident on the plate was followed by a decrease in the photographic effect (insolation). These data pointed toward the existence of an intensity which would give a maximum photographic effect for a constant value of exposure.

In 1900 Schwarzschild[4] formulated an empirical expression for use in this work. This expression,

$$\text{Insolation} = I \times t^p$$

where p is a constant and usually has been given a value of about 0.8, was used by him for determination of stellar magnitudes and in other work where the intensities under consideration were extremely low. The simplicity of the expression and its ease of application, as well as the lack of any other, led to its extension to practically all fields of photography. More recent work on the subject has shown that Schwarzschild's relationship is entirely inadequate to fit the facts over a very wide range of intensities. Even by making the exponent p of variable value the observed effects are not well represented by an equation of the Schwarzschild type. The use of the Schwarzschild relationship has been so wide-spread that we frequently find references in the literature to it as the Schwarzschild *law,* and many workers still continue to assume that the relationship is adequate to represent mathematically the failure of the reciprocity relationship. It is unfortunate that this misleading expression has received such wide application since its failure to fit the experimental facts may introduce serious errors.

From 1903 to 1906 the work of Mees and Sheppard[5] indicated the existence of an intensity at which the photographic effect was a maximum.

The classical work of Kron,[6] in the Potsdam Astrophysical Laboratory, was done in 1913. This is one of the most complete single treatises on the subject. In his exhaustive study of four different emulsions, Kron concluded that the experimental data were best presented in the form of "curves of constant density;" that is, he plotted the logarithm of exposure ($I \cdot t$), required to produce a constant density, against the logarithm of intensity (illumination). For all the emulsions studied by him he found an optimal intensity, or an intensity at which a minimum amount of exposure was required to give a fixed density. Kron found that an analytical expression of a hyperbolic form fitted his experimentally observed facts quite well. He also suggested an equation of the catenary form but did not find that it represented the facts quite as well as the hyperbolic form. He noted that optimal intensity was at a lower value for fast emulsions than for slow emulsions and that the optimal intensity increased with increasing development. Kron's results have been applied extensively by Halm.[7]

Although there are many others who have investigated portions of the intensity range and who have developed special formulas applicable to special problems, the works mentioned seem to be the best known and the most general studies of the behavior of commercial emulsions up to the year 1921, when the problem was taken up by the Kodak Research Laboratories. More complete bibliographies will be found in Kron's paper and one by E. A. Baker.[8]

During the years 1923 to 1927 a group of five papers was published by Jones and his collaborators[9] bearing on various phases of the reciprocity failure. Their experimental results were most perfectly fitted by an equation of the catenary form.

In 1927 Arens and Eggert[11] published a paper on the reciprocity law failure in which a graphical method was presented for showing the effect of reciprocity law failure upon the shapes of the intensity- and time-scale H&D curves. The method consists in drawing constant-density curves in the ($\log I$, $\log t$) plane and then constructing from these curves the intensity- and time-scale H&D curves in the directions of the two coördinate axes of this plane. This method of applying the reciprocity data to the exposure curves obtained in practice was a step forward. The method given here for applying the reciprocity data, while being somewhat similar to that of Arens and Eggert, has the added advantage of being more direct and simpler to use.

This brief discussion of the literature of the subject, while not particularly complete, will serve to give the reader references in case he wishes to delve into the more theoretical aspects of the subject.

GENERAL DISCUSSION OF THE RECIPROCITY LAW FAILURE

The practical effect of the reciprocity law failure may be clearly illustrated by a simple example. If the aperture of a camera lens is changed from $f/3.5$ to $f/7.0$ (all other factors remaining constant), the illumination on the photographic material in the focal plane, where the image is formed by the lens, is correspondingly changed to one-fourth of its original value. If the reciprocity law were valid, it would be necessary to increase the time of exposure to four times the value used at $f/3.5$ in order to obtain the same density in the developed images. Because of the reciprocity law failure, however, a little more or a little less than this exposure time may be required in order to maintain equality of density in the developed images.

In previous work, two methods have been followed generally in studying reciprocity law failure. One of them consists in giving to an emulsion a series of constant-energy ($I \times t$) exposures in which the factors I and t are reciprocally varied as, *e. g.* ($It = 16\times1$, 8×2, 4×4, 2×8, *etc.*), and studying the variations in the densities at different intensities. The other method consists in measuring the amounts of exposure ($I \times t$) required to produce a constant density at different levels of intensity. The latter of these methods, being somewhat more amenable to analytical treatment, will be used here, and the data will be presented by plotting constant-density curves, the ordinates of which represent the log *It* values and the abscissas represent log *I* values. Such curves will be called reciprocity failure curves and each will be labeled by the density value for which it was constructed. The general shape of such curves, characteristic of all emulsions, is illustrated by curve *A* of Fig. 1. Since ordinates of the reciprocity curve represent the log exposure values required to produce a constant density, it is obvious that curve *A* would become the horizontal line *B* if the reciprocity law held rigorously. It is readily seen in the case of the actual curve *A* that there is one intensity level, I_1, at which a minimal amount of exposure is required. This intensity is known as optimal intensity, and its value changes from one emulsion to another. In departing from this optimal intensity and going either to higher or to lower intensities, more exposure is required to produce the same density. Thus there is one most efficient intensity for use with a photographic emulsion. The amount of the excess exposure required to produce a given density at intensity *I*, as compared with the amount required to produce the same density at optimal intensity, is usually termed the magnitude of the reciprocity law failure. Thus, for example, at the value of 100 units, corresponding to log I = 2.0 (see Fig. 1) this excess exposure value is represented by the vertical intercept *ab*. In log units, this amounts to 0.5, which corresponds to a numerical factor of 3.16. In other words, 3.16 times the exposure is required to produce a given density at intensity 100 units as at the intensity of 1 unit.

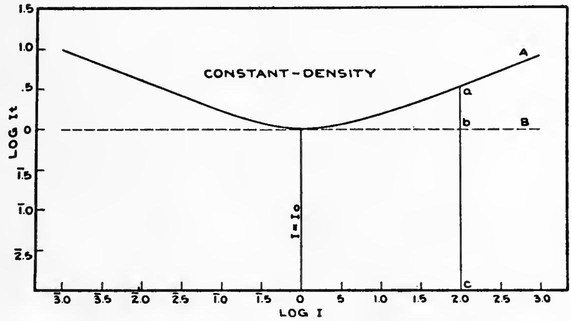

FIG. 1. Illustration of the reciprocity failure characteristic.

The reciprocity curve *A* may vary considerably in shape for different emulsions, some materials possessing very flat curves and others very steep curves. Frequently, the reciprocity curves are symmetrical for a considerable interval on either side of optimal intensity, usually breaking away from this symmetrical shape, however, and turning sharply upward at very low intensities.

Few general rules have been found which make it possible to correlate the shape of the reciprocity failure curves with other characteristic attributes of the emulsion, such as speed, grain size, sensitization, *etc.* Some fast materials have a very large failure while others have a very small failure, and the same applies to slow emulsions. The effect of development upon reciprocity law failure is generally slight. Different developers have been found[9] to shift the optimal intensity somewhat, and variation in the extent of development alters the curvature of the curves to a small degree. However, for the general considerations of reciprocity law failure to be dealt with here, these complications need not be brought in. Also, quality of radiation need not be considered here since it has been shown[10] that the reciprocity characteristic is independent of the quality of radiation when points of the same density and exposure time are compared.

INTERPRETATION OF RECIPROCITY LAW FAILURE AND ITS APPLICATION TO PRACTICAL PHOTOGRAPHIC EXPOSURES

Speed and contrast of an emulsion are the two factors chiefly affected by reciprocity law failure, and these are usually the characteristics of chief importance to the user of photographic emulsions for either pictorial or scientific work. By means of reciprocity failure curves drawn for a series of densities, it is possible to obtain the values of these factors for both intensity- and time-scale H&D curves over the range of intensity covered by the reciprocity curves. Further, the variations in these factors with intensity are also available and usually a casual inspection of the reciprocity failure curves is sufficient to show the general trend of the variations in these factors. It will be shown in this section how this information can be read from the reciprocity failure curves and how it can then be applied to practical photographic exposure.

For illustrative purposes, the curves of Fig. 2 are presented as typical of those from any ordinary photographic emulsion. These curves were obtained from an actual emulsion, and were chosen because of a combination of qualities which made them particularly suitable for demonstration purposes. These curves are given for density values 0.5, 1.0, 1.5, and 2.0, and they cover a range of intensity values from one to one million.

In order to read the reciprocity diagram, it is first essential to locate and establish on this diagram the lines of constant intensity and the lines of constant time. The constant-*intensity* lines on this diagram correspond to the *time-scale* H&D curves, while the constant-*time* lines correspond to the *intensity*-scale H&D curves. Consequently, in order to read the speed and contrast values for these two types of H&D curves it is necessary to know the course of these curves on the reciprocity diagram. It is obvious that any vertical line on the reciprocity diagram is a constant-intensity line, the abscissa values being the same for every point on such a line. Constant-intensity lines are illustrated in Fig. 2 by the dotted vertical lines. Thus, as one proceeds upward along one of these dotted lines, the density and the log *It* values encountered are precisely those which would be encountered by proceeding upward along a time-scale H&D curve. Indeed, as will be shown later, the time-scale H&D curve can be constructed by plotting the values of density *vs.* log *It* obtained from the intersection points of a vertical line with the various reciprocity curves. Also, the gamma, or contrast, value can be obtained for this H&D curve directly from Fig. 2 by dividing the density difference between two curves by the vertical intercept in log

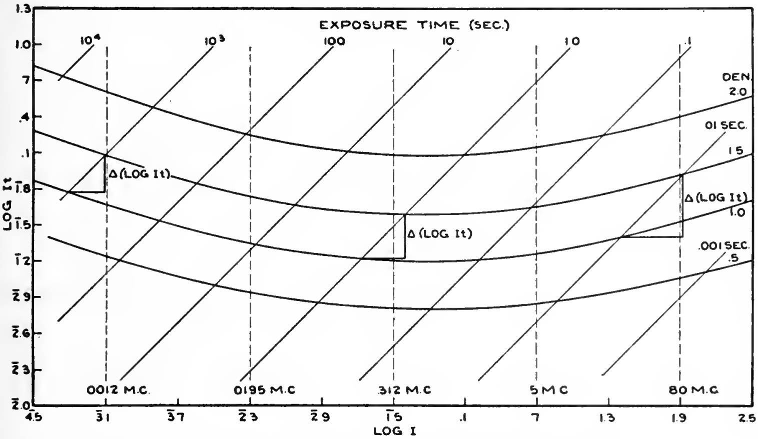

FIG. 2. Typical reciprocity curves, $\gamma = \Delta D / \Delta(\log It)$.

It units between the two curves. For example, on the 0.312 m.c. constant-intensity line between the reciprocity curves of densities 1.5 and 1.0, the difference in density is 0.5 and the log *It* intercept is 0.38. Therefore, the gamma, or slope, of the H&D curve is 1.31, the ratio of these quantities. It is necessary, of course, in computing the value of gamma in this manner, that the density values chosen (in this case 1.5 and 1.0) both lie on the straight-line portion of the characteristic curve. In case they do not, the value obtained will be the average slope of the H&D curve between the particular density values used.

The lines of constant time in Fig. 2 are those shown by the 45-degree lines. That these lines are constant-time lines can be verified by the following argument. Ordinates on the reciprocity diagram represent log *It*, while the abscissas represent log *I* values. By formal analogy with the equation,

$$y = x + \text{constant}$$

which is the equation of a straight line of unit (or 45 degrees if the x and y scales are equal) slope in terms of Cartesian coördinates, it is readily seen that the equation,

$$\log It = \log I + \log t$$

represents a straight line of 45-degree slope on the reciprocity diagram provided log t is a *constant.* The value of this constant for any 45-degree line is readily determined by choosing a point on that line and subtracting its abscissa value, log *I*, from its ordinate value, log *It*, thus,

$$\log It - \log I = \log t$$

This may be verified by noting that the difference between the ordinate and abscissa value for every point along the one-second line is zero, corresponding to the antilog of unity.

The 45-degree lines drawn in Fig. 2, representing constant-time lines at intervals of 10, correspond to the intensity-scale H&D curves. Here again, proceeding upward along one of these 45-degree lines, the values of density and log *It* values encountered correspond to those along an intensity-scale H&D curve. The contrast value at any point along one of these intensity-scale curves can be obtained in the same manner as in the case of a time-scale curve. As before, the density difference between two reciprocity failure curves is divided by the difference in log *It* as read from the ordinates of the intersection points of the constant-time line with the reciprocity curves. For example, choosing the 100-second, constant-time line, the difference in density between the curves for densities 1.5 and 1.0 is 0.5. The corresponding difference in log *It* values read from the intersection points is 0.31. The ratio of these values gives a gamma, or contrast, value of 1.61 for this H&D curve.

In order to illustrate how it is possible to study from the reciprocity diagram the shapes of time-scale and intensity-scale H&D curves, as well as their alterations in shape with intensity, several curves of each type have been derived from the reciprocity failure curves of Fig. 2, and are shown in Fig. 3. Curves of both types have been constructed for three widely separated regions of intensity, as follows: one well below optimal intensity, one near optimal intensity, and one well above optimal intensity. A comparison of the intensity-scale curves with the time-scale curves in Fig. 3 will show clearly the differences in speed and gamma obtained with these two types of curves and how these quantities change with intensity. The H&D curves here presented were obtained by following the constant-intensity and constant-time lines on the reciprocity diagram as previously described. The intensity-scale curves were derived from the 1000-second, the 1-second, and the 0.01-second lines, respectively. The time-scale curves were derived from the 0.0012-m.c., the 0.312-m.c., and the 80-m.c. intensity lines, respectively.

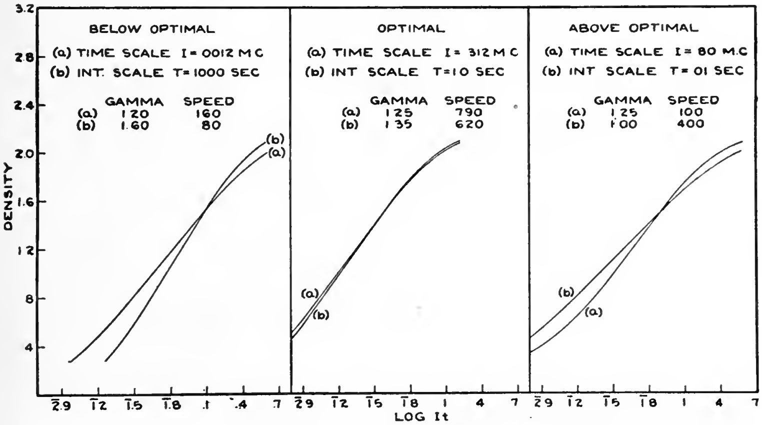

FIG. 3. Comparison of intensity- and time-scale H&D curves at different levels of intensity.

An inspection of these curves will show that in the case of the two

H&D curves below optimal intensity, the *intensity*-scale curve is the steeper. The gamma values for the two curves are in the ratio 1.60 to 1.20. In the region of optimal intensity, the gamma values of the intensity- and time-scale curves are practically equal, being 1.35 and 1.25 for the intensity-scale and time-scale curves, respectively. In the region above optimal intensity, the gamma values are reversed from what they were below optimal intensity, the *time*-scale curve being here the steeper, as shown by the numerical gamma values 1.25 and 1.00. It is to be noted that the slope, or gamma, of the time-scale curve remains practically unchanged with varying intensity, while gamma for the intensity-scale curve changes from 1.60 to 1.00 over the range of intensity covered by this diagram.

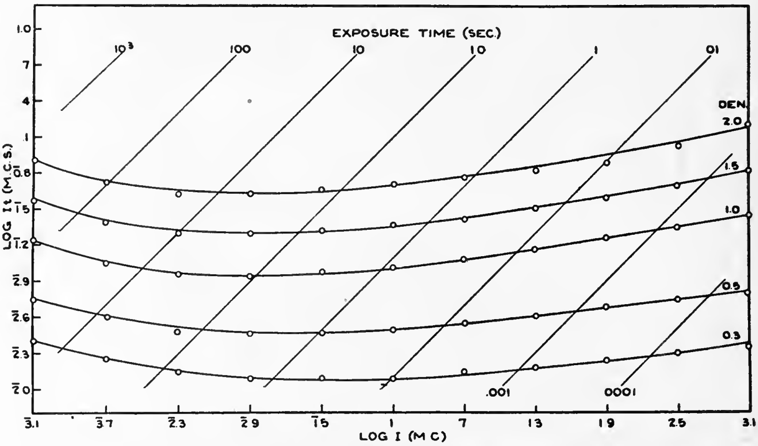

FIG. 4. Super-Sensitive Motion Picture Panchromatic film; reciprocity law failure.

The behavior of the gamma value for each of the types of H&D curves may be seen to be attributable to the shape of the reciprocity curves and to the manner in which these curves are crossed by the constant-intensity and constant-time lines. At low intensities the contant-time lines meet the reciprocity curves more nearly perpendicularly, and hence the vertical log *It* intercept encountered in passing from one density curve to the next is less than in the region of intensity above optimal, where the constant-time lines make a very small angle with the reciprocity curves. In the neighborhood of optimal intensity, the reciprocity curves are nearly flat, and as a consequence, there is little difference between the vertical intercepts on the constant-intensity lines and the constant-time lines. This accounts for the practical equality of the gamma values for the intensity- and time-scale H&D curves in this region. The constancy of gamma with intensity for the time-scale H&D curves may also be understood from an inspection of the reciprocity curves of Fig. 2. Since the reciprocity curves for different densities are nearly parallel vertically, the vertical intercept between curves, and thereby the gamma value, remains substantially unchanged with changing intensity.

The intensity-scale H&D curve is the one which conforms to the type of exposure obtained in practical pictorial photography. In exposures of this type, the entire area of the exposed emulsion is given the same exposure time, the density range being obtained through variations in intensity from point to point in the focused image. On the other hand, the time-scale H&D curve is the one more frequently employed in the sensitometric testing of emulsions because of the greater simplicity and accuracy obtainable in time-scale instruments. From what has gone before, it is clear that, if control test exposures made with time-scale instruments are to yield information of practical value in making exposures, it is necessary to know the reciprocity failure characteristics of the emulsion so that the test exposures can be correctly interpreted for the practical conditions of use.

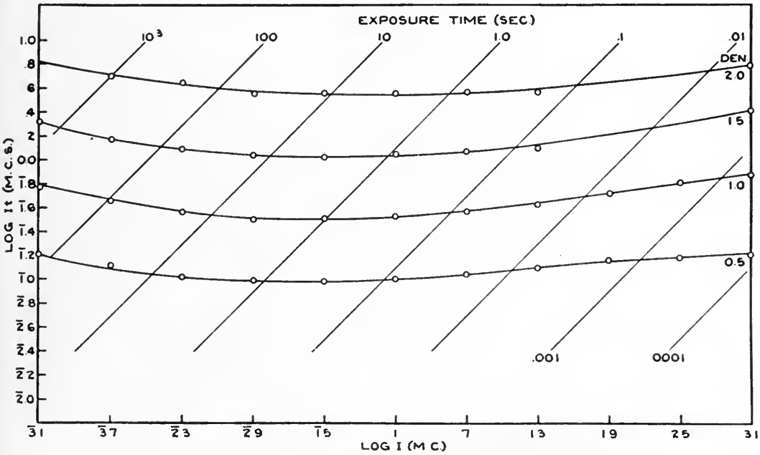

FIG. 5. Eastman *40* plate; reciprocity law failure.

Further information of practical importance contained in the reciprocity failure curves is in regard to the matter of emulsion speed at different levels of intensity. In Fig. 3, the values of the H&D speed calculated from the relation $10/i$ are given for the various H&D curves presented. The speeds as obtained from both types of curves are seen to vary considerably with the intensity level. Moreover, the variations in speed are different for the two types of curves. This difference in speed variation is due to the difference in the behavior of gamma for the two types of curves, as can be understood from the fact that the above manner of determining speed is dependent upon inertia, and therefore gamma.

For the technician working in the laboratory in the design or operation of apparatus for high-intensity exposures, as, *e. g.*, sound recording apparatus and certain types of printers, it is essential for best results to have available information regarding the relative behavior of intensity- and time-scale curves at high intensity. The need for such information is at once apparent from a comparison of the two H&D curves at high intensity shown in Fig. 3. The intensity-scale curve has a much lower contrast here than the time-scale curve, whereas the opposite was true at low intensities. As for the time-scale curve, there is no evidence that there is any loss of contrast at the high intensities even though the loss in speed is considerable in this region.

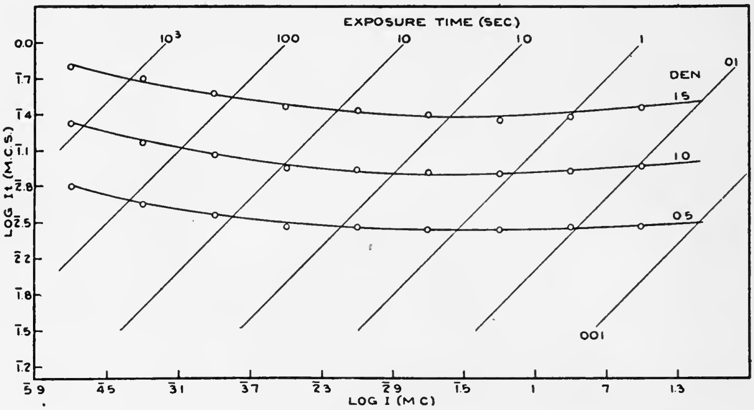

FIG. 6. Eastman *50* plate; reciprocity law failure.

The behavior of the two types of H&D curves of Fig. 3 with changing intensity is typical, qualitatively, for all emulsions. Of course, the magnitude of the changes in gamma and speed with intensity, and the position of optimal intensity, will change from one emulsion to another. In general, then, the behavior of speed and gamma of any emulsion can be summed up as follows: The optimal intensity of an emulsion occurs in the region for which the exposure time necessary to produce a medium density is of the order 0.1 to 10 seconds. The speed of an emulsion decreases as the exposing intensity is either increased above, or decreased below its optimal value. The gamma value of an intensity-scale H&D curve increases for intensities below optimal intensity and decreases for intensities above optimal intensity. The gamma of the time-scale curve is not greatly affected by changes of intensity and usually agrees in value very closely with the gamma of the intensity-scale curve in the neighborhood of optimal intensity.

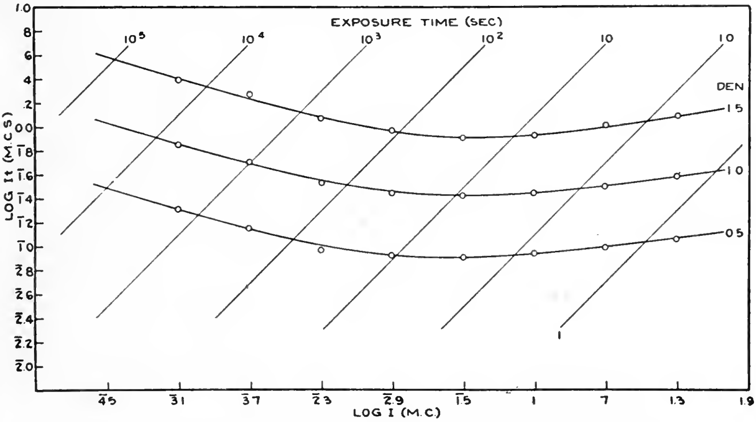

FIG. 7. Eastman Super-Speed film; reciprocity law failure.

THE RECIPROCITY FAILURE CHARACTERISTICS FOR SEVERAL TYPES OF COMMERCIAL EMULSIONS

Curves of the reciprocity failure characteristic for a number of commercial emulsions in common use are exhibited in Figs. 4 to 9. The curves of Fig. 4 are for the Super-Sensitive Panchromatic motion picture film. As this film is used largely for motion picture and still camera photography, the exposures usually are of a duration between 0.1 and 0.001 second. It may be seen that this range of exposure time falls in the region of intensities slightly above optimal intensity. In this region the time-scale H&D curve would be slightly more contrasty than the intensity-scale curve. However, as the reciprocity failure curves are not steep in this region neither the change in speed nor the variation in contrast over this range is serious.

The curves of Figs. 5, 6, and 7 are for a group of high-speed materials used to a large extent in both pictorial and scientific work. The Eastman *40* plate is a high-speed, blue-sensitive emulsion used in portraiture work and to a considerable extent in spectroscopy and astronomy. It is to be noted that this emulsion has a very flat reciprocity characteristic so that it holds its speed well, and changes its contrast only slightly, over wide ranges of intensity. The fact that this emulsion holds its speed so well at low intensities makes it particularly suitable for astronomical exposures. The Eastman *50* plate is an extremely high-speed orthochromatic plate used in high-speed portraiture and to some extent by press photographers. Its reciprocity characteristic is rather flat and its optimal intensity is in the region for which the exposure time is 0.1 second. This higher-than-average value of optimal intensity renders the speed of this emulsion near a maximum in the region of exposure times for which it is mostly used. The low reciprocity failure for this emulsion at low intensities recommends it also for astronomical work. The Super-Speed portrait film is also a high-speed orthochromatic emulsion and its reciprocity failure is seen to be somewhat greater than that

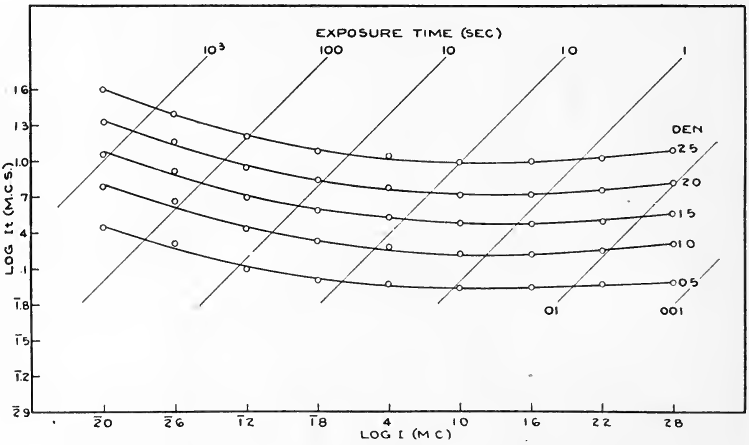

FIG. 8. Motion Picture Positive film; reciprocity law failure.

for Eastman *40* or Eastman *50* plates. This film being intended especially for portrait work, its speed is seen to be near maximum in the region of exposure times for which it is mostly used. This fact is brought out by the reciprocity failure curves.

The reciprocity characteristics for two low-speed emulsions are shown in Figs. 8 and 9. The Motion Picture Positive film, used in the printing of motion pictures for which the exposures are of a duration between 0.1 and 0.01 second, is seen to have a relatively high speed in this region of exposure times. The closeness of the reciprocity curves for this emulsion emphasizes its high contrast. The curves for Eastman Process plates are shown in Fig. 9. These plates are used chiefly in copying work, particularly for such as line drawings, in which strong contrast is needed. Because of the low speed of this emulsion, the exposures are usually of considerable duration, being of the order of from 1 to 10 seconds. Neither the speed of this emulsion nor its contrast is materially affected by reciprocity law failure in this region of exposure times. As in the case of the Motion Picture Positive, the extreme contrast of this emulsion is manifested by the closeness of the reciprocity curves to one another.

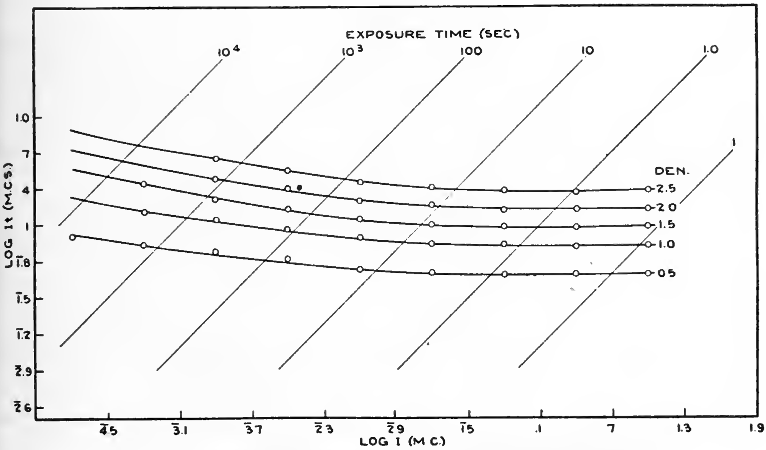

FIG. 9. Eastman Process plate; reciprocity law failure.

In order to compare the foregoing emulsions with regard to exposures for optimal speed, a list of optimal exposure times is given in the following table. These optimal values of exposure time represent, for a density value of 1.0, the exposure time for which the speed of the film is a maximum.

Table of Optimal Exposure Times

Density = 1.0

Emulsion	$t_{opt.}$
Super-Sensitive Motion Picture Pan	1.0 sec
Eastman *40*	1.0 "
Eastman *50*	0.2 "
Eastman Super-Speed	5.0 "
Motion Picture Positive	0.1 "
Eastman Process	0.1 "

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DISCUSSION

MR. MITCHELL: Does the fact that the curves slope upward indicate an advantageous effect in the case of underexposure?

MR. JONES: The answer to that question depends upon what is meant by underexposure. Referring to Fig. 4, it will be seen that the optimal intensity for Super-Sensitive Motion Picture Panchromatic film occurs when log I is equal to $\bar{2}.0$. If the intensity is either less or greater than that value, then the photographic effect for constant exposure is less. It should be remembered, however, that the range of intensity values shown in Fig. 4 is very great, approximately 1 to 1,000,000. In the case of this material, a loss of effective speed, due to failure of the reciprocity law, is encountered only when the intensities are so low that the exposure times must be very great; for instance, as in astronomical work, where the exposure times may be several hours long. On the other hand, this material may be effectively slower where the intensities are so great that the exposure times are extremely short; for instance, 0.0001 second. In the case of the material illustrated in Fig. 7, the reciprocity failure at low intensities is relatively great. The reduction of the intensity level to $^1/_{100}$ of the optimal intensity necessitates increasing the exposure time by a factor of 3.5 in order to attain the same photographic effect as attained for optimal intensity.

MR. KELLOGG: If I understand correctly the difference in the time-exposure product required to obtain a given film density, between the time of exposure for average camera work and the duration of exposure in recording sound on positive film, is quite small; perhaps less than 2 to 1.

MR. JONES: Yes.

MR. KELLOGG: That is of interest to us who are engaged in sound recording. Mr. Blaney, of the RCA Victor Company, has some unpublished figures that indicate distinctly lower gammas with very high-intensity, brief-exposure conditions. Does that check with your curves? Also, does the color of the light have very much to do with it?

MR. JONES: The reciprocity law failure is almost independent of the quality of radiation. With regard to the variation of gamma with the intensity or time of exposure, the values shown in Fig. 3 indicate the relationship. For instance, in the case of density-log E curves, plotted from time-scale sensitometric strips, the values of gamma obtained for wide variations of intensity are relatively small, being 1.20 for $I = 0.0012$ meter-candle, 1.25 for $I = 0.312$, and 1.25 for $I = 80$. On the other hand, if an intensity scale is used, a very marked variation of gamma is obtained for different times of exposure. For instance, with exposure time of 1000 seconds, gamma is 1.60; for an exposure time of 1 second, gamma becomes 1.35; and for an exposure time of 0.01 second, gamma drops to 1.00. The answer to your question, therefore, is a bit complicated since we must specify whether gamma is evaluated in terms of a time scale or an intensity scale.

MR. KELLOGG: Your answer suggests the interesting conclusion that those working with a light-valve of the Western Electric type, which changes the time of exposure, can use the gammas determined by ordinary densitometric measurements with much longer periods of time and lower intensities; whereas those working with a light-valve of the Kerr cell type, which causes changes of intensity, for example, would have to use a different gamma.

MR. JONES: Yes, that is right.

A MOTION PICTURE NEGATIVE OF WIDER USEFULNESS*

P. ARNOLD**

Summary.—*Superpan negative film represents a refinement in film manufacture rather than an invention of startling novelty. The anti-abrasion surface coating protects the emulsion from physical harm, and the anti-halation, gray back-coating, underlying the emulsion, preserves the definition and photographic quality. Possessed of adequately high speed, the emulsion produces superior fine-grain results not common to super-sensitive films. A long gradation scale enhances the fidelity of tonal rendition, and an especially wide latitude in both exposure and development increases the range of pictorial possibilities. A high sensitivity to color, carefully balanced throughout the visible spectrum, permits normal rendering or the attainment of desired color emphasis by the use of filters without demanding serious speed sacrifices.*

The progress and achievements of the motion picture industry have been conditioned and governed to a considerable extent by the picture-taking abilities or possibilities of the negative films that have been provided from time to time by photographic film manufacturers. The tremendous improvements made in negative film materials during the past several years have practically revolutionized the photographic branch of the industry. It may well be expected that, for the present, no radically different types of negative films are in prospect, but that the progress during the next few years will take the form of perfecting and improving the existing types.

The Agfa Ansco Corporation has recently produced a new and improved negative material offering a wider range of usefulness for 35-mm. motion picture work. Several unique improvements have been incorporated in the new material, which has been named *Agfa Superpan Negative.* Its characteristics will be briefly considered, first according to its physical properties, and then according to the emulsion properties of speed, gradation, grain size, and color-sensitivity.

PHYSICAL PROPERTIES OF SUPERPAN NEGATIVE

The photographic characteristics of Superpan negative are related not only to the chemical properties and behavior of the light-sensitive

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

** Agfa Ansco Corp., Binghamton, N. Y.

coating, but also to the physical and mechanical structure of the material. Superpan is complicated in manufacture in order that it may be more simple in use. The base is a clear, almost colorless, nitrocellulose film support specially treated and prepared to prevent the generation and consequent discharge of static electricity. The gray back is an undercoating, not located on the back of the film or diffused through the basic stock, but underlying the emulsion itself. The emulsion is not only double-coated, but triple-coated, and the third coating is of particular merit. (See Fig. 1.)

The Gray-Back Coating.—The gray-back coating is imposed between the first emulsion layer and the cellulose film support at the place where halation principally arises.* This location of the neutral gray layer, with respect to the emulsion coating, effectively prevents halation by inhibiting the reflection of light back into the emulsion from either surface of the film base. The color of the gray backing lightens somewhat during developing, but the layer itself has no chemical effect upon the developing solution or fixing bath, and in turn is not impaired by any unusual condition arising during processing that would not also injure an emulsion coating.

FIG. 1. Magnified cross-section of Superpan: (*a*) anti-abrasion coating; (*b*) first emulsion coating; (*c*) second emulsion coating; (*d*) gray-back coating; (*e*) base.

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* The location of the dark colored anti-halation layer beneath the emulsion rather than on the back of the film is a principle of film manufacture that has been successfully applied by Agfa Ansco for several years to 16-mm. reversible film. In the latter case, however, the chemical properties of the anti-halation layer are much different in order to permit the complete removal or decolorization of the backing during the reversal process. A gray tint obviously would be objectionable in a film intended finally to serve for projection, because it would greatly reduce the screen illumination and lend an undesirable tone to the projected pictures.

The Three Emulsion Coatings.—Superpan negative has two distinct sensitized emulsion coatings differing widely in photographic properties but adjusted to blend their individual characteristics harmoniously into a single photographic result. The third coating (placed over the second emulsion coating, which is also the more sensitive one) consists of an extremely thin layer of clear gelatin. This non-sensitive top coating has very specific properties rigidly controlled in the coating process, but it has no chemical or optical effect upon the emulsion. Its function is to protect the delicate emulsion layer from abrasion caused by contact with other surfaces encountered in normal handling of the film prior to development.

EMULSION PROPERTIES OF SUPERPAN NEGATIVE

The General Sensitivity.—The speed of motion picture negative materials is a matter that has engrossed our attention for the past several years. Today negative films of "super-sensitive" speed have become familiar almost to the complete exclusion of other types, whereas only a few years ago such materials seemed to lie beyond the realm of possibility. Superpan negative belongs to this class of modern high-speed films. It demands no sacrifice in lens opening and no excessive illumination to compensate for a deficiency in sensitiveness.

However, in producing the Superpan negative film, the aim of the manufacturer was not to attain the highest possible speed as a primary requisite—to be accompanied by acceptable pictorial characteristics; but, rather, to combine the finest possible pictorial characteristics of gradation, grain size, and color-sensitivity in a negative film of acceptably high speed. That speed, of necessity, was specified to lie within the range of the super-sensitive film emulsions.

Gradation Characteristics.—The subject of gradation is of utmost importance in making a negative film emulsion because of the great effect that gradation characteristics exert upon the ability of an emulsion to perform the sort of work for which it is intended. Gradation is also important from the manufacturer's point of view, because of the technical difficulties that must be surmounted in order to produce a negative film that will adequately fulfill the requirements of not only one photographic condition, but of a wide range of variable photographic conditions, and to produce satisfactory results throughout that range.

The gradation of a photographic emulsion may be defined as its density response to varying light intensity. By means of the familiar photometric curve, the gradation characteristics of Superpan negative may be viewed in its various relationships (Figs. 2 and 3). Of particular note is the especially long scale of gradation shown by the extended straight-line portion of the curve. Naturally, a material with such a gradation range is adaptable to a great variety of lighting conditions and to a wide range of light intensity. The long scale provides the means for faithful tonal reproduction throughout extremes of illumination.

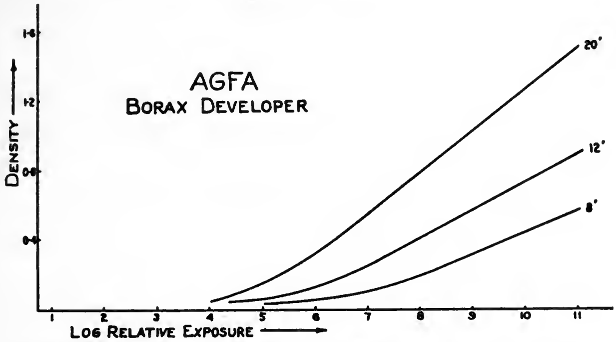

FIG. 2. Characteristic curve of Superpan: Agfa borax developer.

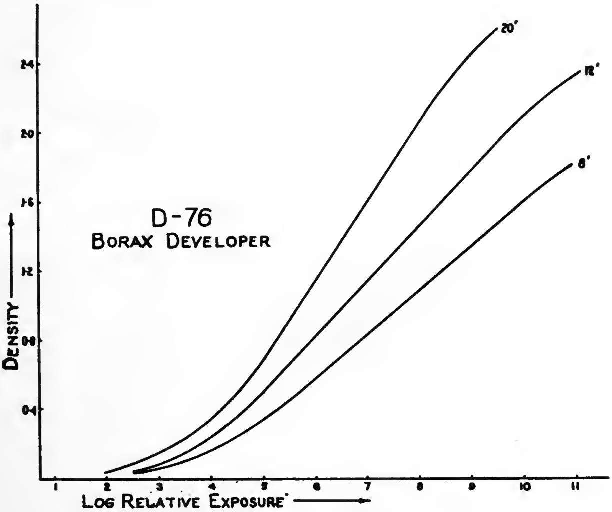

FIG. 3. Characteristic curve of Superpan: *D-76* developer.

A second advantage is the increase in exposure latitude afforded by the long scale; but this possibility may not be, to the skilled cameraman, of so much practical importance as the improvement in rendering fine details and the modulation in the highlights of a subject afforded by the extended upper range of the linear portion of the curve, where the highlights are recorded. Extension of the straight-line portion of the curve facilitates the faithful registration of densities over a wider range of subjects and light intensities than would be possible without tonal distortion with a film of shorter scale.

Development Characteristics.—The development requirements of Superpan negative film are not exclusive or restricted, for any good developing formula may be used, with the type of results common to that developer. The negative responds to the developer more or less in the manner typical of highly sensitive, silver halide emulsions. However, the time-gamma curve and the threshold response to developing time offer interesting possibilities (Fig. 4).

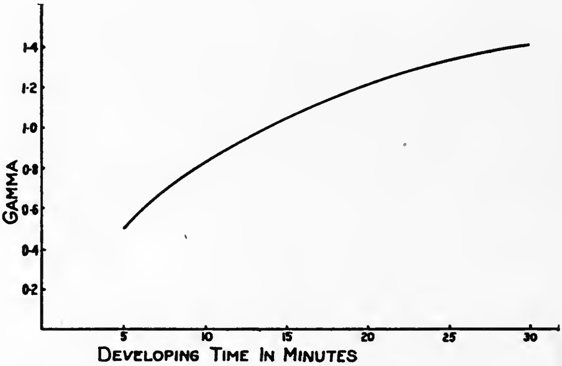

FIG. 4. Relation of gamma of Superpan to developing time: Agfa borax developer.

The threshold of sensitivity, or the toe of the photometric curve, advances with the developing time, thus increasing the effective speed of the emulsion by over-development. The increase of gamma with the time of development may be plotted as a smooth curve. Any gamma from 0.5 to 1.4 may be attained, a range that is particularly valuable when the film is used for background shots. In such work the subject is customarily lighted more brilliantly to compensate for the loss of definition through diffusion.

Fine-Grain Properties.—The matter of grain size has become increasingly important in motion picture technic. Applied to a photographic emulsion, the term "grain" refers to the lack of continuity within given densities in an image projected to many times its normal size, an effect produced by the grouping of silver particles about developing nuclei in the film. Fundamentally, the graininess apparent in motion picture projection is a product of the negative. Grain begins in the negative. Subsequent printing and duplicating processes tend to multiply the effect rather than merely to perpetuate it. Any considerable correction for graininess in motion picture projection, therefore, must begin with the original negative.

Superpan negative film provides the professional motion picture industry with a very fine-grained, super-sensitive type of film.* It provides, in a high-speed negative, a fine-grain quality that has been regarded in the past as incompatible with extremely rapid emulsions. It is the successful culmination of a long period of experimentation and research and the development of an entirely new technic in photographic emulsion making.

Color-Sensitivity.—Apart from its great importance in natural color photography, the subject of color-sensitivity of a new motion picture negative film is of particular interest in black-and-white reproduction. The mastery of panchromatic technic still engages the interest and efforts of cameramen, make-up experts, and others engaged in motion picture photography. It can not yet be regarded as a finished art, for the pictorial possibilities of modern panchromatic emulsions have not yet been completely explored

Basically, the color response of Superpan negative film is far removed from the color-sensitivity pattern of the older super-sensitive panchromatic film that preceded it—the film with the panchromatic sensitivity that made the word "super-sensitive" almost synonymous with "super-red-sensitive." The limitations and technical difficulties imposed by highly red-sensitive emulsions were tolerated because of the tremendous speed advantages those emulsions possessed in comparison with earlier types of negative film. But they did usher in

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* It is well known that in the reversal process fine-grain results are attained that are superior to those attainable with negative films. This decrease in grain size is effected by the reversal process itself, which removes the more coarsely grained image and leaves a positive image composed only of the fine-grain constituents of the original emulsion. However, the reversal process has not been extensively applied to professional motion pictures. Experiments are under way with 35-mm. Agfa Reversible Superpan film that offer promise of successful application to professional motion picture photography where extremely fine-grain results should be attained.

a new era in sensitization by stimulating manufacturers in the search for and discovery of new sensitizing agents (Fig. 5).

The term "panchromatic" has ceased to be a definition for a single type of emulsion. It is now possible to make a silver halide emulsion sensitive to almost any given band of wavelengths, within the visible spectrum and beyond, into the infra-red. It is also possible to produce a maximum, or peak, of sensitivity at practically any desired region within that range.* The task of the film manufacturer has become one of synthesis rather than one of discovery. The emulsion chemist today has at his command an extensive array of specific sensitizers which he can combine in innumerable degrees and proportions. Almost any desired pattern of sensitivity can be produced.

Into a market already supplied with two popular types of high-speed panchromatic emulsions, similar in range of sensitivity but differing in their maximum response, no hesitancy is felt in introducing a third type with its own individual sensitivity characteristics. The spectral sensitivity of Superpan negative was not designed to be identical to the color response of the human eye under a specific light condition. It is, however, quite possible to arrange illumination under which Superpan would exhibit exactly the same color response as the retina. Realizing that the faithfulness of black-and-white rendition is largely determined by the quality of illumination, the endeavor has been to produce a combination of specific sensitivities that would afford the widest possible latitude in color rendition to complement its wide latitude in exposure and development, and to produce a negative material of maximum usefulness.

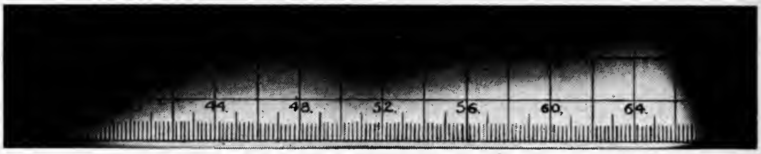

FIG. 5. Spectral sensitivity of Superpan.

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* The ability of the modern emulsion maker to sensitize at will is illustrated by the recent development of a new Agfa 16-mm. reversible film. The requirements of the amateur cinematographer for outdoor work during the spring and summer months are most adequately met by a film of high speed and high sensitivity to yellow and green colors without red sensitization. Fine-grain Plenachrome Reversible film has been given such a high sensitivity to yellow and green that it gives very good correction for the colors most predominant in summer landscapes even without the use of filters.

RECENT OPTICAL IMPROVEMENTS IN SOUND-FILM RECORDING EQUIPMENT*

W. HERRIOTT** AND L. V. FOSTER†

Summary.—*Improvements in sound-film recording equipment relating to increased high-frequency response and volume range are discussed. New low power exciter lamps and new types of recording objective lenses have been developed. A lamp adjustment optical system and split-beam monitoring equipment are described.*

Improvements in Western Electric sound-film recording equipment have recently been effected which offer greater convenience of operation and superior frequency response characteristic and volume range. These improvements relate to the development of new exciter lamps, a lamp adjustment optical system, split-beam monitoring equipment, and two new types of recording objective lenses.

The maximum area of the light-valve aperture which it is required to illuminate is 0.250 inch by 0.002 inch. The condensing lens has a magnification of approximate unity, and it is obvious that only a small area of the filament is effective in illuminating the light-valve aperture.

In Fig. 1 are shown five types of exciter lamps that have been employed either in commercial or experimental light-valve recording. An effort has been made to reduce the high power requirement of lamps of the early types, and it has been found possible to employ lamps of much lower current rating, making use of filaments of the coiled type rather than of the ribbon type, which impose an abnormal drain upon the battery supply, and a resulting high cost for power. The 9.5-ampere, 85-watt coiled filament lamp shown fourth from the left in Fig. 1 is used in studio recording, but the 4.0-ampere, 8.5-volt coiled filament lamp is now being introduced into commercial practice. Satisfactory recordings have been made with the 2-ampere lamp shown at the extreme left. The reduction in

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

** Bell Telephone Laboratories, New York, N. Y.

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the current demand accomplished in successive developments has resulted largely from redesigning the filament from the standpoint of the tungsten area required to illuminate properly the image of the light-valve formed by the objective lens at the film plane.

The length of the filament is established largely by lens and light-valve aperture considerations, from the standpoint of the minimum loss of exposure that can be tolerated at the sides of the sound track. The influences of end-cooling and of partial pencils transmitted by the optical system are two of the factors involved.

The height of the tungsten area is established largely by the requirement of ease of adjusting the exciting lamp with reference to its image at the aperture of the light-valve. If the coil diameter or the filament height is too small the adjustment of the height of the lamp and its orientation become critical.

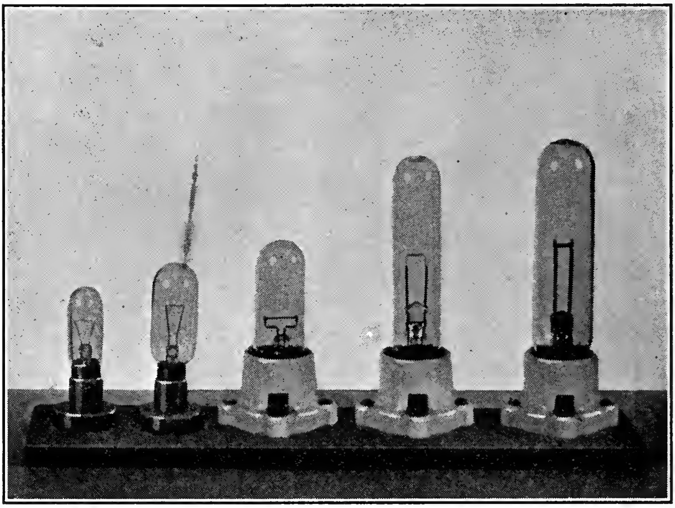


FIG. 1. Five types of exciter lamps used for commercial or experimental light-valve recording.

Excessive filament area is useless, especially in the ribbon filament type of lamp adjusted to the focal position. Coiled filament lamps are employed in an out-of-focus position, being moved toward the condensing lens a short distance, just sufficient to avoid imaging the coil structure upon the unmodulated sound track.

Fig. 2 shows a series of approximately full-sized images obtained with the 4-ampere, coiled filament lamp for a number of different conditions of focus, showing that a reasonably uniform exposure is possible over the area of the light-valve aperture. No loss of image brightness results from using the exciter lamp in an out-of-focus position if the filament is of the correct size, although a small decrease of efficiency due to the smallness of the filament is easily compensated for by operating the lamp at a slightly higher color-temperature.

In Fig. 3 are shown microdensitometric traces of unmodulated sound tracks made with the lamp in several positions. The coil structure is very apparent in the focal position, but becomes obscure to a satisfactory degree as shown in the lower curves of Fig. 3. Visual examination of the sound track exposed with the lamp properly adjusted shows no trace of striation due to the coil structure.

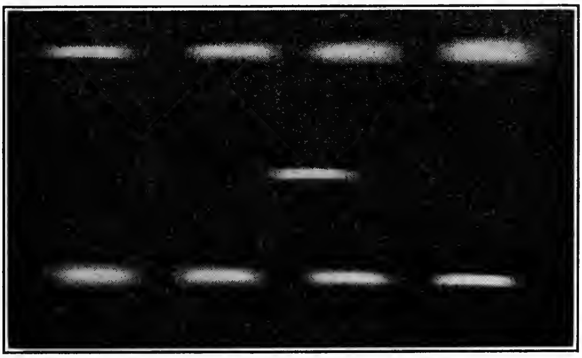


FIG. 2. A series of approximately full-sized images obtained with a 4-ampere, coiled filament lamp for different conditions of focus.

Small coiled filament lamps may be used if screws are provided for adjusting the lamp mounting and if use is made of a simple optical device for determining the correct position of the lamp and permitting the accurate replacement and adjustment of new lamps in a simple manner. This "lamp adjustment optical system" is shown in Fig. 4. It consists of an objective lens at the rear of the exciter lamp for imaging the filament upon a ground-glass screen on which cross-lines are etched. The exciter lamp with the small coiled filament is first adjusted to record satisfactorily in the desired out-of-focus position. The objective lens of the lamp adjustment system is adjusted to image the lamp filament sharply upon the ground-glass screen. The crossed-line screen is then adjusted so that the horizontal line bisects the image of the coil axially and the vertical line bisects the image longitudinally. The device has proved very convenient for replacing and inspecting low-power recording lamps.

Improvements in monitoring systems have been effected by removing the photoelectric cell from its position behind the film, where it was subject to mechanical vibration and where it could be acted upon only by light that was transmitted by the raw-stock film. Both these objections served to impair the sound quality by introducing noise. A system of split-beam monitoring has been developed in which a portion of the modulated light passed by the light-valve is intercepted and deflected to the photoelectric cell. The lamp, condenser lens, and the light-valve apertures can be so designed that a large proportion of the modulated light will be available for the purpose. It is quite possible to utilize as much light for the monitoring as is required for exposing the sound-film record, or even more.

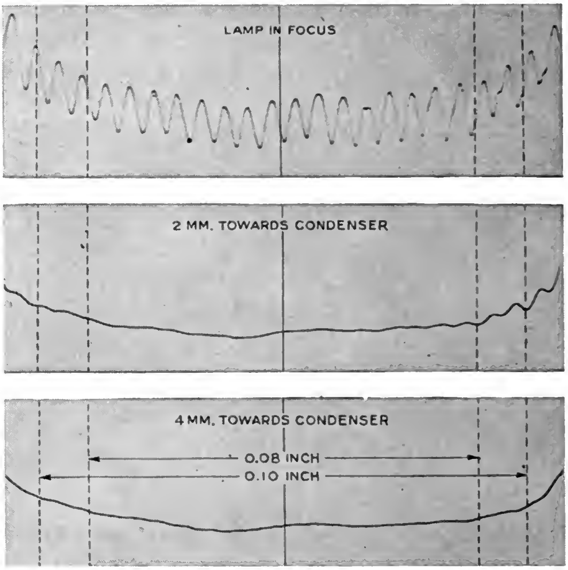


FIG. 3. Microdensitometric traces of unmodulated sound tracks made with the recording lamp in several positions.

Fig. 5 illustrates one form of the split-beam monitoring system, in which the condensing lens is purposely over-apertured in order to transmit through the valve a beam of modulated light having a large dispersive angle. Only the central portion of the beam reaches the objective lens (shown on the right), the remainder being reflected by a concave annular mirror to a small prism having a collective lens cemented to its surface of emergence. The light rays are therefore collimated, and directed toward the photoelectric cell shown in dotted outline on the schematic drawing. Other devices essentially similar to this have been adopted and have given satisfaction in service.

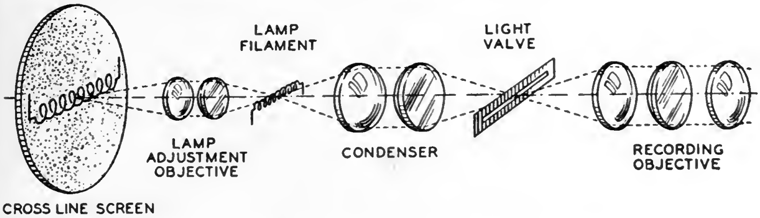


FIG. 4. The lamp adjustment optical system.

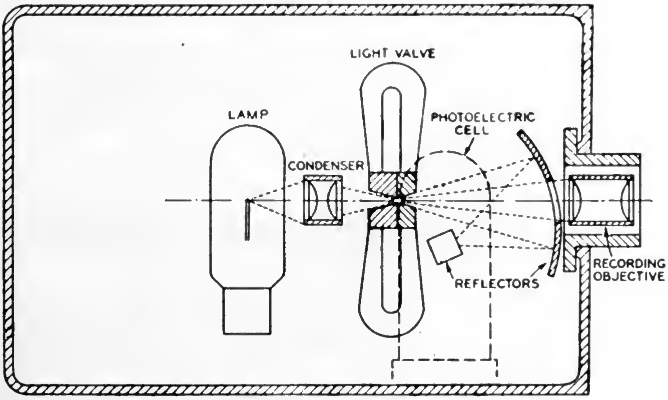
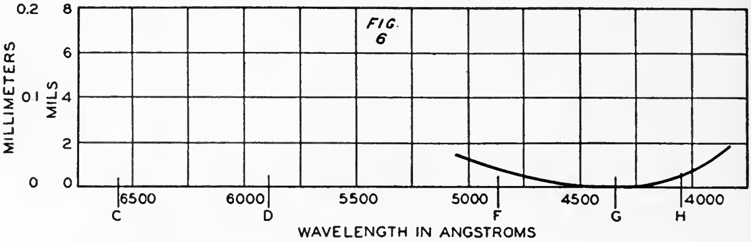


FIG. 5. One form of the split-beam monitoring system.

The objective lens employed in the sound-film recorder must accurately image the aperture formed by the light-valve ribbons upon the layer of emulsion on the photographic film. The use of the tungsten lamp as a light source imposes an additional requirement, that the relative aperture of the lens must be fairly great in order to attain an adequate exposure with a reasonable lamp life. This condition applies particularly when positive, or blue-sensitive, film is used as the recording medium.



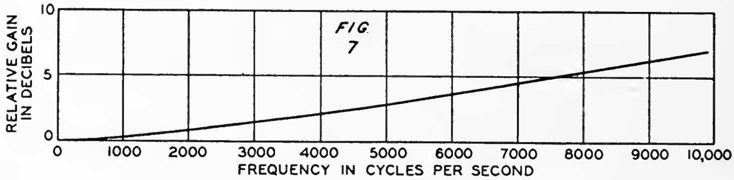


FIG. 6. Chromatic correction of lens to match color-sensitivity of positive film.

FIG. 7. The improvement achieved in high-frequency response with the objective lens corrected for chromatic aberration as in Fig. 6.

The height of the light-valve aperture varies from 0.000 inch to 0.002 inch for full modulation. The average, or unmodulated, spacing is 0.001 inch, for systems not employing noise-reduction methods, and approximately 0.0003 inch when noise-reduction methods are applied. In the latter case, the modulation ranges about this small spacing for low levels of applied signal. To those unfamiliar with the difficulties of imaging small objects, the problem may not appear to be particularly troublesome; but the lens designer realizes that he

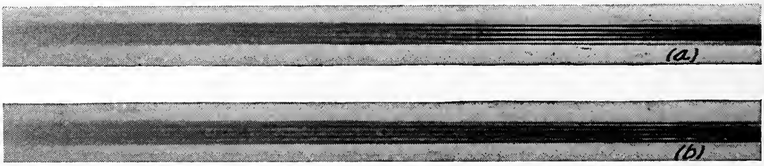
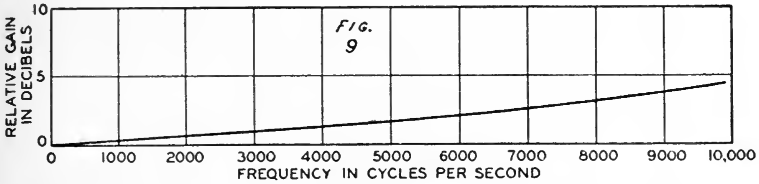
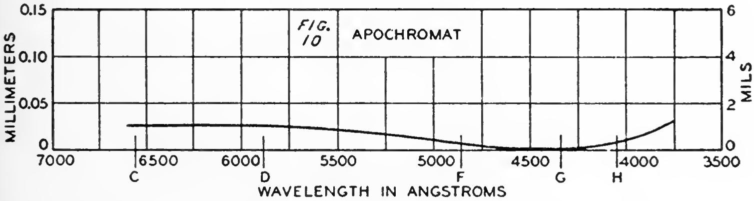


FIG. 8. Photographs of a ruled grating made with (*a*) a new lens corrected for chromatic aberration as in Fig. 6, and (*b*) an old lens.

is definitely limited in attaining accurate images of the light-valve aperture at every instant of its cycle of operation.

In the first place, as noted before, the requisite relative aperture of the lens is fairly large, which condition demands careful correction of spherical and chromatic aberration, in order that the circles of confusion may be reduced to a minimum size. In addition, the image of such a small aperture can not be perfect because of the diffraction that occurs when light passes through very small openings. That difficulty is, of course, beyond the control of the lens designer, and his only recourse is to choose the largest practicable aperture for the lens system compatible with the adequate correction of spherical and chromatic aberration.





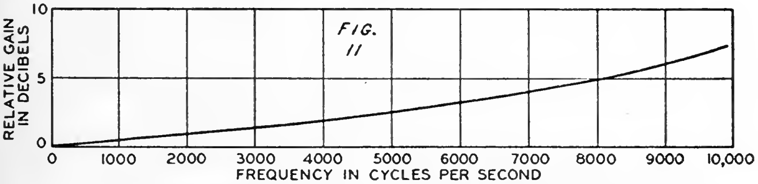


FIG. 9. Improvement in frequency response achieved with a lens of shorter focal length developed for use in small modulator units employing only positive film.

FIG. 10. Correction of apochromatic lens for use with panchromatic film.

FIG. 11. Improvement in frequency response achieved with corrected apochromatic lens over the old achromatic objectives used with panchromatic film in portable recorders.

Practically all sound records are made on either positive or panchromatic film. Early objective lenses used for recording sound were corrected for chromatic aberration in the classical manner, in which the yellow and the blue images are made to coincide. Images corresponding to other colors do not lie in the same plane as the yellow and the blue images, but lie some nearer the lens and some farther from it. Positive film, however, is sensitive principally to a band of spectral radiations of somewhat shorter wavelength than that of the blue selected for chromatic correction of the early recording lenses. It seemed advisable, therefore, to experiment with a lens corrected specifically for the limited spectral band to which the film is most sensitive in order to determine whether the improvement to be expected on theoretical grounds might be realized in practice. A lens was made with the chromatic correction shown in Fig. 6, wherein the image distances for 4040 and 4860 Å are equal. The result was a decided improvement in high-frequency response (Fig. 7).

Photographs made in the focal region with both lenses are shown in Fig. 8. These are photographs of a ruled grating on a plate inclined at a very small angle to the axis of the lens in such a manner that part of the plate is ahead of the true focal plane and part of the plate is behind it: (*a*) was photographed with the new lens; (*b*) with an old lens. A similar lens of shorter focal length has been developed for small modulator units employing only positive film. The improvement in the frequency response characteristic of this lens is shown in Fig. 9.

When the picture and the sound track are recorded on the same film, as in the newsreel type of equipment, the film must be panchromatic or orthochromatic, in view of the picture requirements. This necessitates, in the case of panchromatic film, recording a sound track on an emulsion that is sensitive to the entire visible spectrum, instead of to a relatively narrow band in the blue. The apochromatic lens provides the closest possible approach to the ideal for panchromatic film, so a lens of that character was designed with a chromatic correction such as shown in Fig. 10. The improvement in response with the apochromatic over the old achromatic objective with panchromatic film is shown in Fig. 11.

REFERENCE

[1] HERRIOTT, W.: "A Method of Measuring Axial Chromatic Aberration of an Objective Lens," *J. Opt. Soc. Amer.*, **23** (April, 1933), No. 4, p. 123. Also *J. Soc. Mot. Pict. Eng.*, **XX** (April, 1933), No. 4, p. 323.

PIONEERING INVENTIONS BY AN AMATEUR*

FREDERIC E. IVES**

***Summary.**—A short account of the early scientific interests of the author, an honorary member of the Society of Motion Picture Engineers and one of the pioneers in color photography, is followed by a brief description of his important accomplishments and patents.*

The well-balanced and conventionally educated man can do many things well, and usually makes a useful citizen. Some men, by freak of heredity, are conspicuously better equipped for special accomplishment. Thus we find that some are instinctively politicians, merchants, mechanics, poets, artists, fiction writers, *etc.*, and in order to distinguish themselves, must work assiduously along the line of their special talents. If they attempted to excel in several fields at once, life would be too short for sustained achievement in any one field.

My own case is one of predominant eye-mindedness as distinguished from ear-mindedness. As a child, I could never learn anything word for word by oral teaching, but would repeat the thought in my own language. On the other hand, I could so fix the image of a printed or written paragraph in my mind as to be able to recall and read it off as though it were in front of my eyes. My thoughts were in ideas and images, and not in sounds, and it would have been a hopeless task to undertake to make a musician out of me. But I could visualize and see the relationship of material things as though they were before my eyes. About as soon as I commenced to talk, I could draw pictures, and when, at the age of seven, I made a fairly correct detailed drawing of a steam locomotive from memory, my father tore it up and scolded me for so wasting my time. He said I was big enough to begin doing useful work on the farm, and proceeded to teach me how to spread fertilizer. The fact is that my characteristic instincts and talents were inherited from my mother, while an incessant effort to do useful work was characteristic of my father.

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*Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

** Philadelphia, Pa.

EARLY INTEREST IN COLOR IN NATURE

One of my earliest and most impressive dreams was that of seeing the earth and the skies as one glorious pageant of color, since when I have always been very color-conscious. I might have become an artist but for the fact that I did not possess the poetic imagination, and was drilled to think that everything must have practical value.

My father, on account of ill health, gave up his farm and became a country village storekeeper when I was ten years of age, and I found my first great interest in life in reading an old copy of a schoolbook on natural philosophy, which had somehow gotten into the stock of the store. Then I became possessed of a one-inch focus, double convex lens, and developed an interest in optics that became almost a passion. My father thought I was wasting my time and sent me to live with a farmer relative. My schooling, over brief periods and in different places, never carried me through primary arithmetic. Professor Michelson once asked me how I ever came to do the work I did in applied optics without the aid of mathematics. I reminded him of Robert Louis Stevenson's explanation of his father's similar activity as being due to a "sentiment" for optics. The fact was that I could so clearly visualize the path of light through a refracting medium that a little trial-and-error experimentation brought sufficiently accurate results for my purposes. Edison's method of "calculating" the cubic capacity of a lamp bulb, for example, was to fill it with water and pour the water into a graduate.

FIRST INTEREST IN PHOTOGRAPHY

Just prior to his death, at the age of 34, my father solemnly advised me to "stay on the farm." Instead, I became a clerk in a country general store and an amateur printer. Before I was quite 14 years of age, I apprenticed myself in the printing office of the Litchfield, Connecticut, *Enquirer*, and was a full-fledged journeyman printer before I was 17.

While still a printer's apprentice, I made my first photographs, by the old wet-plate process, with a camera that I constructed from a cigar-box and a spectacle lens, using some of my grandmother's kitchen crockery for chemical containers. Attempting to teach myself wood engraving, I dreamed of making printing plates by a photographic process.

WORK AT PHOTOGRAPHIC LABORATORY, CORNELL UNIVERSITY

At the age of 19, I applied for the position of photographer in the photographic laboratory at Cornell University. There I invented and demonstrated photo-engraving processes, and made the first successful commercial use of color-sensitive photographic plates. The discovery by Vogel, in 1873, that some English collodion dry plates that had been stained with corallin dye to prevent halation, were sensitive to the blue-green spectral rays, a fact then regarded as only of scientific interest, spurred me to experiments that resulted in a commercially practical and useful process with wet collodion silver bromide plates bathed in an alcoholic solution of blue-myrtle chlorophyll, washed, exposed, and developed without drying, and used with a glass tank filled with potassium bichromate solution as a color screen.

This process provided sensitivity throughout the spectrum, and was fast enough for landscape and commercial photography with sunlight illumination. (IVES, F. E.: "On Photographing Color," *Phil. Phot.*, **16** (Dec., 1879), p. 365.)

Having proceeded so far, I prophesied to a group of students that within 10 years photographic processes would supersede wood engraving and chromo-lithography. I made too little allowance for the conservatism of established custom and opinion, but I had the true vision.

My first color-separation negatives for three-color photography and three-color halftone plates were made on the chlorophyll plates and with successive exposures with red, green, and blue filters in the form of liquid solutions in the glass tank.

MANUFACTURE OF FIRST HALFTONE PLATES

In 1881 I was the first to manufacture cross-line halftone process plates to order for printers and publishers, and made the first three-color halftone process prints. That was the practical beginning of a great revolution in the printing and publishing business, but was slow to develop extended use because its full success in large-scale production as we know it today depended upon adapting printing machinery, inks, ink distribution, paper, *etc.*, to meet the special requirements of the processes.

The three-color halftone specimen made at that time was a reproduction of a chromolithograph and had all the characteristics of present-day practice, but it was realized that the time and conditions were not then ripe for its commercial exploitation. I have none of the prints left, but one that had the date of printing endorsed on its back was deposited in the print room of the Smithsonian Institution some years ago. Printing press, ink and paper manufacturers, and pressmen resented the necessity for the changes required to do justice to the processes and were slow to adopt them.

DEMONSTRATION OF ADDITIVE TRICOLOR PHOTOGRAPHY

While that was going on, I made the first convincing demonstration of additive process trichromatic photography at the Franklin Institute in February, 1888—a reproduction by triple lime light lantern projection of an autumn landscape, the negatives for which I had made in 1880 on my chlorophyll plates. It was heralded in the newspapers of that day as a perfectly convincing demonstration of the reproduction of natural colors by a photographic process. A diagram of the lantern is shown in Fig. 1.

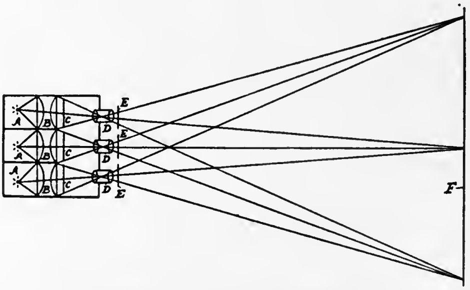

FIG. 1. Triple lime light projector for three-color additive process.

A travel lecture on Yellowstone Park was given by W. N. Jennings at the Franklin Institute on December 18, 1891, illustrated by my subtractive process, natural color lantern slides, made by superposed dyed gelatin photo relief prints.

These prints were made by coating celluloid sheets with bichromated gelatin and exposing them to sunlight partially through the celluloid film held against the negatives (a single 3-inch glass negative made in the camera described in my U. S. Pat. 475,084 was then used). The three transparent relief images were dyed, respectively, minus red (cyan blue), minus green (carmine or eosine), and minus blue (yellow), and superposed in register between glasses with Canada Balsam cement to eradicate refracting effects of the rather high relief. The process was subsequently improved by using a coating of silver bromide gelatin emulsion, and still later by incorporating a soluble yellow dye to limit the penetration of light and to make the reliefs so tenuous that, when varnished, they did not have to be sealed with balsam. The results, on projection, were the same in either case.

Very favorable accounts of the Franklin Institute lecture were published in the Philadelphia *Inquirer*, Dec. 19, 1891, and many other papers. Some of the same lantern slides were shown at the Royal Institute in London, May 17, 1892, and described in the London *Daily Graphic* of May 18, 1892.

Following the lecture at the Franklin Institute, the announcement was made of my first camera producing three geometrically equal images on one plate at one exposure. This camera was used in Yellowstone Park in 1890, and a patent for it issued May 17, 1892. The same optical system was used in my first form of photochromoscope, with three images on a single glass plate (Fig. 2).

FIG. 2. Photochromoscope viewing device.

The following inventions appeared from time to time:

The stereoscopic photochromoscope (and camera) with colored glass transparent reflectors and folding chromograms (U. S. Pat. 531,040, issued Dec. 18, 1894).

Transparent refracting line-screen with particolored light source and juxtaposed line color records (U. S. Pat. 666,424, issued Jan. 22, 1901), a significant fore-runner of the Kodacolor amateur motion picture process, and recently adapted by Dr. Herbert Ives as a convenient pocket-sized device for viewing Kodacolor "stills."

Trichromatic plate pack with superficial dye screen coating on face of emulsion—an element in all bipacks and tripacks (U. S. Pat. 927,144, issued July 6, 1909).

Production of tenuous photographic relief prints, in bichromated gelatin by incorporating a non-actinic dye to limit penetration of the light in printing followed by dye coloring (U. S. Pat. 980,962, issued Jan. 10, 1911).

Production of microscopically sharp dye prints by imbibition printing (Pat. applications March 9, 1912, and July 12, 1912; U. S. Pats. 1,106,816, Aug. 11, 1914, and 1,121,187, Dec. 15, 1914).

A light-splitting element adapted to produce two geometrically alike but different color-selection images from one point of view upon one plane in a motion picture camera (Pat. application July 26, 1913; U. S. Pat. 1,169,161, issued Jan. 25, 1916).

Dichroic light-splitting reflector in color cameras (Pat. application March 11, 1914; U. S. Pat. 1,238,775, Sept. 4, 1917).

In February, 1914, first two-color motion pictures produced in a single coating of ordinary motion picture positive film, one image made from an insoluble color and the other from a soluble dyestuff (Pat. application July 1, 1914; U. S. Pats. 1,170,540, Feb. 8, 1916; 1,278,667; 1,278,668; 1,306,616; 1,306,904).

Tenuous gelatin relief prints by "gaslight" printing, development, bleach-selective hardening, and warm water development (Pat. application March 13, 1915; U. S. Pat. 1,186,000, issued June 6, 1916).

Two-color cinematograph prints made by cementing two differently colored strips of images together (Pat. application, Feb. 4, 1916; U. S. Pat. 1,248,864, Dec. 4, 1917).

Successful motion picture negatives made with bipack films (Pat. 1,320,760, issued Nov. 4, 1919).

Dichroic red-to-yellow image, applied in perfected cine and polychrome print processes (Pat. 1,376,940 issued May 3, 1921).

Light-splitting attachment for cinematograph camera permitting the use of large aperture lenses (Pat. application Sept. 13, 1919; U. S. Pat. 1,383,543, July 5, 1921).

Dye toning of bleached silver images bleached with ferricyanide-chromic acid (several formulas; no patent applied for).

Perfected polychrome process for prints for the album or framing. *J. Opt. Soc. of Amer.*, **22** (April, 1932), No. 4.

A list of other inventions include the following:

The now universally used cross-line screen and diaphragm control halftone process.

A practical suggestion for transmission of photographic images by wire.

Glass-sealed gelatin and collodion color-screens (ray filters).

Photogravure printing plates.

Parallax stereogram and changing pictures.

Modern type of short-tube, single-objective binocular microscope.

Glass-sealed diffraction grating replicas.

Diffraction photochromoscope.

SOCIETY ANNOUNCEMENTS

NOMINATIONS OF OFFICERS FOR 1935

At the last meeting of the Board of Governors the following were nominated for office in the Society for the year 1935:

H. G. TASKER, *President*
E. HUSE, *Executive Vice-President*
J. I. CRABTREE, *Editorial Vice-President*
W. C. KUNZMANN, *Convention Vice-President*
J. H. KURLANDER, *Secretary*
T. E. SHEA, *Treasurer*
M. C. BATSEL, *Governor*
S. K. WOLF, *Governor*
H. RUBIN, *Governor*
T. RAMSAYE, *Governor*

Ballots for voting on the nominations will be mailed to the Honorary, Fellow, and Active members of the Society about September 15th. Of the four nominees for Governor, two are to be elected. The President, Executive Vice-President, Secretary, and Treasurer hold office for one year; the other Vice-Presidents and the Governors, for two years. Ballots will be counted, and the results announced, at the Fall, 1934, Convention, on October 29th, at the Hotel Pennsylvania, New York, N. Y. The successful candidates will assume office on January 1, 1935.

Members of the Board of Governors whose terms do not expire until January 1, 1936, exclusive of the Chairmen of Local Sections, whose terms expire January 1, 1935, are as follows:

L. A. JONES, *Engineering Vice-President*
O. M. GLUNT, *Financial Vice-President*
A. S. DICKINSON, *Governor*
H. GRIFFIN, *Governor*
W. B. RAYTON, *Governor*

SECTIONAL COMMITTEE ON STANDARDIZATION

In the past, standards formulated and proposed by the Society of Motion Picture Engineers have cleared through the American Standards Association, assuming the status of national standards through what was known as the "proprietary sponsorship plan."

The Society has recently sponsored a proposal to the A. S. A. that the project be changed from the proprietary plan to the administrative sectional committee method, under which a committee would be formed consisting of representatives of large and important groups of the industry interested in standardization, and would act to nationalize proposed standards after they have cleared through the S. M. P. E. as the sponsor. Discussions concerning the formation of the sectional committee are now going forward.

FALL CONVENTION, OCTOBER 29TH TO NOVEMBER 1ST, INCL., HOTEL PENNSYLVANIA, NEW YORK, N. Y.

Details concerning the approaching Convention will be mailed to the membership of the Society in the near future. Attention is called to the fact that the date of the Convention was erroneously given in the August issue of the JOURNAL, and that the correct dates are as here stated.

The Convention will begin Monday morning, Oct. 29th, with Society business and reports of Committees, followed by an informal get-together luncheon at noon, at which the members will be addressed by several prominent speakers.

All technical sessions and film programs will be held in the *Salle Moderne*, on the eighteenth floor of the Hotel, where will also be located the registration headquarters, apparatus exhibit, and other activities. Plans are being made to include several interesting lectures on topics of current interest by prominent engineers of the industry, as well as tours of inspection to important studios, laboratories, or manufactories in the New York district.

The S. M. P. E. Semi-Annual Banquet will be held on the evening of Wednesday, Oct. 31st: an evening of dancing and entertainment. The exhibit of newly developed motion picture apparatus will be held on the Convention floor of the Hotel, and is open to all manufacturers or distributors of equipment. Arrangements for entering the exhibit can be made by addressing the General Office of the Society at the Hotel Pennsylvania, New York, N. Y.

Excellent accommodations are assured by the Hotel management, and minimum rates are guaranteed to delegates to the Convention. Reservations should be made as early as possible in order to be assured of satisfactory accommodations.

A detailed program of the Convention will be mailed to the members in the near future. An interesting technical program is being arranged by the Papers Committee, under the direction of Mr. J. O. Baker, *Chairman*, and Mr. J. I. Crabtree, *Editorial Vice-President*. Mr. W. C. Kunzmann is attending to the various facilities of the Convention, assisted by Mr. H. Griffin, in charge of projection, Mr. J. Frank, Jr., in charge of the Apparatus Exhibit, and Mrs. O. M. Glunt, *Hostess*.

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Published monthly at Easton, Pa., by the Society of Motion Picture Engineers
Publication Office, 20th & Northampton Sts., Easton, Pa.
General and Editorial Office, Hotel Pennsylvania, New York, N. Y.

Entered as second class matter January 15, 1930, at the Post Office at Easton, Pa., under the Act of March 3, 1879. Copyrighted, 1934, by the Society of Motion Picture Engineers, Inc.

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PIEZOELECTRIC FREQUENCY CONTROL*

F. R. LACK**

Summary.—*This paper discusses the use made of the piezoelectric effect in designing sub-standard timekeepers and frequency generators. The nature of the piezoelectric effect is outlined and mention is made of the various classes of crystals in which it is found. The technic of setting up, electrically, various types of mechanical vibrations in piezoelectric crystals is described together with methods of obtaining very high frequencies. Other applications of the piezoelectric effect, such as to loud speakers, submarine signaling, etc., are briefly reviewed.*

With the advent of high-frequency carrier communication, both wire and radio, the development and wide distribution of electric clocks, and the increasing demand for synchronizing motion at a distance, has come a need for extending and refining our methods of measuring time and frequency. The world standard of time is astronomical, and depends upon the period of rotation of the earth. Sub-standard chronometers of various forms are used to divide the period of rotation into usable hours, minutes, and seconds, and are, for the most part, mechanical vibrating or oscillating systems having very constant periods of oscillation. Every system is equipped with some means of integrating or counting the number of oscillations in a 24-hour period.

Probably the best-known mechanical oscillator is the pendulum, the classical timekeeper. The period of oscillation of a pendulum depends, to a first approximation, only upon the force of gravity and the length of the pendulum. Because the gravitational force is constant and the length of the pendulum can be maintained constant to a high degree of precision, a pendulum constitutes a very accurate timekeeper. Such oscillators may be, of course, frequency generators as well as timekeepers. Most pendulum systems are so arranged as to be able to produce one or more electrical impulses per second. Although second impulses may be used to synchronize other clocks, when such a generator is used to produce higher fre-

---

* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

** Bell Telephone Laboratories, New York, N. Y.

quencies, considerable complication of apparatus ensues. Hence, when the demand arose for producing accurately known audio frequencies, the pendulum was replaced by magnetically or electrostatically excited tuning-forks.

The period of oscillation of a tuning-fork depends upon its dimensions and the density and mechanical elasticity of the material of which it is made. For frequency stability, therefore, those properties must not vary. The metal used for the forks must be carefully aged, and some form of temperature control provided in order to attain adequate precision. Forks can be constructed for frequencies up to 10 kc. and beyond, although above 10 kc. the dimensions of the fork become very small.

To check the frequency of such a system it is customary to count the number of cycles in an interval of standard time. In order to do so, the generated frequency is stepped down electrically in exact submultiples to a value suitable for operating a synchronous-motor clock. The clock is compared with time signals based upon astronomical observations. A tuning-fork system, carefully designed, can be made as good a timekeeper as the best pendulum.

With the advent of carrier telephony and radio, a demand arose for generators capable of producing currents of accurately known frequencies much greater than those readily obtainable with forks. To fulfill the demand, oscillators employing piezoelectric crystals have been used with considerable success. Such generators differ from the pendulum and the fork only in the mechanism used to sustain the oscillation. Instead of employing mechanical or magnetic forces for driving the fork, the piezoelectric effect is utilized. By "piezoelectric effect" is meant the property of certain crystals by virtue of which a mechanical stress produces an electrical charge, and *vice versa*. The effect was first discovered in crystalline quartz by the Curies[1] in 1880, in connection with their initial studies of radium. Experimental and theoretical extensions by Lippmann, Pockels, Voigt,[2] and others established a definite set of laws relating the effect to the type of crystal structure and the elasticity equations of the material.

From those laws we learn that all crystals that do not possess a center of symmetry can be expected to exhibit the piezoelectric effect. Of the 32 classes of crystal structure, 20 fall into such a group, and hence should be piezoelectric. Only 10 per cent of the known minerals, however, belong to the asymmetric classes. Most of them are unsuitable for precision oscillators, either because they are available only in minute specimens, or because they possess unsuitable mechanical properties.

There are a few, however, that are useful. By far the most important at the present time is quartz (Fig. 1), which is readily obtainable in large quantities at reasonable cost, and has excellent mechanical properties; that is, it is hard, does not change its characteristics with age, and is not hygroscopic. It is not as active piezoelectrically as some of the chemical crystals, but for most purposes that is not a serious disadvantage.

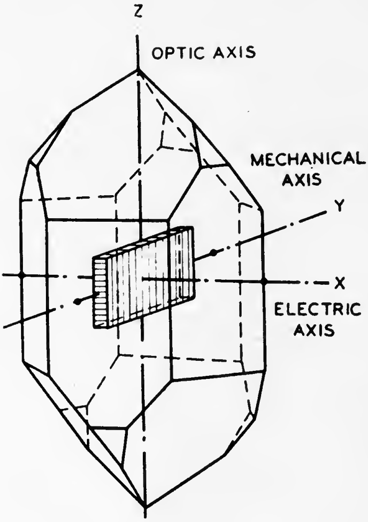
For oscillators generating very high frequencies, tourmaline is beginning to find some application. Tourmaline possesses approximately the same properties as quartz, but occurs only in small crystals; and, as it is regarded as a semi-precious stone because of its color, it is quite expensive. There are some other minerals, such as boracite, scolecite, *etc.*, in the same category, that could be used if necessary, but as they also occur only in minute crystals they are not worth considering as long as quartz is readily available.

There is also a large group of chemical crystals, so called in order to distinguish them from the natural mineral crystals. At the head of the group is Rochelle salt, which is the most active of all known piezoelectric crystals. It is approximately 1000 times as active as quartz. Up to now it has not been used for precision oscillators because of its relatively poor mechanical properties. However, recent improvements in the technic of growing the crystals may lead to their reconsideration as frequency generators. In the same group are tartaric acid, cane sugar, sodium chlorate, benzil, and many others.

FIG. 1. Typical quartz crystal from Brazil.

Before discussing the form of the piezoelectric frequency generator, it may be well to review briefly the technic of producing mechanical vibrations by means of an electrical field.

The plates or bars that are used as vibrators may be cut from the crystal in a number of different ways, depending upon the kind of vibration desired, its frequency-temperature coefficient, and the relation of the piezoelectric effect to the axis of the crystal. In using quartz for some purposes, a section (called the *X* cut) is cut from the mother crystal as shown in Fig. 2. If the electrodes are applied so that an electric field is established in the quartz parallel to the *X*



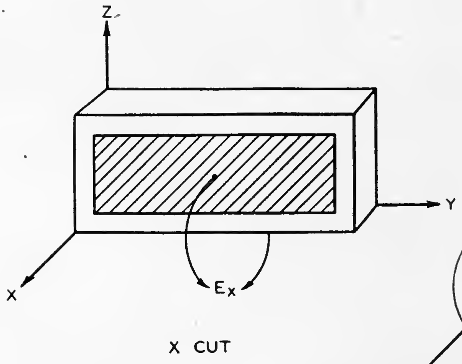
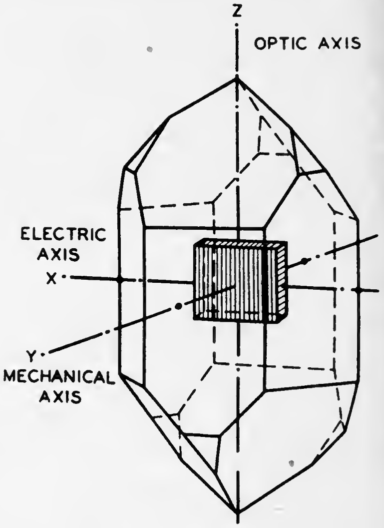


FIG. 2. (*upper*) Relation of *X*-cut quartz plate to axes of mother crystal.
FIG. 3. (*lower*) Application of electrodes to *X*-cut quartz plate.



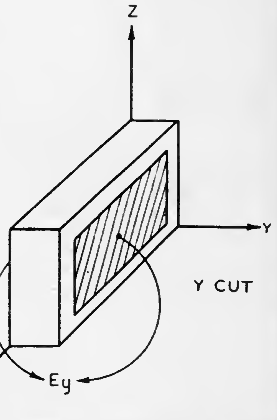
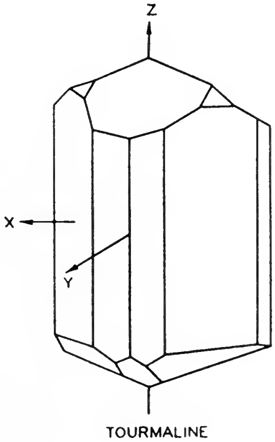


FIG. 4. (*upper*) Relation of *Y*-cut quartz plate to axes of mother crystal.
FIG. 5. (*lower*) Application of electrodes to *Y*-cut quartz plate.

axis (see Fig. 3), then there will be a mechanical expansion (or contraction) along the Y axis, a contraction (or expansion) along the X axis, and a shear in the YZ plane. Conversely an expansion, contraction, or shear of the crystal will produce an electric potential.

Such a bar has a number of free mechanical periods. One period corresponds to a longitudinal vibration along the Y axis, the center of the bar being the node (or region of no motion) while the ends expand and contract along the Y direction. The frequency of vibration depends upon the density of quartz, its elasticity in the Y direction, and the length of the bar. As motion along the Y axis causes a difference of potential between the electrodes, by connecting the latter to an appropriate electric circuit capable of supplying energy, the longitudinal Y vibration in the bar can be sustained electrically in much the same fashion as a clock-spring maintains a pendulum in motion through the escapement mechanism.

In the same way longitudinal vibrations can be set up in the X direction, and shear or flexural vibrations in the YZ plane. If the plate is cut from the crystal as shown in Fig. 4 (the Y cut), the electrodes being applied as shown in Fig. 5, longitudinal vibrations can no longer occur. Because of the shift in orientation, they are replaced by shear vibrations in the ZX and XY planes. The motion of the particles in a shear vibration is perpendicular to the direction of propagation of the wave-front, hence constituting an acoustical analogue of transverse light-waves.



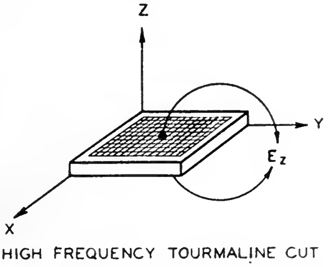


FIG. 6. (*upper*) Crystal structure of tourmaline.

FIG. 7. (*lower*) Application of electrodes to high-frequency tourmaline plates.

For very high frequencies the dimensions of the vibrators become very small; hence some difficulty is experienced in preparing them. As the frequency depends directly upon the square root of the modulus of elasticity and inversely upon the dimensions, the latter can be increased for a given frequency if, by some means (choice of orientation of axes, or different type of crystal), the elasticity can be increased. It so happens that in tourmaline the modulus of elasticity along the Z axis is approximately twice that along the X axis in quartz. Hence, for ultra-high frequencies (10 megacycles and above) plates are sometimes cut from tourmaline with the major face perpendicular to the Z axis. The electrodes are applied as shown in Fig. 7 and the longitudinal vibration in the Z direction utilized. The thickness of such a plate for a given frequency is approximately 40 per cent greater than that of a corresponding quartz plate, which is a real advantage when the plates are only a few thousandths of an inch thick.

FIG. 8. Crystal frequency generator with cover removed, showing crystal holder and oven for controlling temperature.

Using one of these types of vibration, it is possible to construct a frequency generator consisting of a piece of quartz or tourmaline, a vacuum tube, and a few simple electrical circuit elements. If carefully mounted in a temperature-controlled compartment, such a generator would have a high degree of precision. The Bell System frequency standard is of such a form.[3] The crystal is of quartz, and the frequency of vibration is 100,000 cycles per second. A precision of the order of 1 part in 10,000,000 is attained; or, in terms of time-keeping, it never deviates more than $^1/_{100}$th of a second in a day.

The standard frequency generator has many uses: it is supplied to the telephone operating companies and is used by them to calibrate the carrier frequencies of their wire and radio communication circuits; it is supplied to electric power companies who use it to set the frequency of generators of electric power; to watchmakers who use it to regulate watches; to broadcast stations when it is necessary to control the frequency of two stations from a single source; *etc.* For maintaining the frequency of radio stations, fixed or mobile, to their assigned values within very close limits, the piezoelectric generators can be made in very compact form. Figs. 8 and 9 show the details of such a generator capable of a precision of 1 part in 100,000; or, in terms of time-keeping, better than one second a day.

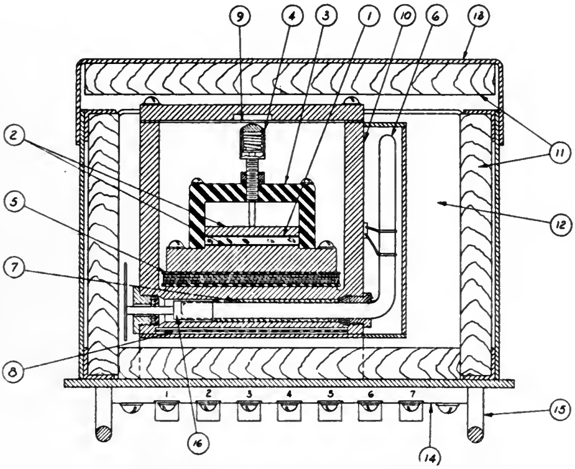


FIG. 9. Cross-sectional view of crystal holder and oven system of crystal frequency generator: (1) quartz crystal plate forming vibrating system; (2) electrodes; (3) and (4) details of crystal holder; (5) heat filter to prevent thermal cycle of thermostat and heater from reaching crystal; (6) thermostat; (8) electric heater controlled by thermostat; (10) external casing of oven.

In addition, the piezoelectric crystal finds many other applications. Rochelle salt crystals are used as loud speakers, microphones, phonograph pick-ups,[4] and oscillographs. As they can be made to vibrate mechanically, they can be used as sources of sound. Sound waves so generated can be used for submarine communication between ships, marine depth finding, *etc.* If generated with sufficient intensity the waves are capable of breaking up the cell structure of living organisms. One practical application has been made of this fact in a device for pasteurizing milk by supersonic sound waves generated by a quartz crystal. The complete list of applications of the piezoelectric crystal is a long one and is being rapidly enlarged as the capabilities of the device become more generally known.

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DISCUSSION

MR. CRABTREE: Perhaps Mr. Lack might explain a little more clearly exactly how the crystal acts as a timekeeper.

MR. LACK: A frequency generator, with an integrating device for counting the number of vibrations, can be used as a timekeeper.

MR. CRABTREE: If the vibrations are of the order of, say, ten million per second, how are they integrated?

MR. LACK: Just as 35-mm. film is reduced to 16-mm. film or *vice versa,* so frequencies can be stepped up or down at will. In the Bell System standard, which operates at 100,000 cycles, the frequency is stepped down successively to 10,000 cycles, 1000 cycles, and 100 cycles. At 100 cycles or less a synchronous motor can be driven, with which, by means of a revolution counter, the number of vibrations over a 24-hour period can be integrated. Checking the 24-hour period against the astronomical time from Washington, the frequency standard forms an interpolating device which will accurately break up the period of rotation of the earth into hours, minutes, and seconds.

MR. ROSENBERGER: Can the crystals be used to control the frequency of slow-motion pictures?

MR. LACK: Yes, but I fail to see why such a high order of precision is necessary. Eventually it is hoped that power companies will tie in their 60-cycle power with some form of frequency standard. That is being attempted at the present time with some success. I should think that the 60-cycle source would provide a more convenient means of getting an accurate speed than by using a crystal, stepping it down to the low frequency and amplifying it sufficiently to operate the motor. If the 60-cycle power is unsatisfactory for some reason or other, and a local frequency standard must be used, a tuning-fork would appear to be more suitable for the purpose than a crystal, on account of the low frequency.

MR. CRABTREE: How do the broadcasting stations control their frequencies by using this crystal.

MR. LACK: A specific crystal is supplied to each broadcasting station, which serves as a fundamental frequency generator and determines whether the radiated frequency will be, say, 495 kilocycles or 496.

MR. CRABTREE: How is the crystal calibrated?

MR. LACK: The frequency depends upon the dimensions and elasticity of the crystal. The size of the crystal, for a given frequency, can be predicted, and the crystal is ground to that size.

MR. CRABTREE: Is it like grinding a lens in the early days; by trial and error?

MR. LACK: No; crystals can be ground to within a few hundred cycles by machine and micrometer entirely. The final calibration is done by hand.

MR. CARPENTER: How are the raw crystals selected?

MR. LACK: If one can assure himself that the quartz is free from such defects as twinning, bubbles, cracks, and so forth, it can be assumed that the performance of the crystals is predictable.

To eliminate the defects, careful examination of the raw material is necessary. With experience, one can predict pretty well just how much twin material will be found in a given crystal when it is cut, from the external markings on the natural crystal surface.

As for the bubbles and cracks, a high-intensity arc can be used to look into the raw crystal, which usually has a number of faces clear enough for the purpose.

MR. TUTTLE: What is the order of the temperature effect upon the frequency of a given piece of quartz?

MR. LACK: Inasmuch as frequency depends upon the elasticity along the axis of vibration, it depends upon the type of vibration. Crystals can be produced having a temperature coefficient less than one part in a million, per degree centigrade. The average commercial crystal will have a higher coefficient than that. The maximum is around 100 cycles per million per degree of centigrade.

PIEZOELECTRIC MICROPHONES*

A. L. WILLIAMS**

Summary.—*The development of the Rochelle salt crystal microphone, with particular reference to the grille and sound-cell type, is described; and the construction of the sound-cells and the method employed for rendering them air-tight and water-proof are explained. Due to the small size of the microphones they are relatively free from distortion arising from cavity resonance, diffraction, and phase-shift, and are non-directional.*

Comparative response curves ranging in frequency from 50 to 10,000 cycles per second are presented. Special types of piezoelectric microphones for sound picture recording, radio broadcasting, and theater sound-reënforcing systems are described. Some of their physical, electrical, and acoustical characteristics are discussed, including those of a new unidirectional instrument.

Due to the increasing use of piezoelectric microphones in the various fields concerned with the measurement, recording, and reproduction of sound, and as their commercial development is comparatively new, it is the object of this paper to outline briefly the history of piezoelectricity, particularly as manifested in homogeneous crystals of Rochelle salt, and to discuss the design and construction of microphones based on this principle.

Piezoelectricity, or pressure electricity, is said to have been known to Coulomb, as early as 1780, who discovered that certain substances, when subjected to pressure, exhibited an electrical charge upon opposing surfaces. Later work by Becquerel,[1] about 1833, led to his report of the measurement of this effect in various substances. He investigated a large number of substances and was disappointed when he found that oranges lost their piezoelectric effect upon drying.

In 1880, the Curies,[2] studying the relationship between piezoelectricity and pyroelectricity, published the results of their work with quartz and other substances in which they determined the voltage generated by unit pressure along various crystallographic axes. They derived the "law" that the potential generated was pro-

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

** Brush Development Co., Cleveland, Ohio.

portional to the pressure, and determined the piezoelectric constants of about thirty materials.

This work of the Curies is the important phase of the early work in piezoelectricity from the point of view of present-day microphone developments. It is interesting to note that very soon the Curies were able to show that if a substance produced a voltage under pressure, then, in accordance with the law of the conservation of energy, the converse was likewise true—that an applied voltage produced a distortion in the same substance.

Rochelle salt crystal, however, was recognized to be superior in piezoelectric effect to any other crystal known,[3,4,5] and was found to have a piezoelectric constant more than 1000 times as great as that of quartz (Table I).

TABLE I

Piezoelectric Constants

Substance	$d = \frac{\text{e. s. u. per sq. cm.}}{\text{dynes per sq. cm.}}$
Tourmaline	$+5.78 \times 10^{-8}$
Quartz	-6.94×10^{-8}
Rochelle salt at 20°C.	$+8100 \times 10^{-8}$

That might have made Rochelle salt extremely interesting, except for the facts that clear homogeneous crystals of useful size were not available, and Rochelle salt was regarded as too weak and impermanent. Moreover, there was a general lack of appreciation of the sensitiveness of clear crystals of Rochelle salt. In 1919, Nicolson published results achieved by using rapidly grown composite Rochelle salt crystals. The entire crystal was utilized, and the unhomogeneous portion apparently played a part in the effect attained.[6]

It is not necessary to discuss the years of work that were involved in developing a process of making useful Rochelle salt crystals and methods of fabricating them. Suffice it to say that, to the far-seeing, commercial opportunities were present, if only such processes and methods could be developed. Moreover, crude Rochelle salt was produced as a by-product in manufacturing warming wines, and its availability was not dependent upon natural crystalline deposits in the earth.

Theoretical and practical experimentation with crystal blocks and slabs of Rochelle salt brought to light serious difficulties in applying the material commercially (Valasek, Isley, Frayne, *etc.*). Outstanding among the difficulties were saturation and hysteresis, wide variations in the piezoelectric performance of the crystal at different temperatures, and different crystals produced different results at identical temperatures.

It has been shown by C. B. Sawyer[7] that when two plates of Rochelle salt crystal, with electrodes attached, are cemented together in a suitable manner, if a voltage is applied to the electrodes one plate will tend to expand and the other to contract, causing a bending of the whole unit in a manner similar to a bimetallic thermostat. Saturation and hysteresis almost completely disappear and the temperature effect is considerably reduced. Such a combination is nicknamed a "bimorph" element, and may operate either by bending or by twisting, according as the construction employs "bending elements" or "torque elements."

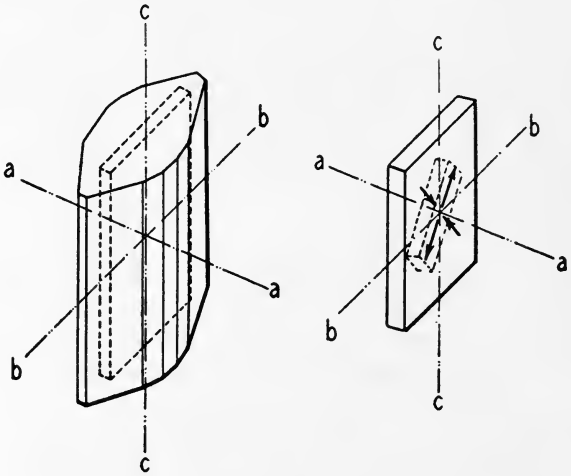


FIG. 1. The three axes of a homogeneous Rochelle salt crystal.

Fig. 1 shows the *a*, *b*, and *c* axes of a homogeneous Rochelle salt crystal. Long crystalline plates of Rochelle salt cut perpendicularly to the *a* axis and with edges 45 degrees to the *c* axis, expand and contract longitudinally in response to varying applied electric potentials. Consequently, a bimorph element consisting of two such plates cemented together and provided with appropriate electrodes will, when held at one end and electrically charged, bend and move perpendicularly to its major surfaces and parallel to the *a* axis. Conversely, when mechanically deformed in such a manner, a difference of potential will be produced between the electrodes. It is evident that a substance that is capable of reproducing in motion variations of electrical potential applied to it, and, conversely, of reproducing in voltage variations mechanical distortion to which it is subjected, should prove immediately applicable in the field of acoustical reproduction, particularly in loud speakers, phonograph pickups, and microphones.

In practice, a special bimorph element is frequently employed, in which a double curvature of the element is produced and utilized. Such double curvature is easily attained with Rochelle salt in consequence of the fact that, when the 45-degree diagonal of a plate cut perpendicularly to the *a* axis expands, the other diagonal, 90 degrees from the first, contracts. Consequently, and for example, a wider bimorph element composed of two rectangular Rochelle salt plates will, upon being electrified, assume a double curvature. If the curvature along the 45-degree diagonal at any time is convex, the curvature along the complementary diagonal is concave. When such a wide bimorph element, in an electrically neutral condition, is supported at the centers of two opposite edges and pressure is applied over the whole of one of the broad surfaces, this double distortion will result, and a voltage will be generated in proportion to the magnitude of the distortion.

Before leaving the specific discussion of Rochelle salt crystal and crystal elements, attention should be called to the success that has attended our efforts to overcome effects of excessive temperature and humidity upon the crystal microphone. Though Rochelle salt crystal is certainly soluble in water, it is also as certain that neither water nor water vapor can dissolve crystal that it can not touch. Various water-proofed papers, waxes, *etc.*, provide insulation against moisture to such an extent that a microphone is not rendered inoperative even after hours of total immersion in water. Moreover, although Rochelle salt melts at 165°F., and becomes inoperative if maintained at a temperature of 131°F. for a considerable period of time, experience has proved that those limitations do not interfere with its use.

Valasek[8] has shown that in Rochelle salt crystal there is a very interesting value of temperature (22°C., or 72°F.) known as the Curie point, at which the piezoelectric effect is greatest, indicating that the piezoelectric "constant" of Rochelle salt varies greatly with the temperature. The bimorph construction, however, assisted by using very thin sections of the crystal, has so reduced the temperature effect that tests have shown a microphone to vary only ±2 db. in a range from 40° below zero to 120° above zero Fahrenheit. The decrease in the temperature effect resulting from the bimorph construction has been pointed out by Ballantine[9] in connection with the much thicker sections used in loud speakers.

Crystal Microphones.—The more conventional type of crystal microphone, in which the energy absorbed by a separate diaphragm is converted into electricity by means of a suitable crystal unit, presents variations in design and construction that are nearly unlimited, but such designs may be divided into two main classes: the first, in which the diaphragm is rigidly connected to the crystal; and the second, in which the diaphragm exerts a varying pressure upon the crystal unit through a resilient intermediate member.

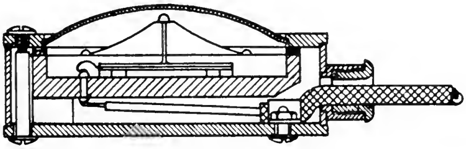
In the former case, the mass and elasticity (restoring force) of the diaphragm and crystal must be considered together when calculating the natural period and mechanical impedance of the assembly. A fairly flexible bending bimorph unit is now being used, which is supported at one end, the other end being attached to the center of a flexibly mounted, stiff diaphragm. In the commercial model, illustrated in Fig. 2, the diaphragm is of formed duralumin.

If a resilient coupling is used between the diaphragm and the crystal unit, the crystal can, without loss of efficiency, be considerably stiffer, thus having a higher natural period than the diaphragm. The final acoustical characteristic of such an instrument will depend upon the judicious selection of the various variables, sometimes with the assistance of damping applied at the proper place.

To reduce the number of parts, it is possible to make the diaphragm itself out of crystal. One way in which to do that is to attach the electrodes to a Rochelle salt bimorph disk in four sections, in such a way that pressure at the center of the diaphragm will produce a voltage on each quadrant. When suitably supported in a case, a $1^1/_2$-inch disk, 0.020 inch thick, makes a good average microphone when a fraction of the output is sacrificed in the interest of reducing mechanical resonance and improving fidelity. Such a unit, however, still retains its point of resonance within the musical range and suffers from pressure doubling due to reflection. It is not regarded satisfactory from the laboratory view-point, although it was marketed commercially and a number of them were very successfully used.

Spherical Microphones.—To avoid those defects, a spherical microphone was developed, having a band of rectangular crystal diaphragms on its equator, each crystal of such size that its natural period was above the range for which it was designed. If the works of Rayleigh,[10] Stewart,[11] and Ballantine[12] are studied, it will be seen that such a band on the surface of a sphere 3 inches in diameter shows very little frequency discrimination. However, this type was never introduced commercially because of the superior theoretical and practical advantages of the sound-cell.

Sound-Cell and Grille Type Microphones.—Fig. 3 shows the construction of the piezoelectric sound-cell. It consists of a rectangular frame, usually of bakelite, in each side of which is supported a thin Rochelle salt crystal bimorph unit. The crystals are supported by the frame at two points, and a clearance is provided between the frame and the crystal sealed by a flexible, air-tight annulus, thus leaving the crystal free to be distorted by variations of pressure. Silver leads are brought out from the crystals at the point of support and are usually connected in parallel. The whole cell is then impregnated with wax at 140°F., in order to render it air-tight and moisture-proof. The result is a small, flat, hollow, air-tight box, the two major sides of which generate voltage in proportion to the pressure, the voltage generated by one side being in phase with that of the other when caused by sound, and out of phase when caused by mechanical shock or vibration.



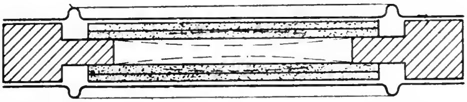


FIG. 2. (*Upper*) Diaphragm type crystal microphone.

FIG. 3. (*Lower*) Section through piezoelectric sound-cell (four times actual size).

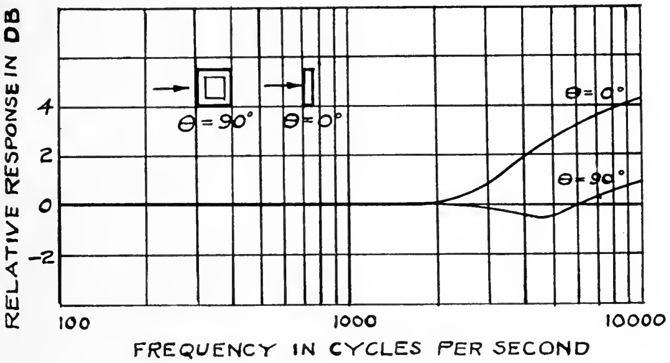
One of the major considerations governing the size of an individual sound-cell is that the mechanical resonance of the crystal units should be above the highest frequency to be reproduced, an objective that must be attained without sacrificing much sensitivity. In present commercial sound-cells, the crystal units are $^7/_{16}$ inch square and 0.020 to 0.030 inch thick over-all, which means that the two separate slabs composing the bimorph unit, without their electrodes, are about 0.006 inch thick. The units are designed to resonate just over 10,000 cycles per second, causing the characteristic to rise at the upper end. This increased output is usually found useful in compensating for high-frequency loss in associated equipment, but may easily be compensated for in the amplifier.

The second consideration governing the size is that the dimension of the sound-cell in any direction should be considerably smaller than the shortest sound-wave to be reproduced. Consider a plane wave normally incident to a major surface of the unit: it has been shown by Rayleigh that an increase of pressure will occur due to reflection when the length of the sound-wave approaches the size of the unit. When considering the effect, it must be remembered that the whole area of the sound-cell, including the frame, must be taken into account, as the frame acts as a baffle. For general purposes, the cell utilizing the $^7/_{16}$-inch square crystal, already mentioned, is $^3/_4$ inch square over-all.

H. C. Harrison and P. B. Flanders[13] have computed the diffraction from Ballantine's equation,[12] and the result is shown in Fig. 4 for sound approaching at angles of zero and 90 degrees to the surface. Actually, the curves shown are computed for a rigid sphere, but they may be regarded as sufficiently close approximations for showing that, even for a microphone as small as $^3/_4$ inch square, the distortion resulting from diffraction will be very appreciable at high frequencies for sound-waves approaching from a direction normal to the surface; *but small for waves 90 degrees from the normal.* For that very important reason the cells are mounted edgewise; and, where a number are mounted in a single case, in the form of a grille.

In a larger microphone, the use of the instrument at the 90-degree angle to the source introduces another serious form of distortion, due to phase-shift. Fig. 5, also due to Harrison and Flanders,[13] shows the loss of response at the high frequencies from that cause up to a frequency of 10,000 cycles for a sound-cell whose active surface is $^7/_{16}$ inch, and for a $1^1/_2$-inch diaphragm, which is a common size for commercial carbon, condenser, and dynamic microphones. It will be seen that the effect due to phase-shift tends somewhat to cancel that due to diffraction and that the total error from the two causes is small.

As mentioned before, the voltage output of a sound-cell will increase at the resonance frequency of the crystal element. In a sound-cell employing crystals $^7/_{16}$ inch square by 0.030 inch thick, the increase in the output will amount to about 2 db. at 10,000 cycles. When two or more sound-cells are connected in series, the effect will increase proportionately, whereas a parallel connection will cause it to decrease. Fig. 6 shows a conventional resistance-capacity coupled amplifier suitable for use with such a microphone, in which is indicated, at X, a condenser in the grid circuit of the second tube, ar-



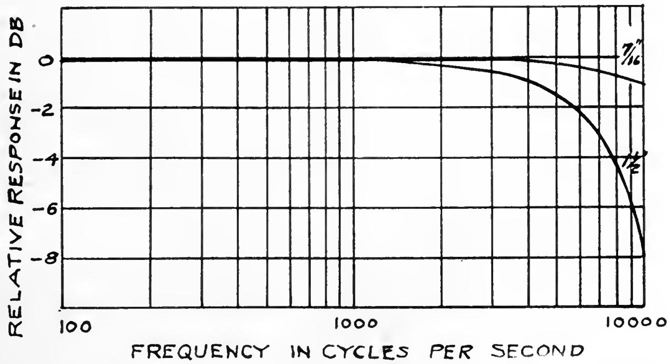


FIG. 4. (*Upper*) Effect due to diffraction in a $^3/_4$-inch square sound-cell.

FIG. 5. (*Lower*) Effect due to phase-shift when the sound approaches from a direction in the plane of the sensitive surface, for a standard sound-cell and for a $1^1/_2$-inch diaphragm.

ranged to compensate for the increase in output at the high frequencies.

In the commercial grille microphones, in order that the impedance may be low enough to permit using a reasonable length of cable between the microphone and the amplifier, enough cells are connected in parallel to make it unnecessary, in most cases, to employ special compensation.

For use as laboratory standards, sound-cells as small as one-half the usual size have been made. In a typical example of such a unit, the bimorph crystals are $^7/_{32}$ inch square by 0.010 inch thick, and are designed to resonate above 20,000 cycles.

Electrical Characteristics.—In the usual commercial sound-cell, the two bimorph crystal units are connected in parallel in such a way that when strained by mechanical shock the respective outputs tend to cancel, but when strained by pressure due to a sound-wave, the outputs are additive. Such a construction has the very practical advantage of allowing the unit to be handled during operation without having to use elaborate methods of suspension, and renders it remarkably quiet in a wind.

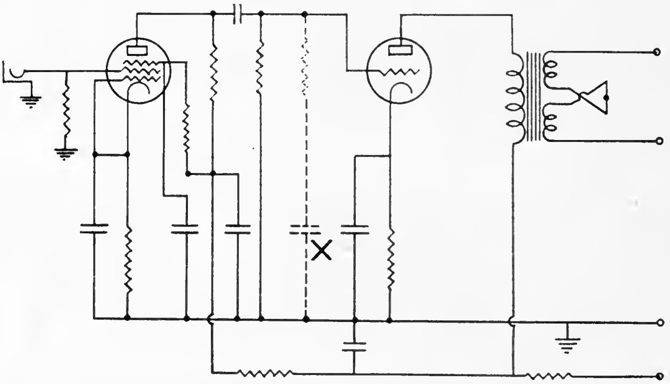


FIG. 6. Conventional resistance-capacity coupled amplifier circuit, suitable for use with the sound-cell.

The electrical impedance of a sound-cell below its point of mechanical resonance may be represented by a capacity of about 0.003 microfarad in series with a small resistance. A single sound-cell has an output of approximately 0.125 millivolt per bar. As the impedance is almost always capacitive, little frequency discrimination due to the capacity of the leads between the microphone and the grid of a tube is noticeable, although such capacity will reduce the useful available voltage. It is not, therefore, necessary to use a transformer to step down the output voltage in order to eliminate the effects due to the capacity of the cable; and owing to the frequency differentiation between the cable capacitance and the leakage reactance of the transformer, it is generally undesirable to do so.

It will be seen from the foregoing that a sound-cell is a complete but very small microphone, requiring neither polarizing voltage nor exciting current. It is entirely a pressure-operated device; and as piezoelectricity (as its name implies) is a pressure, and not a velocity phenomenon, there is no low-frequency cut-off. On open circuit, a sound-cell can respond as well at 1 cycle as at 1000. The cell is so small that it is almost free from distortion due to cavity resonance, phase-shift, or diffraction. It is non-directional in the plane of its major surface. The limitation in the output of the single sound-cell is overcome by using a number of cells to the microphone, from four to twenty-four, connected in series-parallel when long leads are to be used, or simply in series when the microphone is situated near the amplifier tube.

Fig. 7 illustrates a type *G-4S6P* grille type microphone containing twenty-four cells.

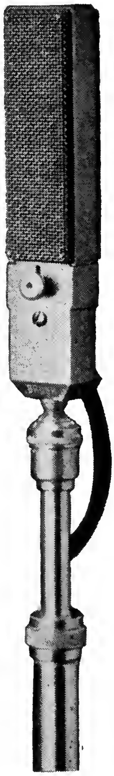


FIG. 7. Type *G-4S6P* microphone.

A sound-cell, being only $^1/_8$ inch thick, may be mounted close enough to a large reflecting surface to avoid audible frequency discrimination caused by a train of waves meeting their own reflection. The practical result, in such a case, is an increase in output to a value double that of the output of the same unit in free air. Advantage has been taken of that fact in designing the *L-2S2P*, *T-2S4P* microphones, and, to a certain extent, in the *D-2S2P* microphone. The first is a small, flat unit containing four standard cells, connected two in series and two in parallel, mounted $^1/_{16}$ inch from the back of the case. It may be placed upon a table, wall, or floor, as when it is required to conceal the microphone in motion picture recording. It may also be used as a lapel microphone.

The *T-2S4P* (Fig. 8) has twice as many cells in parallel, so that two or three may be connected in series without permitting the impedance and the consequent loss of voltage in the leads to become too great. The cells are similarly mounted in a cast metal case, primarily designed for installation near the front of a stage for sound reënforcement, and are also useful in churches, mounted on the pulpit, for example. When used on the stage, they may be spaced 10 feet apart along the footlights; four will comfortably cover a 60-ft. stage, allowing 15 feet at each end, although in the installation in the Roxy Theater at New York, four are successfully used to cover an 85-ft. stage.

To fill the demand of the motion picture industry and others for a more completely directional microphone, considerable work has been done by the Brush Development Company toward producing a unit in which the output of some of the sound-cells in the microphone is shifted in phase by means of resistances and condensers, so that a sound-wave coming from one direction will produce an additive effect, and one coming from the opposite direction will produce a subtractive effect on the output of the remainder of the sound-cells over a comparatively wide frequency range.

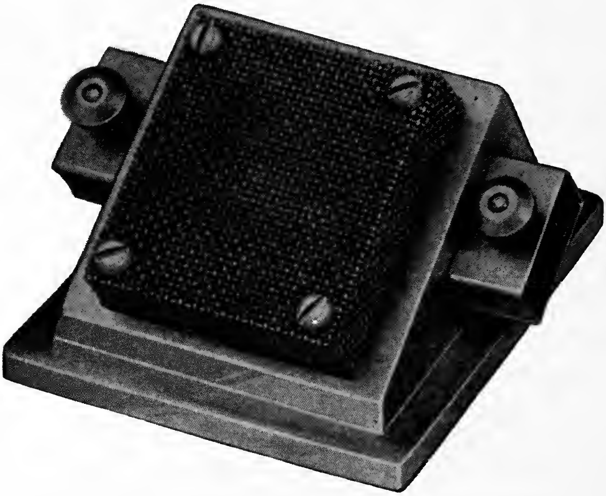
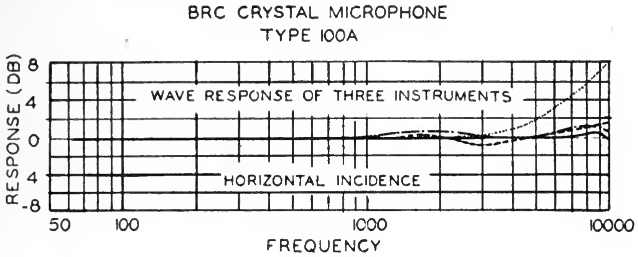
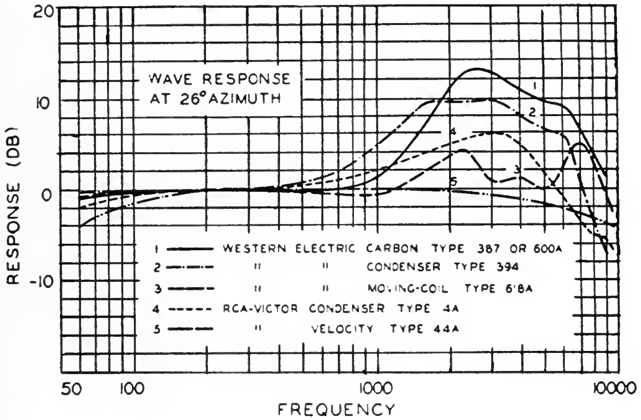


FIG. 8. Type *T-2S4P* microphone for theatrical sound reënforcement.

Performance.—The curves of Fig. 9, due to Ballantine,[14] show the free-space calibration of three of these microphones; and those of Fig. 10, of five other commercial types. The dotted curve of Fig. 9

shows the increase of output at high frequencies due to mechanical resonance when four cells are used in series without compensation.





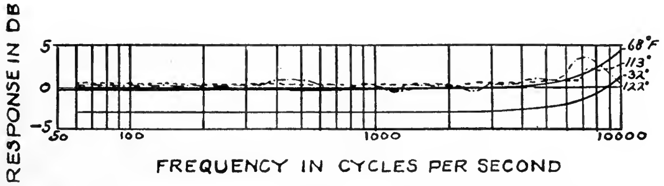


FIG. 9. (*Upper*) Free-space calibration of three sound-cell microphones.

FIG. 10. (*Center*) Free-space calibration of five other commercial types.

FIG. 11. (*Lower*) Effect of temperature upon a standard 4-cell microphone (type *G-2S2P*).

Fig. 11 shows the effect of temperature upon a standard four-cell microphone (type *G-2S2P*), which employs bimorph elements 0.020 inch thick. It may be expected that the use of 0.030-inch elements would not show a very much greater deviation from the normal. The upper curves were obtained by placing the microphone in a stream of hot air; the lower curve by cooling with "dry-ice." The temperature was measured by means of two thermometers in contact with the unit, and the output across a 5-megohm resistance was compared with that of a similar microphone at room temperature (65°F.). Less accurate cold tests made on the microphones for the Byrd Antarctic Expedition showed no further reduction of output above a temperature of −40°F., below which point the output fell off rapidly.

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DISCUSSION

Mr. Kellogg: How is the crystal made so nearly independent of temperature. Also, how is the unidirectional effect achieved?

Mr. Williams: The temperature effect is largely annuled by the bimorph construction, in which two sections of crystal are put together in opposition. It appears that if the crystals are completely restrained from moving in the direction in which they tend to move, the temperature effect becomes negligible. In the bimorph construction, this restraint would not be perfect unless the crystals were infinitely thin. In other words, the thinner the unit, the better is the compensation. For example, in a quarter-inch thick bimorph, the fall-off due to temperature is very noticeable over 100°F. With a 1/8-inch bimorph, it is much less, and with one 0.0020 inch thick, as used in these microphones, it is almost negligible.

As regards the uni-directional microphone, it is a matter of phase-shift in some of the cells.

MR. TASKER: Is there any particular limit to the size to which Rochelle salt crystals can be grown?

MR. WILLIAMS: No, but there are certain economical sizes.

MR. CARPENTER: Is the performance uniform throughout the crystal?

MR. WILLIAMS: Yes.

MR. CRABTREE: If a voltage is applied to the crystal, what is the amplitude of vibration of the crystal?

MR. WILLIAMS: That depends upon the voltage and the thickness of the crystal. In a piece $2^1/_2$ inches square and a quarter-inch thick, made of four layers of crystal, it is about three-thousandths of an inch per hundred volts applied. As much as 300 volts can be applied.

MR. CRABTREE: Are the loud speakers available commercially?

MR. WILLIAMS: Yes. We are trying them out in quite large numbers—small compared with dynamic speakers, but up to 200 a week.

MR. COFFMAN: Have any comparative measurements been made between the output of such a microphone as you have described and those of the more common types that have been used in the past, the velocity or the electrodynamic type of microphone?

MR. WILLIAMS: As I mentioned in the paper, the output of a single standard sound-cell of the size described is $^1/_8$ millivolt per bar. Two or four cells are usually used in series, making the output as great as $^1/_2$ millivolt per bar. That is lower than the dynamic microphone, which is about 9 millivolts per bar. I believe the velocity microphone is about 1 millivolt per bar. As the sound-cell is non-directional, the average pick-up of sound is much greater, which tends to produce a larger electrical output and is quite sufficient for use with standard amplifiers today.

RECENT IMPROVEMENTS IN EQUIPMENT AND TECHNIC IN THE PRODUCTION OF MOTION PICTURES*

E. A. WOLCOTT**

Summary.—*Many improvements have been made in recent years in the equipment used in producing motion pictures. This paper describes some of the uses and advantages of the new equipment, and the problems involved in adapting it; and refers to the personnel of the sound crew, the use of velocity microphones, a new kind of visual amplitude indicator, the use of cloth and hard surfaces in set construction, the advantages of process projection, and the new silent Debrie motion picture camera.*

Sound engineers have realized for a long time that theater audiences are becoming increasingly critical of the quality of the sound in a motion picture. As a result, new refinements in sound recording and reproducing equipment have been found necessary; in particular, recording and reproducing equipment for extending the frequency range.[1,2,3]

The application of the new sound recording equipment in making motion pictures demands considerable precision in operating the various devices, controls, *etc.*, particularly in connection with the manipulation and placement of the velocity microphones[4] furnished with one system of extended frequency-range equipment.

During the filming of a picture, the sound crew consists of the following members:

(1) The first sound man, usually termed the "mixer" or "recordist."
(2) The second sound man, or "stage man."
(3) The third sound man, or "assistant."
(4) The fourth sound man, also known as "stage electrician."

The mixer is in charge of the sound crew, and is directly responsible for the quality and volume of the recorded sound. It is his duty also to see that harmonious relations exist at all times between the sound crew and the other members of the company producing the picture.

The stage man operates the boom to which the microphone is attached. The work calls for considerable skill, particularly in

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

** RKO Studios, Hollywood, Calif.

making moving or dolly shots, and whenever the actors have occasion to move about the stage during dialog sequences. In some of the large studios in Hollywood he acts also as contact man between the recordist and the director of the picture.

The assistant has charge of the film recording machine, which is usually located in a permanent booth some distance from the mixing booth. His duties consist in loading the recorders, keeping a complete log or report of the operations of the sound crew throughout the day, and also aiding the recordist to keep a careful check on the operation of the anti-ground-noise device.

The fourth sound man, or stage electrician, operates a starting panel on which are placed suitable controls for starting the cameras and recorders and placing the synchronizing marks upon the edges of the sound and picture negatives by means of an electrical marking system. He also aids the stage man in connecting the cables and suspending the microphones in the various requisite positions on the set.

Extended frequency-range sound recording equipment is particularly suitable for the velocity microphone, although the standard condenser type may be used. The directional properties of velocity microphones are very advantageous, particularly when it becomes necessary to pick up and record a dialog spoken in the midst of a large group of persons, such as in a mob scene. Another advantage is the possibility of achieving what is known as "close-up quality" during the filming of a scene, using two or more cameras, one camera photographing a fairly long shot and the other a medium shot. Usually when the picture is edited, the medium shot is used for the greater part of the scene, and it is necessary to match the perspective of the sound to the closer camera as much as possible. In a recent feature picture,* this characteristic was very helpful, inasmuch as practically all the scenes consisted of medium and long shots, very few of them being close-ups.

When using the velocity microphone, it is important that some means be provided to rotate it, so that it may always be directed toward the source of the sound. The device for rotating the condenser microphones, as used in the past in practically all the major studios in Hollywood, is quite satisfactory for rotating the velocity microphones. However, due to the greater sensitivity of the ve-

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* *Frankie and Johnnie.*

locity microphone to transmitted shocks, or to vibrations generated in the boom that carries it, a new kind of suspension was required. A suspension developed by the RCA Victor Company consists of an inverted metal yoke to which the microphone unit is attached by means of a 4-point rubber suspension. It possesses excellent qualities as a mechanical filter, and is quite satisfactory for all practical purposes. When using the velocity microphone in motion picture work, it is very important that the operator of the microphone boom be very adept in manipulating it. He must remember the actors' cues so that the microphone may always be aimed at the person speaking. If the source of sound is outside the beam or area of sensitive coverage, a considerable loss of volume will occur, although no great change of quality will be noticed.

Recently, the directional properties of velocity microphones have been utilized to control the brilliance, or the reverberant energy "pick-up," in a room in which orchestral recordings are made. For such purpose, two microphones are used; one is aimed at the orchestra in the usual manner, and the other is so placed as to pick up the reverberant energy. The output of each microphone is fed into separate positions on the mixing panel, and the gain of each adjusted to afford the proper "life" or brilliance to the recording.

Occasionally, the directional characteristic of the velocity microphones becomes a slight handicap, particularly in a close-up shot, when the director wishes to include the lines of an actor not in the scene being photographed. Such a difficulty is solved by using an additional microphone, so placed as to provide the proper volume and quality for the off-stage voice.

Another recent development is the device known as the visual amplitude indicator, which makes use of a series of small neon glow lamps arranged on a panel attached to the mixing panel and immediately above it. The voltages necessary to operate the lamps are obtained from an additional amplifier which utilizes a small part of the output signal of the standard recording amplifier. Sixteen glow lamps are suitably arranged to indicate a total volume range of 53 decibels. A gain control is incorporated in the additional amplifier in order that the amplitude indication of the instrument may be adjusted to correspond to the amplitude of the sound track.

The uses of the amplitude indicator are quite varied. It is particularly adaptable to motion picture sound recording and broadcasting. It is also very useful for restricting the volume range of large symphony orchestras within certain required limits. The calibration of the instrument was checked several times a day over a period of several weeks of motion picture production, and the maximum deviation from the original calibration was not more than $\pm 1/2$ db.

Another important factor in recent years that has contributed considerably to the improvement in sound recording, is the use of sets made of cloth. Cloth of the proper color, conforming to the specifications of the art director, is stretched over wooden frames, care being taken to brace the frames securely when they are placed in position, particularly those sections adjacent to doorways in the scene. As the cloth used for the purpose is of a fairly thin texture, it is necessary to cover the back of each frame with black cloth, so as to prevent any light from shining through. This type of set construction is particularly satisfactory for scenes of small rooms, in which hard walls would impart a very disagreeable booming quality to the recording. It is still common practice, however, to use hard walls for very large sets, such as ballrooms, churches, theaters, *etc.*, which is quite all right from a sound standpoint, as a fairly brilliant quality is necessary in order to produce the proper illusion. This is particularly true in recording music, in which case the brilliance resulting from the reverberation often improves the final result.

Process projection,[5] recently introduced in making motion pictures, has made it very simple to record many scenes which heretofore were practically impossible to record. For instance, dialog scenes in flying airplanes, speed boats, racing automobiles, and many others, can now be photographed on the sound stage, where the recording conditions are ideal. The real sound effects can be added later, thus lending a degree of reality to the scene heretofore unattainable. Examples of what can be accomplished with the process are illustrated in several recent feature productions.* Process projection is comparatively simple; the essential requirements are a projector, a camera, and a suitable translucent screen. The camera and projector must be equipped with interlocking motors so that their respective shutters operate synchronously. A translucent screen developed for the purpose at the RKO Studios was found to be exceptionally well suited for this type of work.

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* *Flying Down to Rio* and *King Kong.*

Recently in New York, the new silent Debrie cameras[6] were used with extended frequency-range sound recording equipment in the regular production of motion pictures. The camera is self-contained, no silencing blimp being necessary. The camera is practically silent, and it is possible to record normal dialog with the camera at a distance of only three feet from the microphone, without introducing perceptible camera noise in the recording. It is light in weight, and is equipped with a base or tripod capable of adjustment to various camera heights. The base is also equipped with suitable mechanism so that it may be used for moving or dolly shots, and is adaptable to the standard Mole-Richardson camera dolly used in many of the major studios.

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FALL CONVENTION

HOTEL PENNSYLVANIA, NEW YORK, N. Y.

OCTOBER 29–NOVEMBER 1, 1934

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H. Griffin	J. H. Kurlander	M. W. Palmer

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Mrs. O. M. Glunt, *Hostess*

Assisted by

Mrs. G. C. Edwards	Mrs. J. H. Kurlander	Mrs. M. W. Palmer
Mrs. H. Griffin	Mrs. M. D. O'Brien	Mrs. O. F. Neu
Mrs. J. Frank, Jr.		Mrs. E. I. Sponable

OPENING OF CONVENTION

The Convention will begin at 10:00 A.M., Monday, October 29th, at the Hotel Pennsylvania, in the *Salle Moderne*, on the eighteenth floor. At noon of the opening day there will be an informal get-together luncheon, during which the members of the Society will be addressed by several prominent speakers. The morning preceding the luncheon will be devoted to registration, Society business, and reports of technical committees.

SESSIONS

Technical sessions and film programs will be held in the *Salle Moderne*, adjacent to which will be located the registration headquarters. The sessions will be held on the mornings of Monday, Tuesday, Wednesday, and Thursday; and on the afternoons of Monday, Tuesday, and Thursday. Wednesday afternoon, preceding the semi-annual banquet, will be devoted to visits to various laboratories, studios, theaters, and equipment and instrument manufactories in the New York area. The film programs of recently produced outstanding features and shorts will be held on Monday and Tuesday evenings. Interesting semi-technical lectures by well-known scientists will also be presented on those evenings preceding the film programs. Mr. J. I. Crabtree, *Convention Vice-President,* and Mr. J. O. Baker, *Chairman* of the Papers Committee, are in charge of the technical program.

HALLOWE'EN BANQUET AND DANCE

The S. M. P. E. Semi-Annual Banquet and Dance will be held in the Grand Ballroom of the Hotel on Wednesday, October 31st, at 7:30 P.M.—an evening of dancing, movies, and entertainment. Several addresses will be made by eminent members of the motion picture industry. Banquet tickets should be obtained in advance at the registration headquarters: tables reserved for six or eight persons.

HOTEL RATES

Excellent accommodations are assured by the management of the Hotel, and minimum rates are guaranteed. Room reservation cards mailed to the membership of the Society should be returned immediately in order to be assured of satisfactory reservations. Special garage rate, $1.25.

European Plan

Single: $3.50 per day; one person, single bed.
Double: $5.00 per day; two persons, double bed.
Double: $6.00 per day; two persons, twin beds.

LADIES' HEADQUARTERS

A reception suite will be provided for the ladies attending the Convention, and an attractive program for their entertainment is being prepared by the Ladies' Committee.

EXHIBIT OF MOTION PICTURE APPARATUS

Arrangements are being made to conduct an exhibit of newly developed motion picture apparatus, in order to acquaint the members of the Society with the newly devised tools of the industry. The exhibit will not be of the same nature as the usual trade exhibit; there will be no booths, but each exhibitor will be allotted definite space, and all exhibits will be arranged in a single large room. Requests for space should be directed to the General Office of the Society at the Hotel Pennsylvania, New York, N. Y., stating the number and nature of the items to be exhibited. The charges for space will be as follows: up to 20 sq. ft., $10; every additional 10 sq. ft., $5.

W. C. KUNZMANN, *Convention Vice-President*
J. I. CRABTREE, *Editorial Vice-President*

SOCIETY ANNOUNCEMENTS

FALL CONVENTION

As announced in the preceding section of this issue of the Journal, the Fall, 1934, Convention will be held at the Hotel Pennsylvania, New York, N. Y., October 29th–November 1st. Members are urged to make every effort to attend the Convention, and to participate in the very attractive and interesting programs that are being arranged.

ELECTION OF OFFICERS FOR 1935

Ballots for voting for the 1935 officers of the Society were recently mailed to the voting membership of the Society, and will be counted on October 29th, the first day of the Fall Convention. The names of the successful candidates will be announced at that time, but officers-elect will not assume office until January 1st, in accordance with the provisions of the recent revision of the Constitution and By-Laws.

PROJECTION PRACTICE COMMITTEE

At a meeting held at New York, N. Y., on September 12th, an outline of the report to be presented at the forthcoming Convention was prepared. At the next meeting of the Committee, to be held on October 24th, the draft of the report, based on the outline, will be edited by the Committee and put into final shape.

JOURNAL AWARD COMMITTEE

In accordance with an enactment of the Board of Governors on April 22, 1934, the Journal Award was revived. It consists of a cash award of $50, accompanied by an appropriate certificate to the author or authors of the "most outstanding paper originally published in the Journal during the preceding calendar year."

The Committee will report its findings to the Board of Governors at the next meeting, October 28th, and the award will be made some time during the Convention beginning on the following day.

STANDARDS

An up-to-date revision of the Standards Booklet, including all the standards that have been approved by the Society up to the present moment, and upon which the Standards Committee has been working for almost two years, will be ready for publication in the next issue of the Journal. In addition to being published in the Journal, reprints will be available shortly after.

The plan of changing the standardization of motion picture projects from the proprietary method to the administrative sectional committee method, sponsored by the S. M. P. E., according to the procedure of the American Standards Association, has been approved by the Standards Council of the latter body.

Plans for forming the Sectional Committee are going forward, and the S. M. P. E. Board of Governors at its next meeting on October 28th will take whatever steps may be necessary to enable the Committee to begin its work.

STANDARD S. M. P. E.

VISUAL AND SOUND TEST REELS

Prepared under the Supervision

OF THE

PROJECTION PRACTICE COMMITTEE

OF THE

SOCIETY OF MOTION PICTURE ENGINEERS

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JOURNAL

OF THE SOCIETY OF

MOTION PICTURE ENGINEERS

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JOURNAL
OF THE SOCIETY OF
MOTION PICTURE ENGINEERS

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Subscription to non-members, $8.00 per annum; to members, $5.00 per annum, included in their annual membership dues; single copies, $1.00. A discount on subscriptions or single copies of 15 per cent is allowed to accredited agencies. Order from the Society of Motion Picture Engineers, Inc., 20th and Northampton Sts., Easton, Pa., or Hotel Pennsylvania, New York, N. Y.

Published monthly at Easton, Pa., by the Society of Motion Picture Engineers
Publication Office, 20th & Northampton Sts., Easton, Pa.
General and Editorial Office, Hotel Pennsylvania, New York, N. Y.

Entered as second class matter January 15, 1930, at the Post Office at Easton, Pa., under the Act of March 3, 1879. Copyrighted, 1934, by the Society of Motion Picture Engineers, Inc.

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STANDARDS ADOPTED BY THE SOCIETY OF MOTION PICTURE ENGINEERS

The preceding edition of this booklet, known as the "Standards Adopted by the Society of Motion Picture Engineers," published originally in J. Soc. Mot. Pict. Eng., **XIV** *(May, 1930), No. 5, p. 545, and approved by the American Standards Association September 20, 1930, contained the first fifteen of the following charts. Although in this revised edition of the booklet some of those charts have been superseded, they have been retained for purposes of reference, the original chart numbers being unchanged. Some of the changes involved new dimensions, whereas others involved merely a new and clearer presentation of the existing dimensions; in any case, the captions following the chart numbers indicate the new charts to be consulted.*

The present revision of the booklet was completed by the Standards Committee in October, 1934, with the addition of Charts 16 to 32, inclusive.

DIMENSIONAL STANDARDS

1. Dimensions of Newly Cut and Perforated Film.

(*a*) *Standard 35-mm. film.*

Chart 16, for positive and negative stock; superseding Charts 1 and 2. See also Chart 23.

(*b*) *Standard 28-mm. film.* (Not in general use.)
Chart 3.

(*c*) *Standard 16-mm. film.*

Chart 17, for positive and negative film; superseding Chart 4. See also Chart 27.

2. Perforations.

(*a*) *Standard 35-mm. film.*

A single style of perforation shall be used for all 35-mm. film, to be the same as the perforation known prior to July 14, 1933, as the standard positive perforation, and to be known thereafter as the standard S. M. P. E. perforation. See Charts 16 and 23.

N. B.—Readers of the JOURNAL are invited to submit comments on this report to the General Office of the Society.

3. Film Splicing Specifications, for Laboratories and Exchanges.

(*a*) *35-Mm. film.*

Chart 18, superseding Chart 5.

(*b*) *16-Mm. film.*

Chart 12.

4. 35-Mm. Projector Sprockets.

(*a*) *Take-up sprocket.*

Chart 19, superseding Chart 6. The take-up sprocket, which is a hold-back sprocket in the motion picture projector, should have the same pitch as the perforations of film that has shrunk to the maximum extent found in films supplied by exchanges in a commercially useful condition. Such shrinkage is accepted as 1.5 per cent, for which value the dimensions given in the chart were computed.

(*b*) *Intermittent and feed sprockets.*

Chart 19, superseding Chart 7. The intermittent and feed sprockets should have the same pitch as the perforations of film that has shrunk 0.15 per cent, for which value the dimensions given in the chart were computed. The transverse distance between sprocket teeth has been calculated on the bases of film shrinkage of 1.13 per cent maximum.

5. 16-Mm. Projector Sprockets.

(*a*) *Feed sprockets.*

Chart 20, superseding Chart 8.

(*b*) *Take-up* (*hold-back*) *sprockets.*

Chart 21, superseding Chart 9.

(*c*) *Combination sprockets.*

Chart 22, superseding Chart 10.

6. Width of Film Track in 16-Mm. Cameras and Projectors.

A clearance of 0.005 inch (0.13 mm.) shall be allowed in designing the film track in cameras and projectors.

7. Frame Line.

(*a*) *Standard 35-mm. film.*

The center of the frame line shall be midway between two successive perforations on each side of the film.

(*b*) *Standard 16-mm. film.*

The center of the frame line shall pass through the center of a perforation on each side of the film.

8. Camera and Projector Apertures.

(*a*) *Standard 35-mm. film.*

Charts 23, 24, and 25.

(*b*) *Standard 16-mm. film.*

Charts 11, 27, 28, and 29.

9. Scanning Beam and Sound Track.

(*a*) *Standard 35-mm. film.*

Charts 23 and 26, superseding Charts 13 and 14.

(*b*) *Standard 16-mm. film.*

Charts 27 and 30.

10. Sound Film Speed.

(*a*) *Standard 35-mm. film.*

24 Frames per second.

(*b*) *Standard 16-mm. film.*

24 Frames per second.

11. Sound Record Relative to Picture Aperture.

For 35-mm. sound film, the center of any picture shall be 20 frames farther from the beginning of the reel than the corresponding modulation of the sound-track. In other words, the "sound start" mark shall be twenty frames nearer the beginning of the reel than the "picture start" mark.

For 16-mm. sound film, the center of any picture shall be 25 frames farther from the beginning of the reel than the corresponding modulation of the sound-track. The "sound start" mark shall be 25 frames nearer the beginning of the reel than the "picture start" mark.

12. External Diameter of Projection Lenses.

(*a*) *No. 1 projection lens.*

External diameter of lens barrel $2^1/_{32}$ inches (51.59 mm.).

(*b*) *No. 2 projection lens.*

External diameter of lens barrel $2^{25}/_{32}$ inches (70.65 mm.).

13. Lantern Slide Mat Opening.

3.0 Inches (76.20 mm.) wide, by 2.35 inches (59.69 mm.) high.

14. Unit of Photographic Intensity.

The unit of photographic intensity adopted by the International Congress of Photography in 1933 shall be adopted for negative materials.

DEFINITIVE SPECIFICATIONS

1. Number of Teeth in Mesh.

The number of teeth in mesh with the film (commonly referred to as "teeth in contact") shall be the number of teeth in the arc of contact of the film with the drum of the sprocket, the pulling face of one tooth being at the origin of the arc, as shown in Chart 15

2. Safety Film.

The term "Safety Film," as applied to motion picture materials, shall refer to materials which have a burning time greater than ten (10) seconds and which fall in the following classes: (*a*) support coated with emulsion, (*b*) any other material on which or in which an image can be produced, (*c*) the processed products of these materials, and (*d*) uncoated support which is or can be used for motion picture purposes in conjunction with the aforementioned classes of materials.

The burning time is defined as the time in seconds required for the complete combustion of a sample of the material 36 inches long, the determination of burning time being carried out according to the procedure of the Underwriters Laboratory. This definition was designed specifically to define Safety Film in terms of the burning rate of the commercial product of any thickness or width used in practice. The test of burning time, therefore, shall be made with a sample of the material in question having a thickness and width at which the particular material is used in practice.

RECOMMENDED PRACTICE

1. Leaders and Trailers.

The Standard Release Print adopted by the Academy of Motion Picture Arts and Sciences in 1930 is shown in Chart 32 (Seventh revision; April 1, 1934). Manufacturers of sound film should place a leader on each roll of film, on which is designated the framing of the picture and the corresponding sound.

2. Thumb Mark.

The thumb mark on a lantern slide should be located in the lower left-hand corner adjacent to the reader when the slide is held so that it can be read normally against the light.

3. Projection Lens Height.

The standard height from the floor to the center of the projection lens of a motion picture projector should be 48 inches.

4. Projection Angle.

This should not exceed 12 degrees.

5. Observation Port.

Observation ports should be 12 inches wide and 14 inches high and the distance from the floor to the bottom of the openings shall be 48 inches. The bottom of the opening should be splayed 15 degrees downward. In cases where the thickness of the projection room wall exceeds 12 inches, each side should be splayed 15 degrees.

6. Projector Lens Mounting.

The projector lens should be mounted in such a manner that the light from all parts of the aperture shall traverse an uninterrupted path to the entire surface of the lens.

7. Projection Lens Focal Length.

The focal length of motion picture projection lenses should increase in $^1/_4$-inch steps up to 8 inches, and in $^1/_2$-inch steps from 8 to 9 inches.

8. Project on Objectives, Focal Markings.

Projection objectives should have the equivalent focal length marked thereon in inches, quarters, and halves of an inch, or in decimals, with a plus (+) or minus(−) tolerance not to exceed 1 per cent of the designated focal length also marked by proper sign following the figure.

9. Sensitometry.

The principle of non-intermittency shall be adopted as recommended practice in making sensitometric measurements.

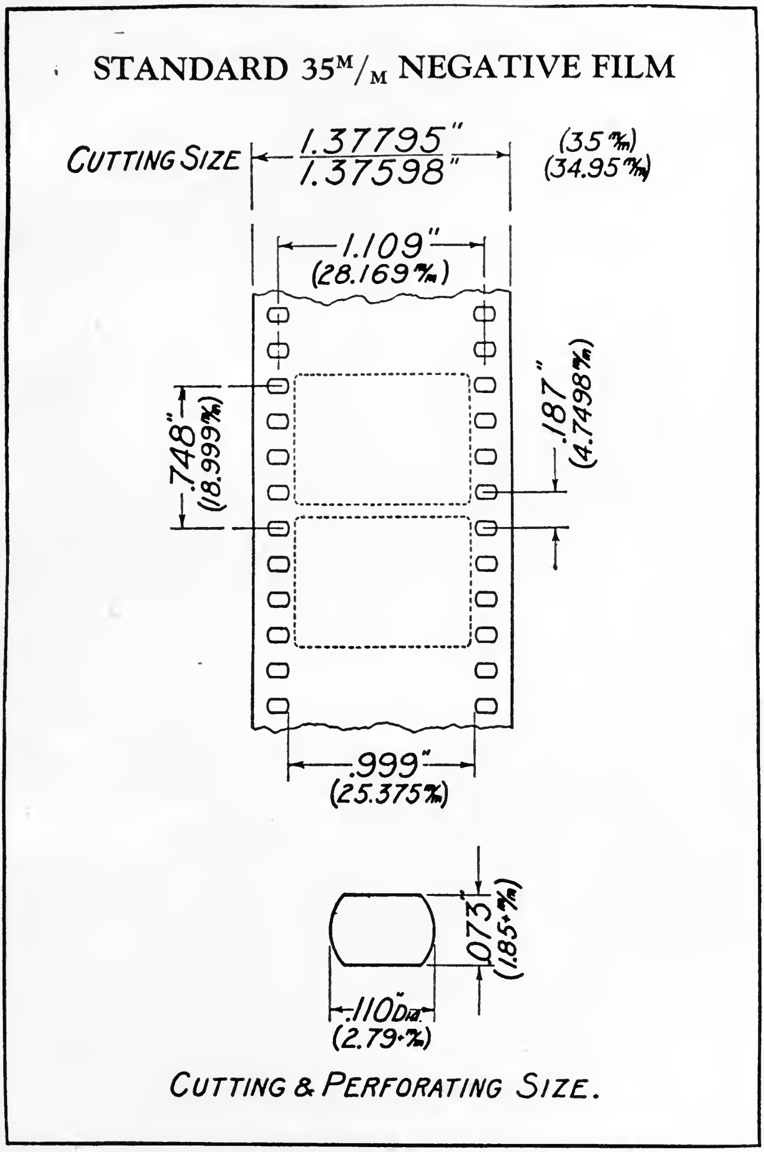

STANDARD $35^{M}/_{M}$ NEGATIVE FILM

CHART 1. Superseded April, 1934, by Chart 16.

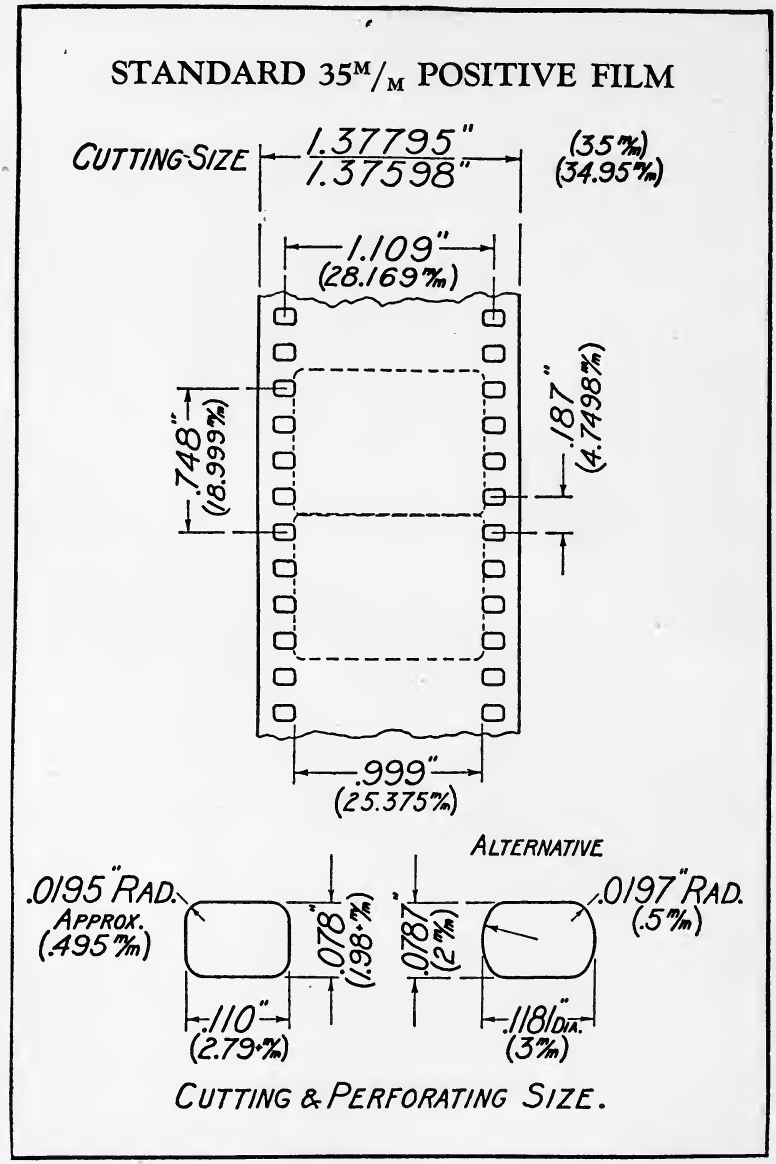


CHART 2. Superseded April, 1934, by Chart 16.

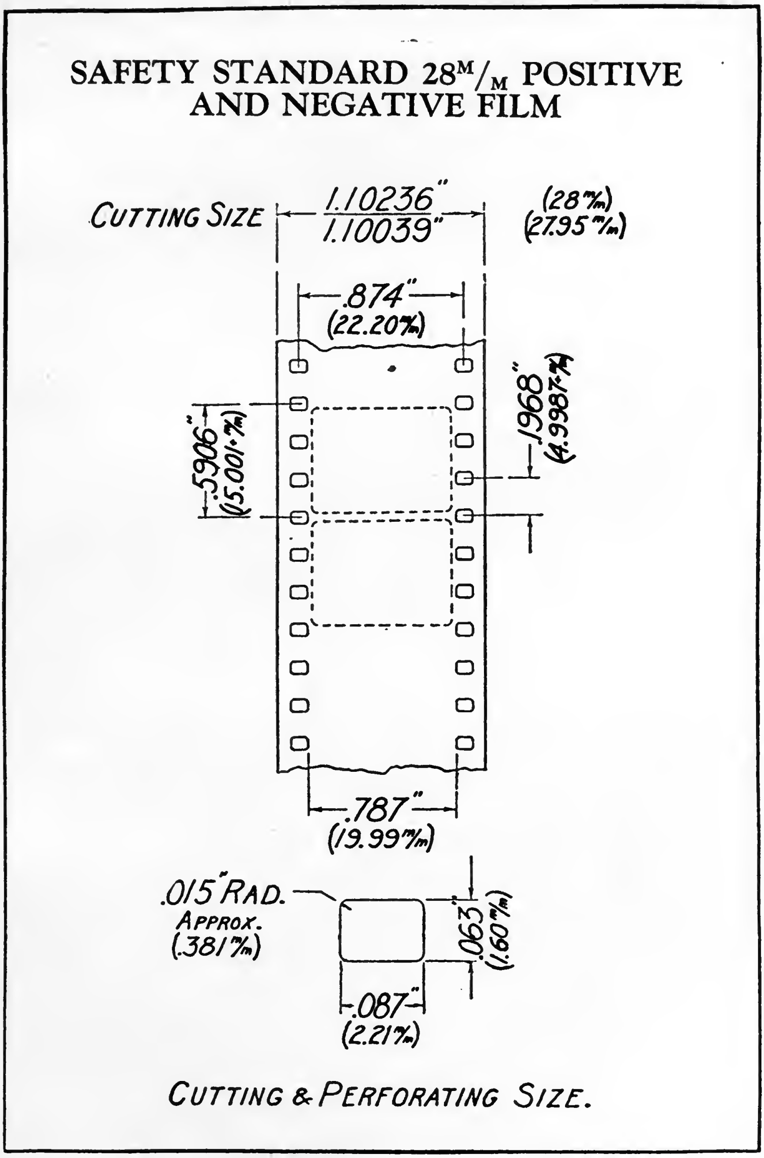


CHART 3. (Not in general use.)

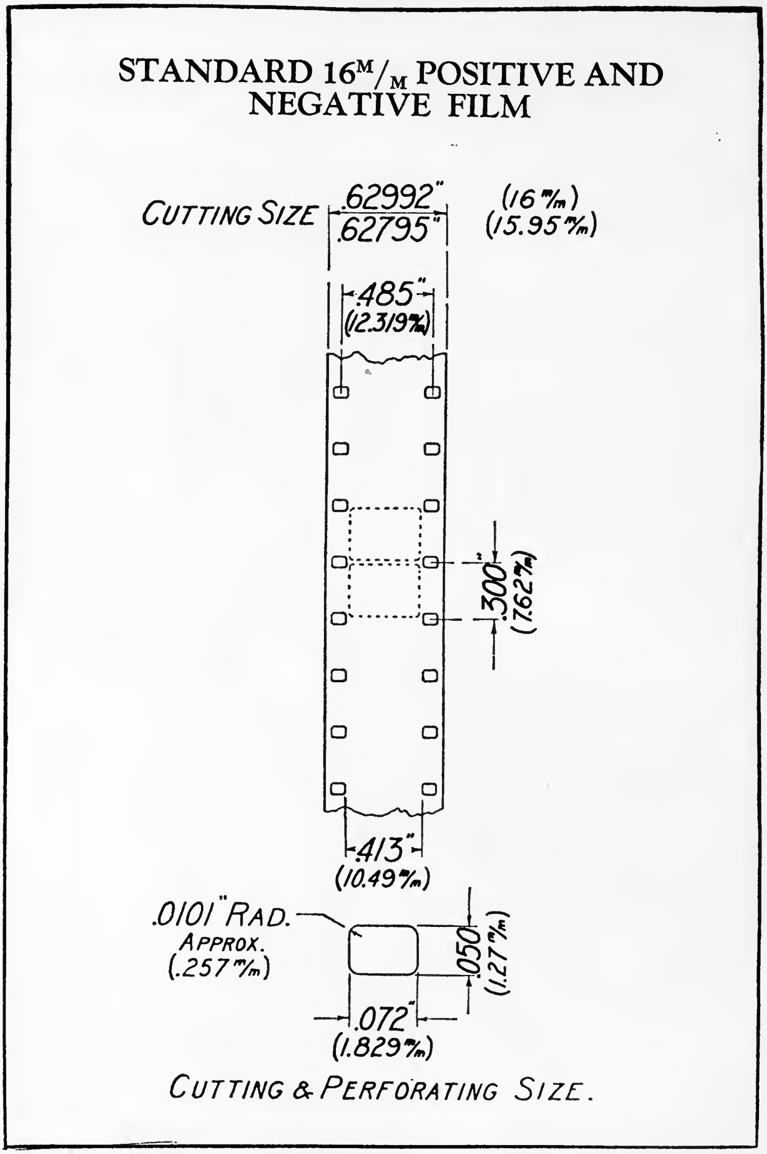

STANDARD 16 M/M POSITIVE AND NEGATIVE FILM

CHART 4. Superseded April, 1934, by Chart 17.

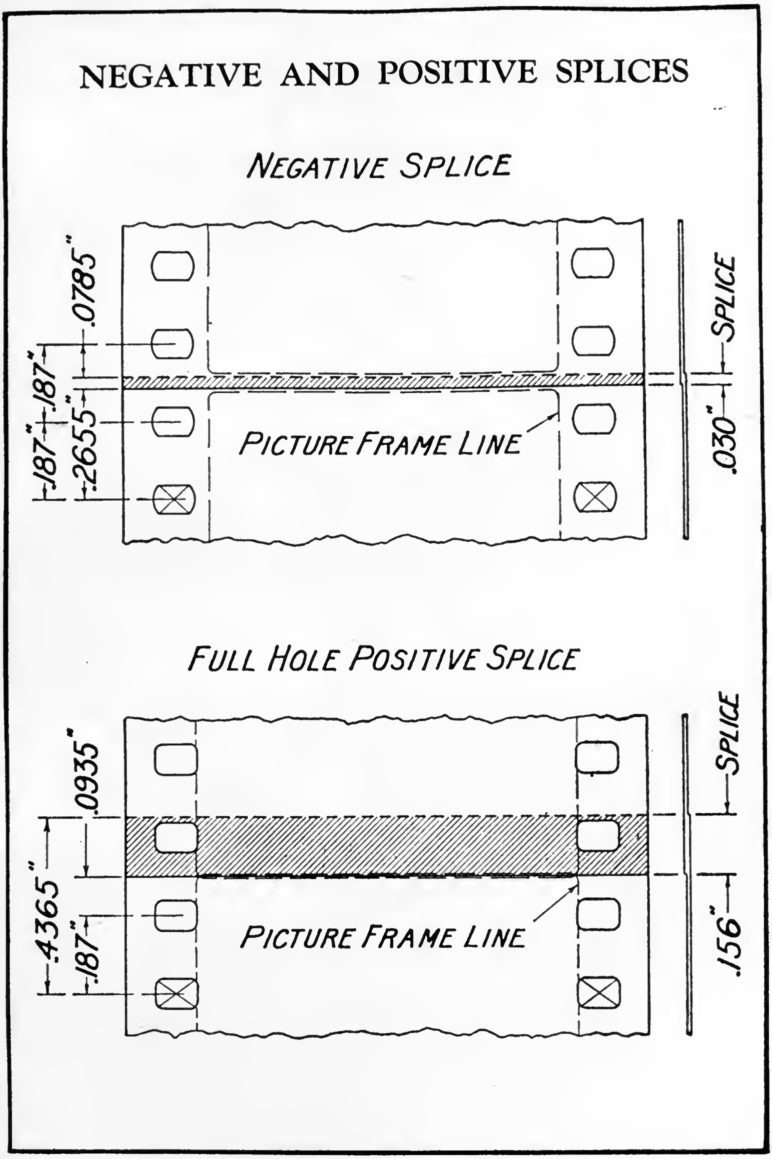


CHART 5. Superseded April, 1934, by Chart 18.

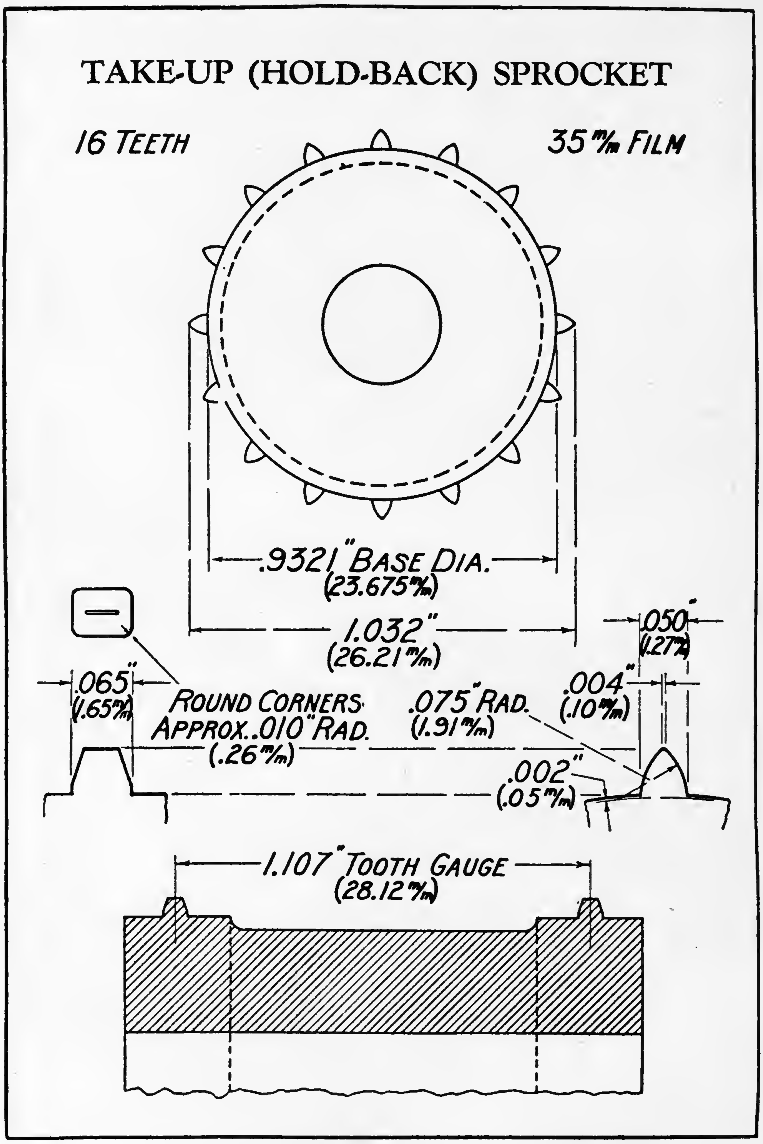


CHART 6. Superseded April, 1934, by Chart 19.

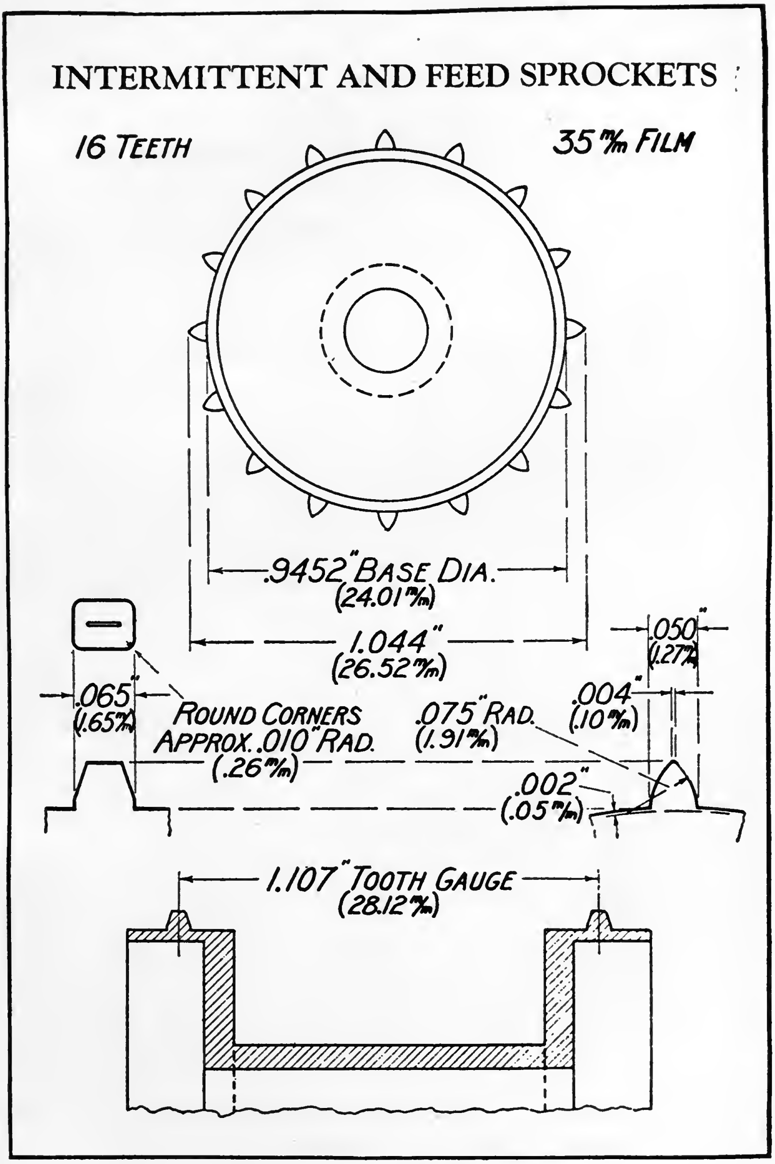
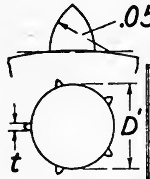


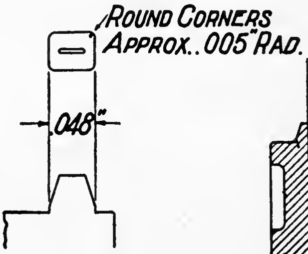
CHART 7. Superseded April, 1934, by Chart 19.

$16^{M}/_{M}$ FILM
STANDARDIZED SPROCKET SIZES

FEED SPROCKETS



	NUMBER OF TEETH IN CONTACT WITH FILM.								
	2			3			4		
NO. SPROCKET TEETH	D' INCHES	t INCHES	RANGE 0 TO MAX. SHRINKAGE	D' INCHES	t INCHES	RANGE 0 TO MAX. SHRINKAGE	D' INCHES	t INCHES	RANGE 0 TO MAX. SHRINKAGE
5	.4714	.039 .040	0 1.54%	.4714	.034 .035	0 1.57%			
6	.5669	.039 .040	0 1.54%	.5669	.034 .035	0 1.57%	.5669	.030 .031	0 1.52%
7	.6624	.039 .040	0 1.54%	.6624	.034 .035	0 1.57%	.6624	.030 .031	0 1.52%
8	.7579	.039 .040	0 1.54%	.7579	.034 .035	0 1.57%	.7579	.030 .031	0 1.52%



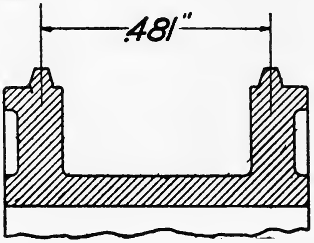
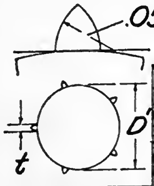


CHART 8. Superseded April, 1934, by Chart 20.

16 M/M FILM
STANDARDIZED SPROCKET SIZES

TAKE UP (HOLD BACK) SPROCKETS



	NUMBER OF TEETH IN CONTACT WITH FILM								
	2			3			4		
	D'	t	RANGE	D'	t	RANGE	D'	t	RANGE
NO. SPROCKET TEETH	INCHES	INCHES	SHRINKAGE	INCHES	INCHES	SHRINKAGE	INCHES	INCHES	SHRINKAGE
5	.4643	.037 .038	0 1.50%	.4643	.031 .032	0 1.50%			
6	.5584	.037 .038	0 1.50%	.5584	.031 .032	0 1.50%	.5584	.030 .031	0 1.50%
7	.6524	.037 .038	0 1.50%	.6524	.031 .032	0 1.50%	.6524	.030 .031	0 1.50%
8	.7464	.037 .038	0 1.50%	.7464	.031 .032	0 1.50%	.7464	.030 .031	0 1.50%

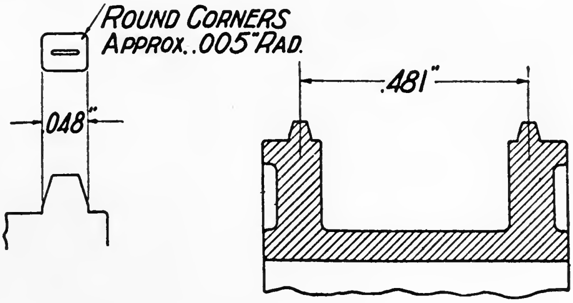
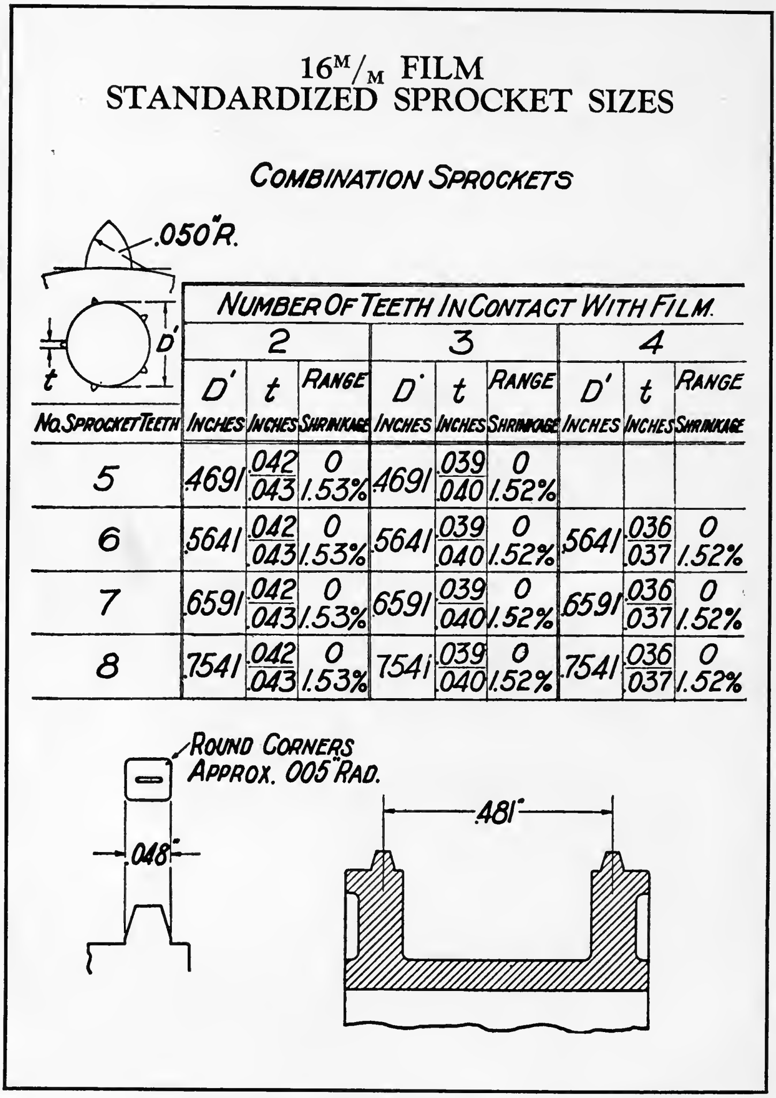


CHART 9. Superseded April, 1934, by Chart 21.



16$^M/_M$ FILM
STANDARDIZED SPROCKET SIZES

COMBINATION SPROCKETS

	NUMBER OF TEETH IN CONTACT WITH FILM								
	2			3			4		
NO. SPROCKET TEETH	D' INCHES	t INCHES	RANGE SHRINKAGE	D' INCHES	t INCHES	RANGE SHRINKAGE	D' INCHES	t INCHES	RANGE SHRINKAGE
5	.4691	.042 .043	0 1.53%	.4691	.039 .040	0 1.52%			
6	.5641	.042 .043	0 1.53%	.5641	.039 .040	0 1.52%	.5641	.036 .037	0 1.52%
7	.6591	.042 .043	0 1.53%	.6591	.039 .040	0 1.52%	.6591	.036 .037	0 1.52%
8	.7541	.042 .043	0 1.53%	.7541	.039 .040	0 1.52%	.7541	.036 .037	0 1.52%

CHART 10. Superseded April, 1934, by Chart 22.

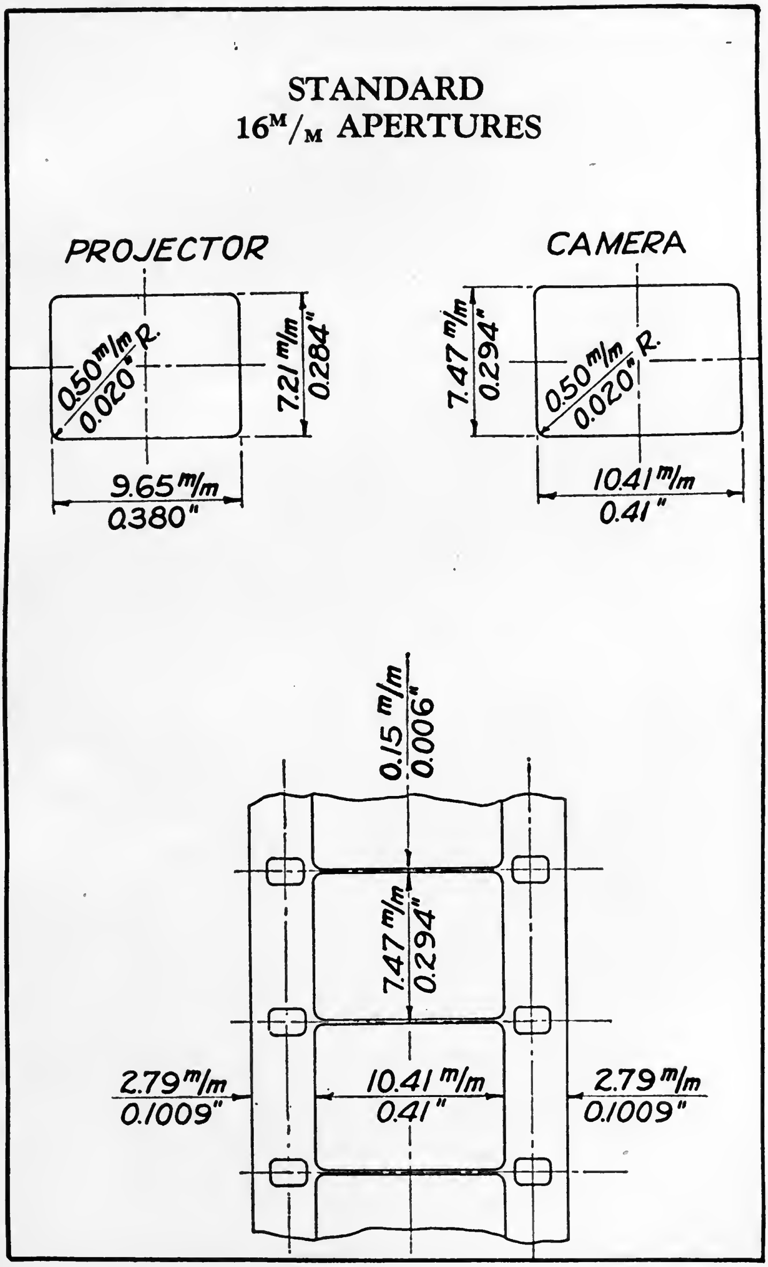


CHART 11. See also Charts 27, 28, and 29.

$16^{M}/_{M}$ FILM SPLICES

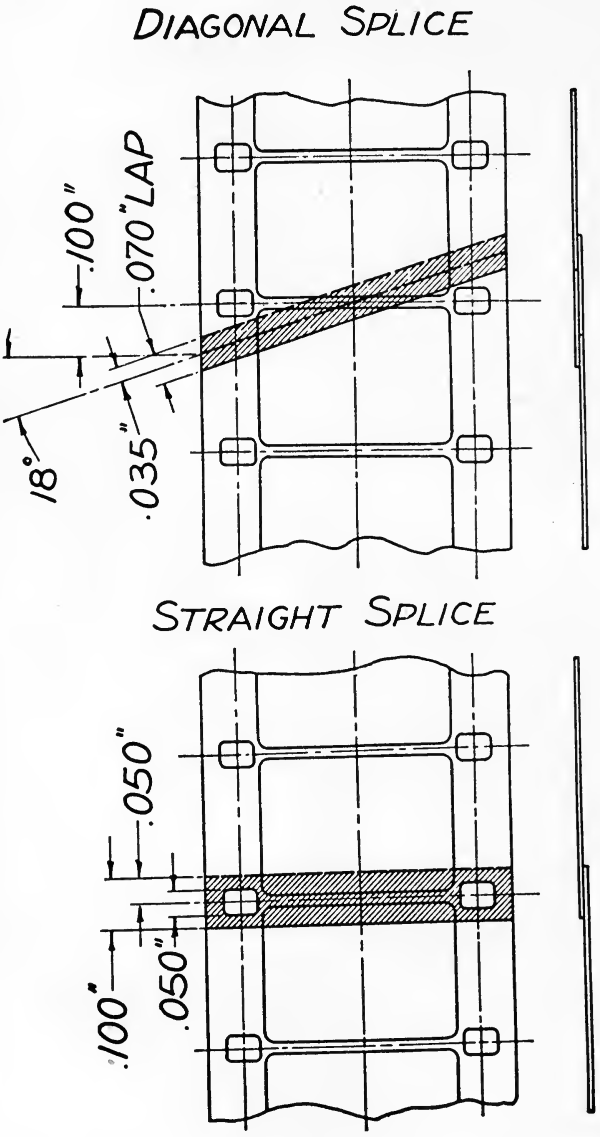


CHART 12.

POSITION AND DIMENSION OF SCANNING LINE

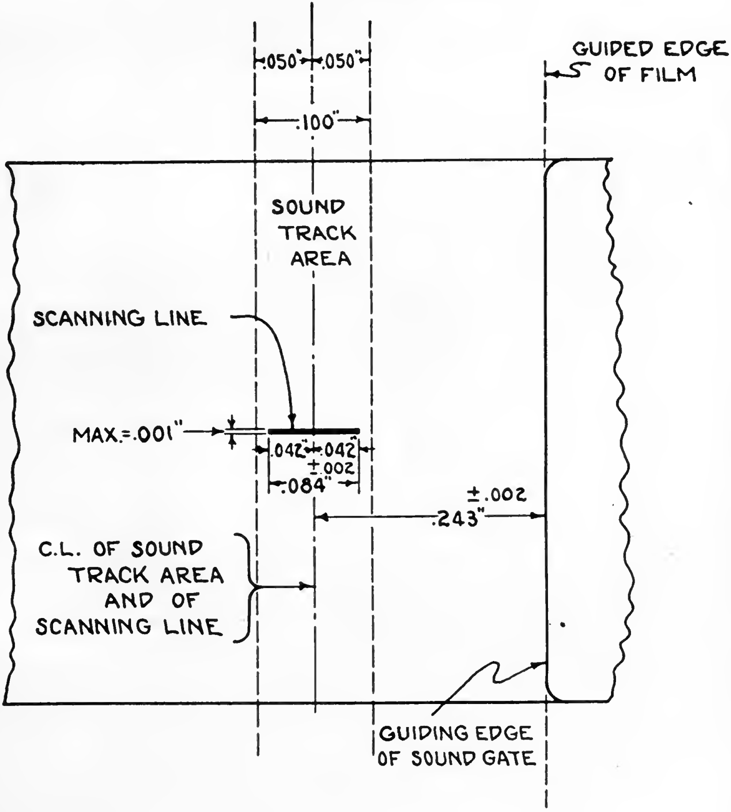


CHART 13. Superseded April, 1934, by Charts 23 and 26.

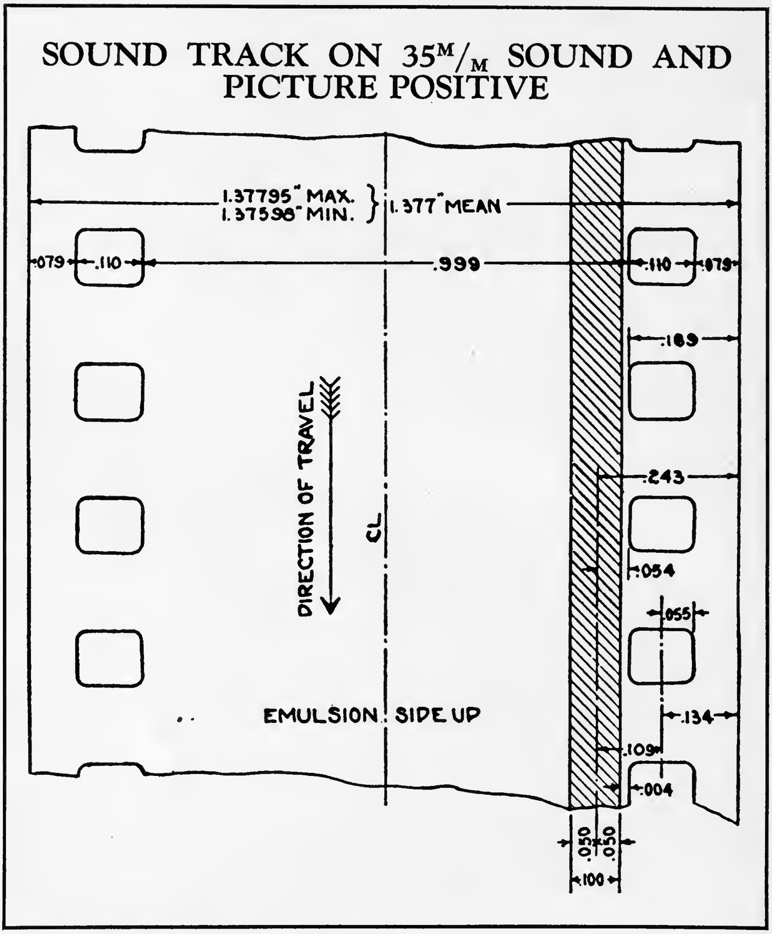


CHART 14. Superseded April, 1934, by Charts 23 and 26.

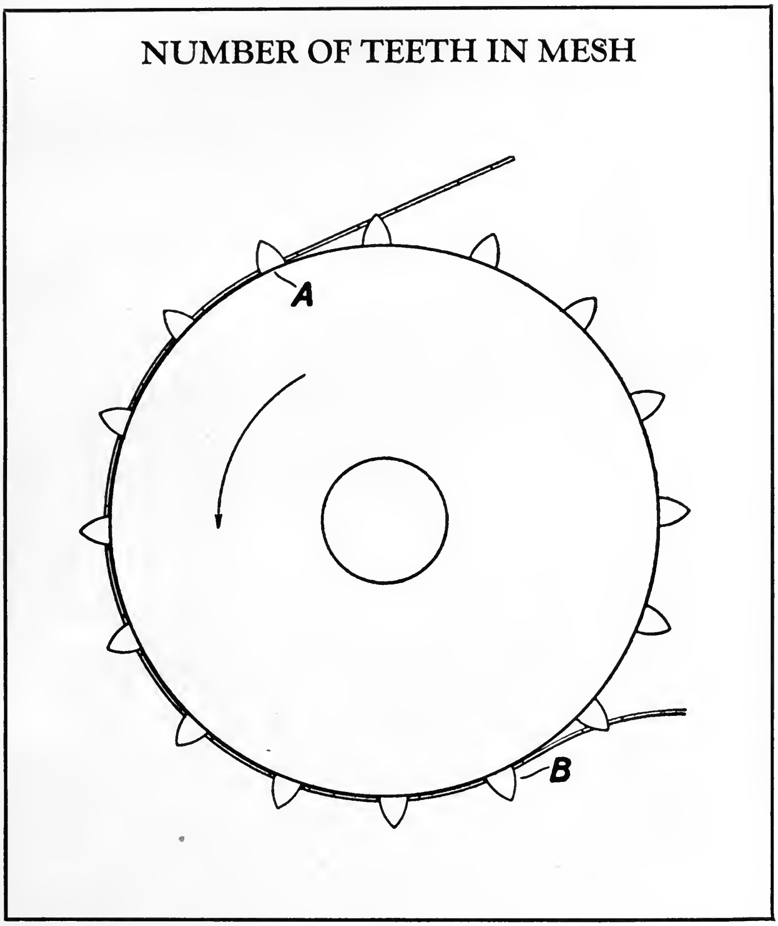
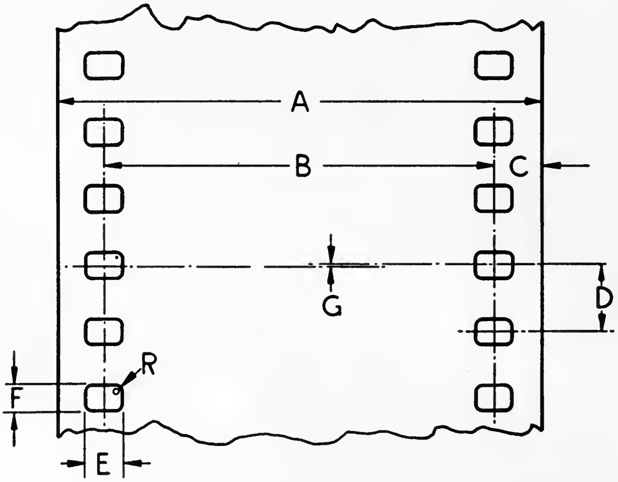


CHART 15.

STANDARD 35-MM. FILM

CUTTING AND PERFORATING DIMENSIONS OF NEGATIVE AND POSITIVE RAW STOCK

These dimensions and tolerances apply to the material immediately after cutting and perforating.



	Inches	*Millimeters*
A	1.378 + 0.000 − 0.002	35.00 + 0.00 − 0.05
B	1.109 ± 0.002	28.17 ± 0.05
C	0.134 ± 0.002	3.40 ± 0.05
D	0.187 ± 0.0005	4.75 ± 0.013
E	0.110 ± 0.0003	2.79 ± 0.008
F	0.078 ± 0.0003	1.98 ± 0.008
G	Not > 0.001	Not > 0.025
R	0.020 approx.	0.51 approx.
*L**	18.70 ± 0.015	475.0 ± 0.381

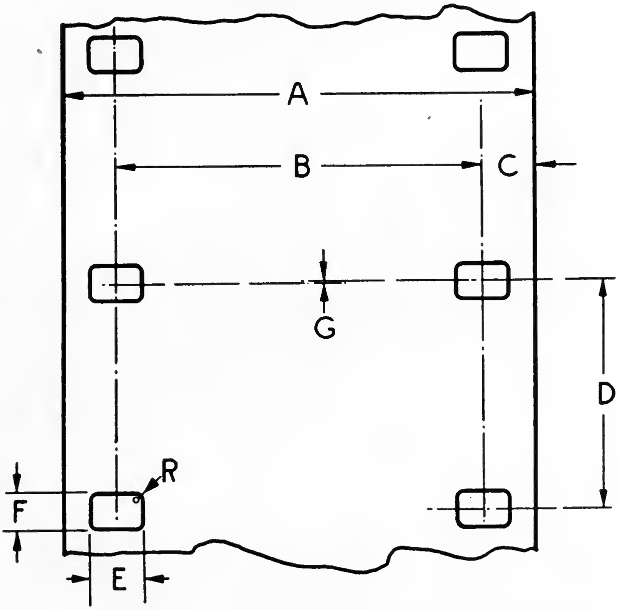
* *L* = the length of any 100 consecutive perforation intervals.

CHART 16.

STANDARD 16-MM. FILM

CUTTING AND PERFORATING DIMENSIONS OF NEGATIVE AND POSITIVE RAW STOCK

These dimensions and tolerances apply to the material immediately after cutting and perforating.



	Inches	*Millimeters*
A	0.630 + 0.000 − 0.002	16.00 + 0.00 − 0.05
B	0.485 ± 0.001	12.32 ± 0.025
C	0.072 ± 0.002	1.83 ± 0.05
D	0.300 ± 0.0005	7.62 ± 0.013
E	0.072 ± 0.0002	1.83 ± 0.005
F	0.050 ± 0.0002	1.27 ± 0.005
G	Not > 0.0005	Not > 0.013
R	0.010 approx.	0.25 approx.
*L**	30.0 ± 0.03	762.0 ± 0.76

* *L* = the length of any 100 consecutive perforation intervals.

CHART 17.

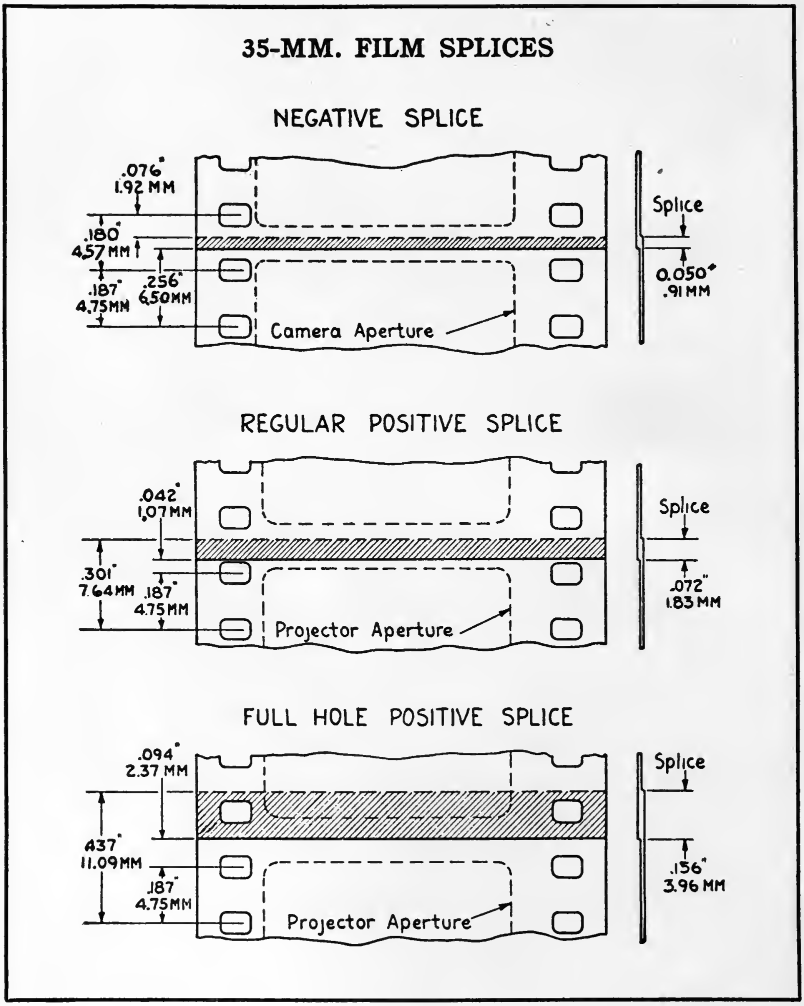

35-MM. FILM SPLICES
NEGATIVE SPLICE
.076"
1.92 MM
.180"
4.57 MM
.187"
4.75 MM
.256"
6.50 MM
Camera Aperture
Splice
0.050"
.91 MM
REGULAR POSITIVE SPLICE
.042"
1.07 MM
.301"
7.64 MM
.187"
4.75 MM
Projector Aperture
Splice
.072"
1.83 MM
FULL HOLE POSITIVE SPLICE
.094"
2.37 MM
437"
11.09 MM
.187"
4.75 MM
Projector Aperture
Splice
.156"
3.96 MM

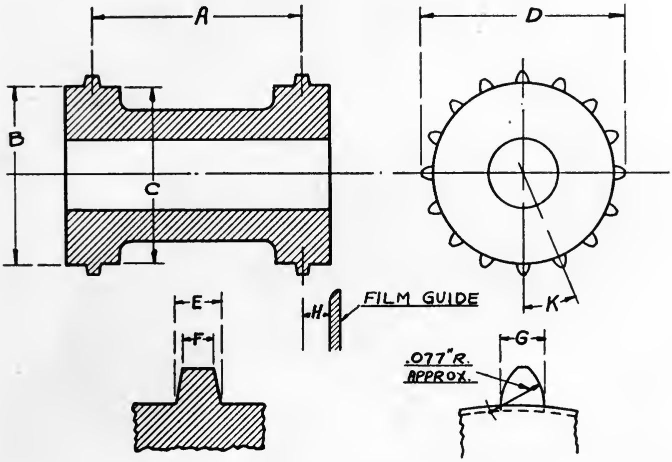
CHART 18.

STANDARD 35-MM. SPROCKETS

PROJECTOR FEED AND HOLD-BACK SPROCKETS

(*Not Sound Sprockets*)

16 TEETH



	Feed Sprocket		Int. Sprocket		Hold-Back Sprocket	
	Inches	*mm.*	*Inches*	*mm.*	*Inches*	*mm.*
A	1.097 ± .001	27.86 ± .025	1.097 ± .001	27.86 ± .025	1.097 ± .001	27.86 ± .025
B	.945 ± .001	24.00 ± .025	.945 ± .0002	24.00 ± .005	.932 ± .001	23.67 ± .025
C	.935 ± .002	23.75 ± .051	.935 ± .002	23.75 ± .051	.922 ± .002	23.42 ± .051
D	1.045 ± .002	26.54 ± .051	1.045 ± .002	26.54 ± .051	1.032 ± .002	26.21 ± .051
E	.055 + .000 − .002	1.4 + .000 − .051	.055 + .000 − .002	1.4 + .000 − .051	.055 + .000 − .002	1.4 + .000 − .051
F	.040 ± .002	1.02 ± .051	.040 ± .002	1.02 ± .051	.040 ± .002	1.02 ± .051
G	.055 + .000 − .002	1.4 + .000 − .051	.055 + .000 − .002	1.4 + .000 − .051	.055 + .000 − .002	1.4 + .000 − .051
H	.139 + .000 − .001	3.531 + .000 − .025	.139 + .000 − .001	3.531 + .000 − .025	.139 + .000 − .001	3.531 + .000 − .025
K	22 Deg. 30 Min. ± 1.5 Min.		22 Deg. 30 Min. ± .75 Min.*		22 Deg. 30 Min. ± 1.5 Min.	

* The accumulated error over 16 teeth not to exceed 4.00 min.

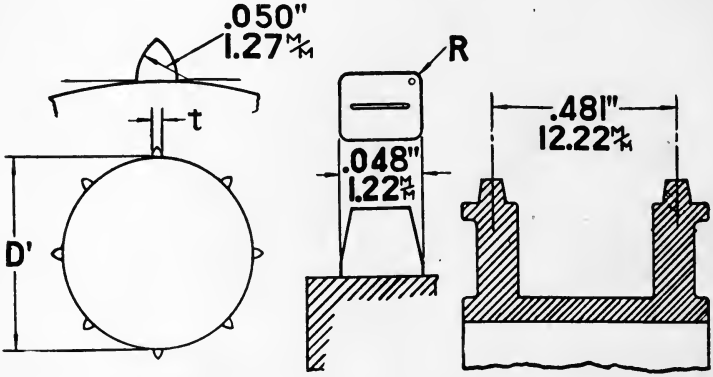
Note.—The center about which the tooth radius is drawn is located 0.004" ±0.0002" below the periphery of the drum.

CHART 19.

STANDARD 16-MM. SPROCKETS

FEED SPROCKETS

(Not Sound Sprockets)



			Number of Teeth in Mesh							
			3		4		5		6	
N	*D'* *in.*	*D'* *mm.*	*t* *in.*	*t* *mm.*	*t* *in.*	*t* *mm.*	*t* *in.*	*t* *mm.*	*t* *in.*	*t* *mm.*
6	0.566	14.38	0.040	1.02						
8	0.757	19.23	0.040	1.02	0.036	0.91				
12	1.139	28.93	0.040	1.02	0.036	0.91	0.031	0.79	0.027	0.69
16	1.521	38.63	0.040	1.02	0.036	0.91	0.031	0.79	0.027	0.69

R = Round corners with approximately 0.005″ radius
N = Number of teeth on sprocket.
Tolerances for *D'* and *t* = +0.000″, −0.001″.
Maximum allowable film shrinkage = 1.50%.
Values given for *D'* are 0.001″ less than he theoretical.

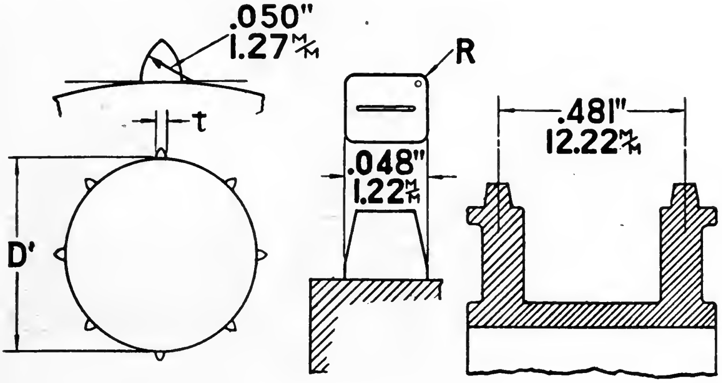
Values of *t* are not given in cases where the ***number of teeth in mesh*** as related to *N*, ***the number of teeth on the sprocket***, is such that the wrap of the film on the sprocket would be greater than 180°.

CHART 20.

STANDARD 16-MM. SPROCKETS

TAKE-UP (HOLD BACK) SPROCKETS

(*Not Sound Sprockets*)



			Number of Teeth in Mesh							
			3		4		5		6	
N	*D′*		*t*	*t*	*t*	*t*	*t*	*t*	*t*	*t*
	in.	*mm.*	*in.*	*mm.*	*in.*	*mm.*	*in.*	*mm.*	*in.*	*mm.*
6	0.557	14.15	0.040	1.02						
8	0.745	18.92	0.040	1.02	0.036	0.91				
12	1.122	28.50	0.040	1.02	0.036	0.91	0.031	0.79	0.027	0.69
16	1.498	38.05	0.040	1.02	0.036	0.91	0.031	0.79	0.027	0.69

R = Round corners with approximately 0.005″ radius.
N = Number of teeth on sprocket.
Tolerances for *D′* and *t* = +0.000″, −0.001″.
Maximum allowable film shrinkage = 1.50%.
Values given for *D′* are 0.001″ less than the theoretical.

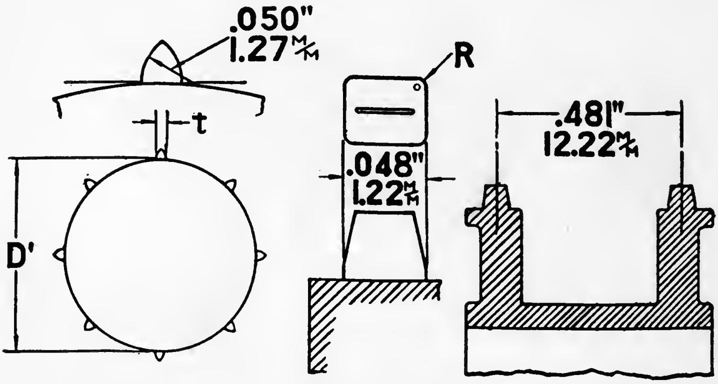
Values of *t* are not given in cases where the *number of teeth in mesh* as related to *N*, *the number of teeth on the sprocket*, is such that the wrap of the film on the sprocket would be greater than 180°.

CHART 21.

STANDARD 16-MM. SPROCKETS

COMBINATION SPROCKETS

(*Not Sound Sprockets*)



			Number of Teeth in Mesh							
			3		4		5		6	
N	*D'* *in.*	*D'* *mm.*	*t* *in.*	*t* *mm.*	*t* *in.*	*t* *mm.*	*t* *in.*	*t* *mm.*	*t* *in.*	*t* *mm.*
6	0.563	14.30	0.043	1.09						
8	0.753	19.13	0.043	1.09	0.040	1.02				
12	1.133	28.78	0.043	1.09	0.040	1.02	0.037	0.94	0.034	0.86
16	1.513	38.43	0.043	1.09	0.040	1.02	0.037	0.94	0.034	0.86

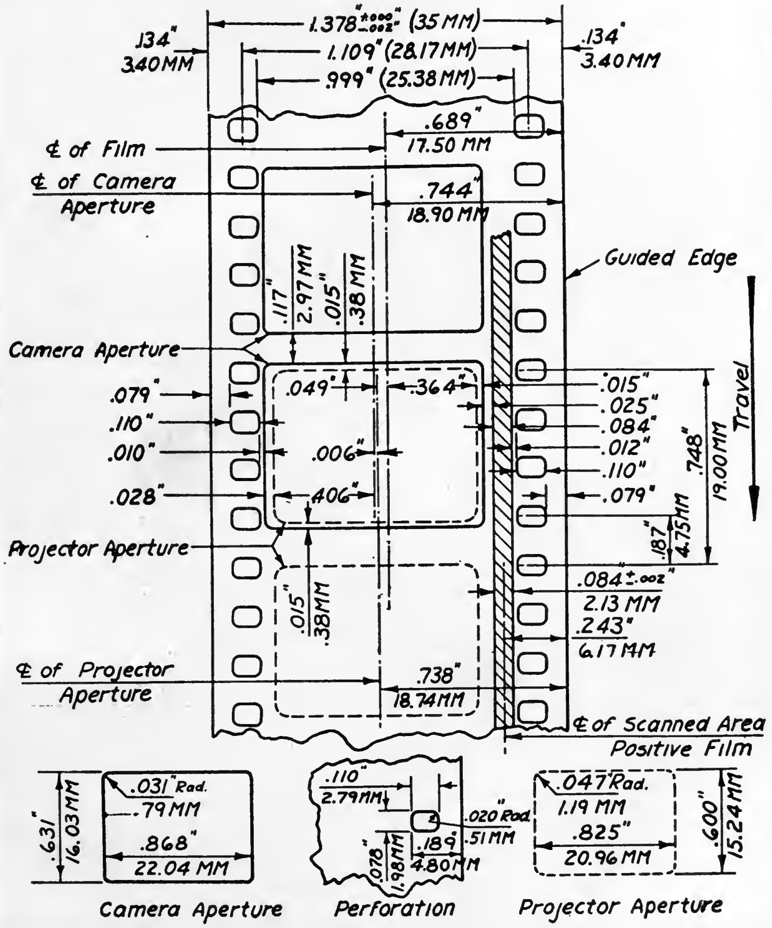
R = Round corners with approximately 0.005″ radius.
N = Number of teeth on sprocket.
Tolerances for D' and t = +0.000″, −0.001″.
Maximum allowable film shrinkage = 1.50%.
Values given for D' are 0.001″ less than the theoretical.
Values of t are not given in cases where the ***number of teeth in mesh*** as related to N, ***the number of teeth on the sprocket***, is such that the wrap of the film on the sprocket would be greater than 180°.

CHART 22.

STANDARD 35-MM. SOUND FILM

CAMERA APERTURE, PROJECTOR APERTURE, AND SCANNED AREA

These dimensions and locations are shown relative to unshrunk raw stock. Positive; emulsion side up. Negative; emulsion side down.



In the camera the emulsion side of the film faces the objective. Viewed from the objective the sound track is to the left.

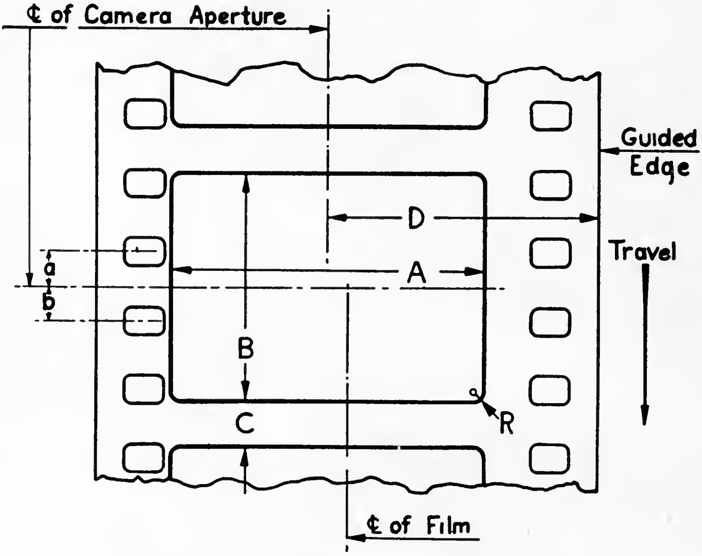
In the projector the emulsion side of the film faces the light source. Viewed from the light source the sound track is to the right.

CHART 23.

STANDARD 35-MM. SOUND FILM

CAMERA APERTURE

These dimensions and locations are shown relative to unshrunk raw stock. Negative; emulsion side down.



$a = b = {}^1/_2$ longitudinal perforation pitch.

	Inches	*Millimeters*
A	0.868	22.05
B	0.631	16.03
C	0.117	2.97
D	0.744	18.90
R	0.031	0.79

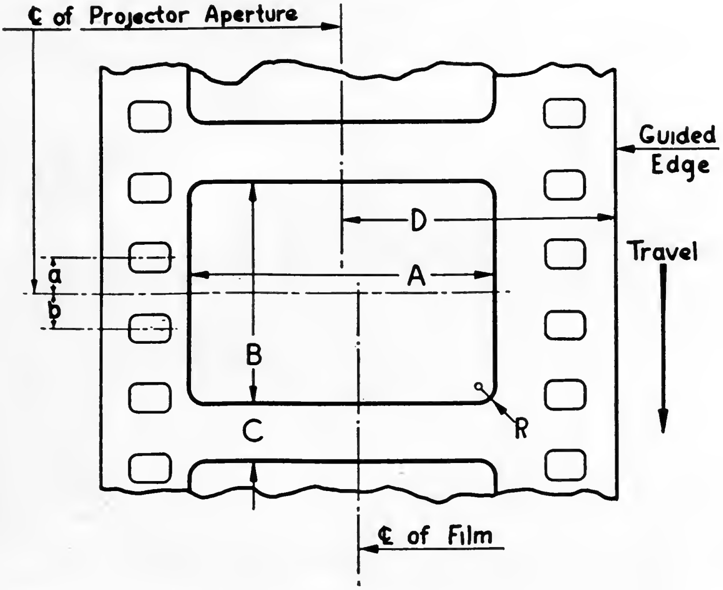
In the camera the emulsion side of the film faces the objective. Viewed from the objective the sound track is to the left.

CHART 24.

STANDARD 35-MM. SOUND FILM

PROJECTOR APERTURE

These dimensions and locations are shown relative to unshrunk raw stock. Positive; emulsion side up.



$a = b = {}^1/_2$ longitudinal perforation pitch.

	Inches	*Millimeters*
A	0.825	20.96
B	0.600	15.24
C	0.147	3.73
D	0.738	18.74
R	0.047	1.19

In the projector the emulsion side of the film faces the light source. Viewed from the light source the sound track is to the right.

CHART 25.

STANDARD 35-MM. SOUND FILM

SOUND RECORDS AND SCANNED AREA

These dimensions and locations are shown relative to unshrunk raw stock. Positive; emulsion side up. The dimensions as shown include the necessary allowance for film weave.

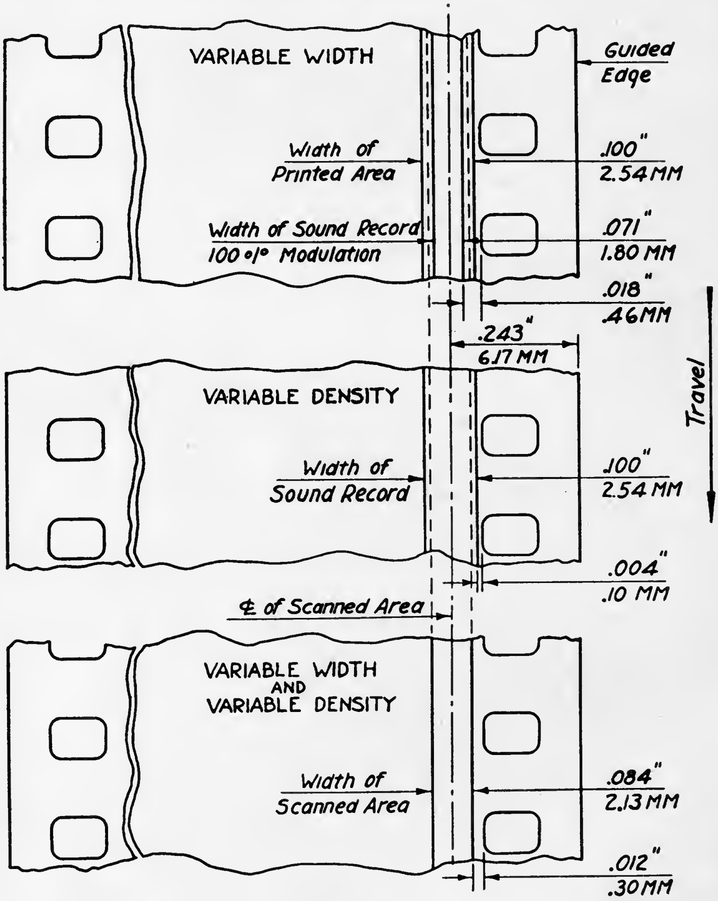
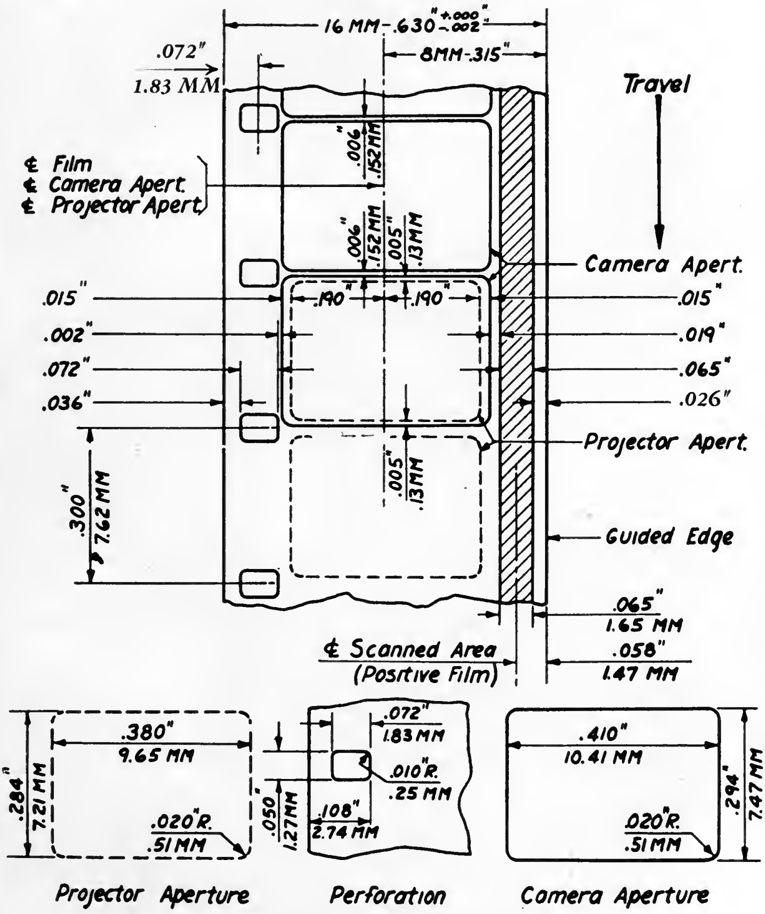


CHART 26.

STANDARD 16-MM. SOUND FILM

CAMERA APERTURE, PROJECTOR APERTURE, AND SCANNED AREA

These dimensions and locations are shown relative to unshrunk raw stock. Positive; emulsion side up. Negative; emulsion side down.



In the projector the base (not emulsion) side of the positive, made either by the reversal process or by optical printing from 35-mm. negatives, or from negatives produced by optical printing from 35-mm. film, faces the light source. Viewed from the light source, the sound track is to the left.

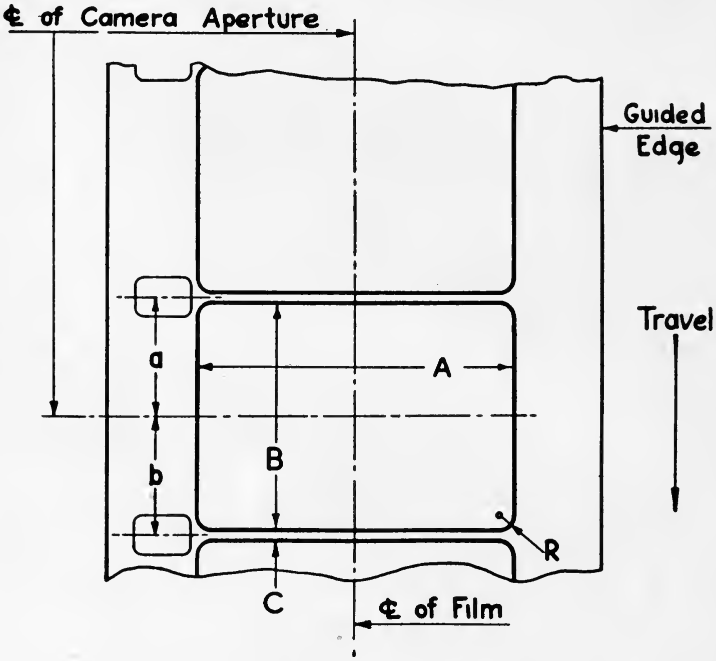
The emulsion side of the films used for color systems employing lenticulated film processes or screen-plate processes, and contact prints made from original 16-mm. negatives, must face the light source.

CHART 27.

STANDARD 16-MM. SOUND FILM

CAMERA APERTURE

These dimensions and locations are shown relative to unshrunk raw stock. Negative; emulsion side down.



$a = b = {}^1/_2$ perforation pitch.

	Inches	*Millimeters*
A	0.410	10.41
B	0.294	7.47
C	0.006	0.15
R	0.020	0.51

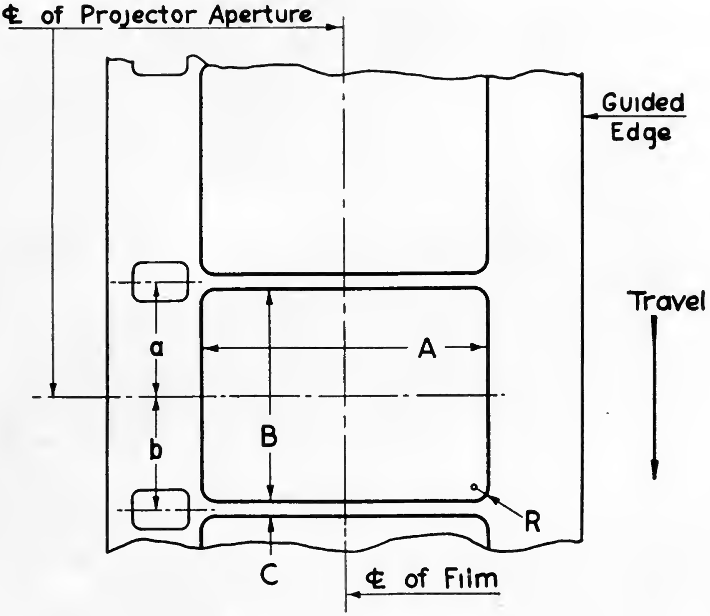
In the camera the emulsion side of the film faces the objective. Viewed from the objective the sound track is to the right.

CHART 28.

STANDARD 16-MM. SOUND FILM

PROJECTOR APERTURE

These dimensions and locations are shown relative to unshrunk raw stock. Positive; emulsion side up.



$a = b = {}^1/_2$ perforation pitch

	Inches	*Millimeters*
A	0.380	9.65
B	0.284	7.21
C	0.016	0.41
R	0.020	0.51

In the projector the base (not emulsion) side of the positive, made either by the reversal process or by optical printing from 35-mm. negatives, or from negatives produced by optical printing from 35-mm. film, faces the light source. Viewed from the light source, the sound track is to the left.

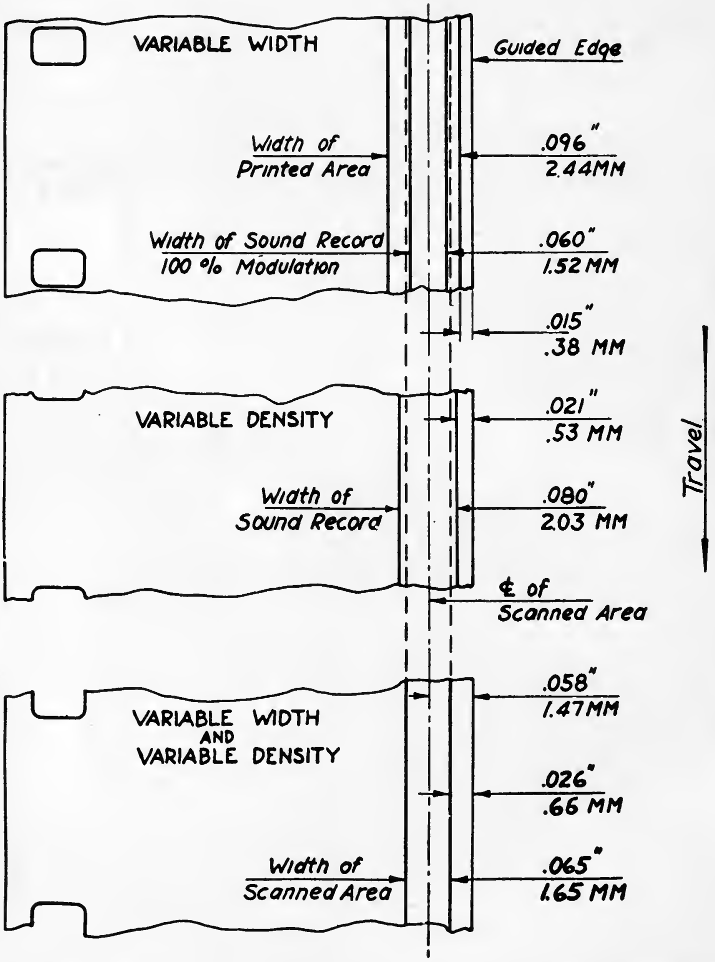
The emulsion side of the films used for color systems employing lenticulated film processes or screen-plate processes, and contact prints made from original 16-mm. negatives, must face the light source.

CHART 29.

STANDARD 16-MM. FILM

SOUND RECORDS AND SCANNED AREA

These dimensions and locations are shown relative to unshrunk raw stock. Positive; emulsion side up.



In the projector the base (not emulsion) side of the positive, made either by the reversal process or by optical printing from 35-mm. negatives, or from negatives produced by optical printing from 35-mm. film, faces the light source. Viewed from the light source, the sound track is to the left.

The emulsion side of the films used for color systems employing lenticulated film processes or screen-plate processes, and contact prints made from original 16-mm. negatives, must face the light source.

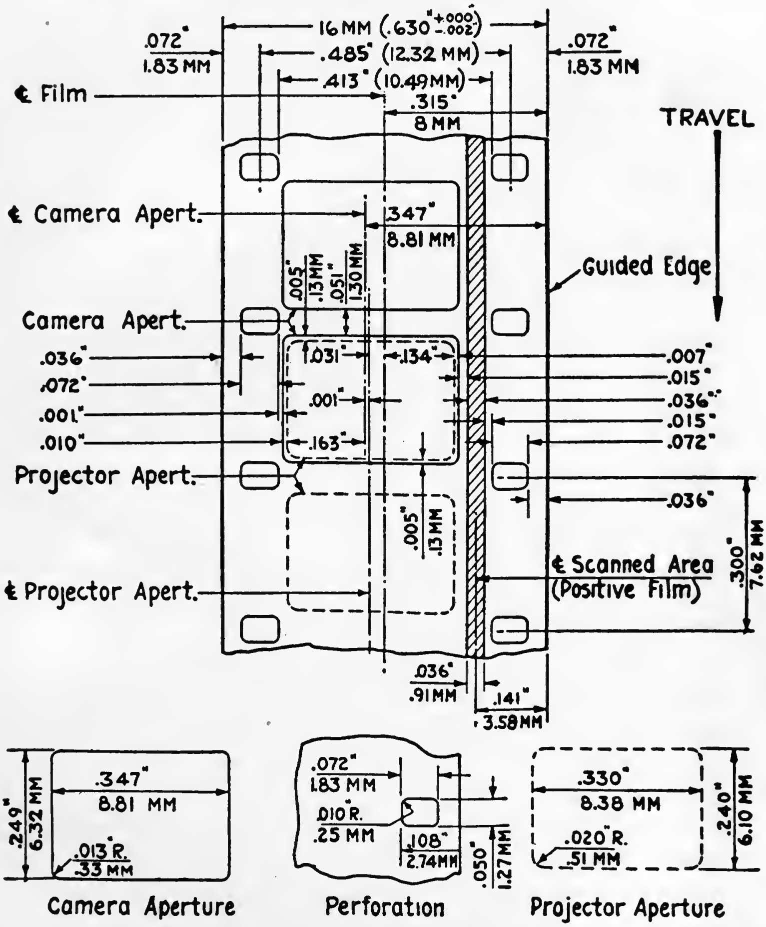
CHART 30.

16-MM. SOUND FILM

Non-recommended Specification

CAMERA APERTURE, PROJECTOR APERTURE, AND SCANNED AREA

These dimensions and locations are shown relative to unshrunk raw stock. Positive; emulsion side up.



In the projector the base (not emulsion) side of the positive, made either by the reversal process or by optical printing from 35-mm. negatives, or from negatives produced by optical printing from 35-mm. film, faces the light source. Viewed from the light source, the sound track is to the left.

The emulsion side of the films used for color systems employing lenticulated film processes or screen-plate processes, and contact prints made from original 16-mm. negatives, must face the light source.

CHART 31

STROBOSCOPIC-LIGHT HIGH-SPEED MOTION PICTURES*

H. E. EDGERTON AND K. J. GERMESHAUSEN**

Summary.—*A discussion of various methods of producing motion pictures at speeds higher than at present attainable with intermittent mechanisms; followed by a description of a high-speed motion picture camera (1200 frames a second, on 35-mm. film) using intermittent light from mercury-arc stroboscope lamps developed at the Massachusetts Institute of Technology. Several examples of the use of the lamp are given.*

The development of the motion-picture camera provided an excellent means for recording the motions of objects and for reproducing them whenever desired. Furthermore, it provided a means of changing the time-scale so that actions too slow to be seen in life (like the growth of a flower) or too fast (like the splash of a drop of liquid) might be projected upon the screen at such a rate that the eye would be able to see and the mind to comprehend. The usual type of intermittent-motion camera, when carefully designed and constructed, is able to take pictures at rates up to about 200 per second. Motion pictures taken at 200 frames per second and projected at 16 per second portray on the screen the motion of the subject slowed down by a factor of about 12.5 times.

The value of high-speed photography in its varied forms has long been recognized. From 1878, when Muybridge[1] first used a number of cameras tripped in succession to study the action of running horses, to the present day there has been a steady effort to develop photographic technic to enable one to see and record events too quick for the eye.

For many subjects the number of pictures per second attained by intermittent mechanisms is sufficient. Slow-motion pictures taken at such speeds have proved valuable for making time-motion studies of people doing production work, recording the winners of races, studying the movements of athletes, and for measuring the actions of

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

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machinery. There are, however, many problems that require a far greater speed than is practicable with the intermittent-type of camera, and a great deal of thought and effort has been applied to speed up the camera mechanism. Intermittent mechanisms were abandoned for speeds above about 200 frames per second because of the mechanical difficulties involved in accelerating the film between pictures, and cameras that employed film moving at a constant speed were designed.

There are two general methods of making exposures on a continuously moving film:

(1) Those employing a moving optical system, which holds the image stationary with respect to the film during the exposure time.

(2) Those employing a source of stroboscopic light, the flashes of which are of sufficiently brief duration to produce a sharp image on a moving film.

High-speed motion-picture cameras have been constructed utilizing one or the other of the two methods, or both. Each method has advantages and disadvantages, which must be carefully considered with respect to the particular problem at hand. The first type of camera[2,3,4,5,6] is especially adapted to studying subjects that produce their own light or are brightly illuminated, common examples of which are the burning of vapors, the action of explosives, the movements of an electric arc, the reactions in a photoflash lamp, and many others. The stroboscopic-light type of camera is of very limited use in the study of such problems.

The principal advantage of the stroboscopic-light type of camera[7,8,9,10] over the moving-optical-system type is that the exposure time may be made so short as effectively to stop the motion of rapidly moving objects. The stroboscopic light in its present state of development makes an exposure of a few millionths of a second, which is considerably shorter than is feasible by the moving-optical-system method; especially because as long an exposure as possible is usually desired in the moving-optical-system method in order to attain sufficient density of image on the film. In high-speed cameras employing stroboscopic light, the film is moved past the lens at a constant speed; and each time the film has moved the distance occupied by one frame, the subject is illuminated by a short brilliant pulse of light. The time at which the flash occurs is controlled by a commutator rigidly attached to the film-driving mechanism, and the duration of the flash is so short that no appreciable blurring of the picture occurs. Normal illumination such as that encountered indoors is insufficient to fog the film in a stroboscopic-light camera because the film passes the lens so rapidly.

When motion pictures are taken at high speed with any type of camera* the film must move rapidly, and one of the important problems in the design of either type of cameras is to make the film travel at the requisite speed without vibrating, fluttering, or breaking. The rapidly moving film must be guided properly, but the friction in sliding contacts may generate enough heat to ignite it. Static charges of electricity resulting from the friction must also be avoided, as they cause dendriform exposures on the film. Further than simply traveling smoothly at a high speed, it is important that the film accelerate rapidly so that it will attain the proper speed before much of it has passed through the camera. The acceleration must be uniform as well as rapid, as sudden jerks are likely to break the film.

TABLE I

Speed of Film in Terms of Frame Height and Rate of Exposure

Frame Height,	Exposures per Second							
	500	1000	2000	4000	8000	16,000	32,000	64,000
(inches)	Film Velocity (Ft. per Sec.)							
0.75[a]	31.25	62.5	125.0	250	500	1000	2000	4000
0.30[b]	12.50	25.0	50.0	100	200	400	800	1600
0.15	6.25	12.5	25.0	50	100	200	400	800
0.075	3.175	6.25	12.5	25	50	100	200	400

[a] Standard 35-mm. frame height.
[b] Standard 16-mm. frame height.

The height of the frame as well as the rate of making exposures is a factor influencing the film speed, since it is not necessary for the film to move as rapidly for a small frame as for a large one. Most of the very high-speed pictures are small in size, in some cases so minute as to be of little use in presenting detail even after enlargement. Conversely, if the film speed is increased in order to produce larger pictures, the camera becomes so bulky that it is no longer portable, and the subjects must be brought to the camera—a serious limitation to its usefulness. Table I shows the speed of the film in feet per second as a function of the height of the frame and the number of exposures per second.

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* Possible exceptions are those high-speed cameras employing stationary film and a large number of lenses,[11] or a number of spark sources of light (method of Cranz,[8] described by Ende[6]).

When film speeds higher than about 150 or 200 ft. per sec. are desired, the film is usually placed on the periphery of a drum.[3,4,7,8,9] The length of film that can be used is limited to the circumference of the drum, but very high film velocities can be attained in this way more easily than with a long strip. There are no acceleration problems, since the film may be brought up to speed as slowly as desired. Cameras of this type require a shutter that remains open during one revolution only, to prevent multiple exposure of the film.

In motion picture photography a certain amount of blurring of the images of moving objects is desirable, since the blurring produces the proper impression to the eye when the pictures are projected. If, however, the pictures are to be used to obtain scientific or engineering data from a frame-by-frame study, then maximum sharpness is desirable.

The exposure time of cameras employing a moving optical system usually is from one-half to two-thirds of the time elapsing between successive frames, although in some cameras the exposures may be longer than the interval between the pictures, as described by Jenkins.[2] It is possible to design the optical system for short exposure, but this leads to the difficulty of lighting the subject adequately. Light of high intensity is accompanied by heat, which may prove detrimental to the subject. Shadow or silhouette photographs are often employed for high-speed motion pictures, because the amount of light required is much less than that required for taking photographs by reflected light. However, this technic has its limitations, because the arrangement of the subject or the character of the results desired may often prevent its being employed.

The exposure time for the stroboscopic-light camera is usually less than $^1/_{100,000}$th of a second. It can not be made longer, as the motion of the film during exposure would blur the picture. Pictures taken with the stroboscopic-light camera will never for that reason show a moving object blurred by the motion of the object, except for such very high velocities as are attained by bullets or for close-ups of very rapidly moving subjects. The heat of the stroboscopic light is less than of a continuous light, as the light is extinguished between exposures.

A stroboscopic light that has been extensively used is the electric spark in air[7,8,9] produced when an electrical condenser discharges into an open air-gap. The duration of the flash can be made as short as $^1/_{1,000,000}$th of a second, or less. A spark-gap, however, presents serious problems when it is desired to produce enough light to illuminate an area two or three feet square 1000 or more times a second, because of the great power required and the difficulty of controlling it. Although a spark is not an efficient source of light, it is sufficient for some purposes. The light is highly concentrated, having a high intrinsic brilliancy which permits the use of reflectors and condensing lenses.

The discharge of electrical condensers through mercury lamps has proved a very useful source[10] of intermittent light, since they may be easily and accurately controlled, and the light produced by them is very actinic. The lamp is connected to a condenser and is made to flash at the desired instant by charging an external grid to a suitable potential. The voltage is produced by a pulse amplifier by means of which a large amount of power in the lamp can be controlled by a very small pulse. Any number of lamps may be connected in parallel and all flashed at the same instant, making it possible to build up the desired amount of illumination. The lamps used at present have a light-duration time of from one to ten microseconds, and may be flashed as often as 6000 times a second with suitable control circuits.

A Stroboscopic-Light High-Speed Camera.—Fig. 1 shows a stroboscopic-light camera for taking high-speed motion pictures on continuously moving film, developed at the Massachusetts Institute of Technology. The camera is simple in construction, consisting of a supply reel, a take-up reel, and one large sprocket. The supply reel is at the top, the film passing down over the sprocket to the take-up reel at the bottom. The reels are interchangeable, and have a core diameter of $2^1/_2$ inches and an outside diameter of $4^1/_2$ inches, with a film capacity of 135 feet. The core diameter was made larger than usual in order to reduce the speed of rotation and to lessen the difference between the speed of the full and that of the empty reel.

Because of the difficulty of decelerating the moving parts, no attempt has been made to stop the film after part of it has been exposed. All the film is run through for each shot, the length that is used depending upon the subject. Either 16-mm. or 35-mm. film can be used in the camera, since reels and sprockets are available for both sizes and are interchangeable. The camera in Fig. 1 is equipped with 35-mm. reels and sprocket, the 16-mm. equipment lying next to the camera. An appropriate aperture plate and lens mount are also available for both sizes of film.

The drive for the camera was designed with two objects in view: first, to accelerate the film rapidly; and, second, to move the film at a constant speed after the acceleration period. Two motors are used, one being a series motor connected directly to the take-up reel, and the other an induction motor belted to the sprocket shaft. The function of the series motor is to take up the film as it comes from the sprocket, and also to assist the other motor in pulling the moving parts of the camera up to speed quickly. A series motor is especially adapted to drive the take-up reel, because it has a large starting torque and a drooping speed-torque characteristic. The second motor is a three-phase induction motor rated at 3600 rpm., $^1/_4$ hp. It is connected to the sprocket shaft by means of a *V*-belt, which affords a convenient means of changing the speed by using different pulleys. Experiment shows that when double voltage is applied to both the motors, the film accelerates to a speed of 75 ft. per sec. while 10 feet of film pass through the camera. At that speed the camera takes 1200 35-mm. or 3000 16-mm. frames per second.

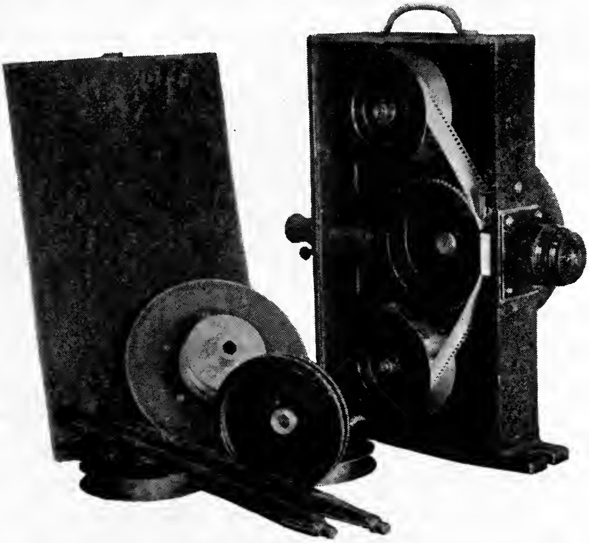

FIG. 1. Continuously moving-film type of high-speed motion picture camera constructed at the Massachusetts Institute of Technology for use with stroboscopic light.

The film does not slide through a gate or against any stationary part in the camera, because friction at such high speeds would generate heat and electrostatic charges. The camera shown in Fig. 1 is constructed in such a manner that during exposure the film lies against a large moving sprocket instead of against a gate. The sprocket must be large enough to prevent the curvature of the film from throwing the image appreciably out of focus, but not so large as to introduce difficulties in acceleration or to make the camera bulky and awkward. A consideration of those and other factors leads to a compromise, resulting in a sprocket of about 5 inches in diameter with twenty 35-mm. frames around its periphery; or, in the case of 16-mm. film, fifty frames. An aluminum roller is pressed by a spring against the sprocket in order to force the film down to the base of the teeth as it comes from the supply reel. A metal plow is located at the bottom of the sprocket to peel off the film from the teeth in case the take-up motor should not exert enough pull.

Two square holes cut into the sprockets conveniently permit lining up the camera and adjusting the focus, since a clear view of the image cast by the lens on the film may be viewed through the film from the back. A telescope is mounted through the rear of the camera in such a way as to afford an enlarged view of the center of the frame for finally adjusting the focus critically just before starting the camera.

The location of the pictures on the film is determined by the position of the film at the instant the stroboscopic lights flash. For satisfactory projection the pictures must be accurately and definitely located with respect to the sprocket holes; so, to accomplish this, a commutator is located on the same shaft as the sprocket, having as many contacts as there are frames around the sprocket. In order to eliminate vibration, the commutator must be carefully and accurately made, so that the segments are uniform and the surface is smooth. Only a small amount of power is needed to trip the electrical circuits, and therefore the brush may be light in construction. The brushes are adjusted when the camera is at rest, as there is no appreciable time-lag in the electrical circuits after the brush makes contact.

The source of stroboscopic light that has made this type of camera possible consists of mercury-arc tubes through which electrical condensers are discharged. Its important properties are: (1) the light is actinic; (2) the discharge time is short; (3) the timing of the flashes may be accurately controlled by a small amount of power; (4) the tubes are relatively simple; and (5) as many tubes may be operated in parallel as desired.

Fig. 2 is the wiring diagram of the stroboscope. A polyphase rectifier unit supplies about 10 kw. of power at 1000 volts to charge the condensers. In series with each condenser is a resistor large enough to limit the current from the source of power at the instant of discharge, but still small enough to allow the condenser to charge for the succeeding flash.

The power required to operate a camera of the stroboscopic type depends upon the subject being photographed The size and color of the subject are the primary factors that determine the amount of light necessary for each exposure. The power is, of course, proportional to the number of exposures per second. The number of exposures required depends upon the degree to which it is desired to slow down the motion. To illuminate an area of a few square feet with subjects of fairly light color requires a bank of at least four 12-inch tubes with condensers of 2 microfarads' capacity connected to each, charged to 1000 volts. At 1200 flashes per second nearly 10 kilowatts of power are required to operate this bank of lamps.

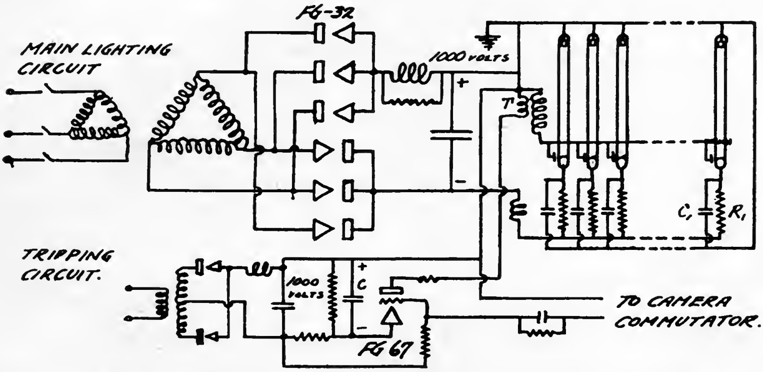

FIG. 2. Wiring diagram of stroboscopic lighting source for taking high-speed pictures.

The circuit diagram of the pulse amplifier is shown in the lower part of Fig. 2. The operation is as follows: The commutator on the camera has narrow segments that close the circuit so marked at the right of the diagram. The grid of the thyratron, an *FG-67* tube, is thus made positive for a few microseconds. Energy stored in the condenser *C* then discharges through the primary of the step-up transformer *T*. The high potential induced in the secondary of *T* is led to external starting bands or grids on the mercury-lamp tubes at the junction of the mercury and the glass. Such a high potential applied suddenly at that point starts a cathode spot in the liquid mercury where it touches the glass, which supplies the electron emission for the large peak currents in the mercury-arc stroboscope tube. Immediately after the condenser *C* discharges through the transformer and thyratron, a negative bias appears upon the grid of the thyratron, which thus regains control. Between flashes the condensers throughout the circuit accumulate charges, so that they are prepared for the next flash.

Uses of High-Speed Motion Pictures, and Examples.—The most obvious use of the high-speed camera is for taking motion pictures of fast or complicated motions in order that they may be slowed down, when projected on the screen, to such a speed that the eye is able to see and the mind to comprehend. Subsequent showings often bring out obscure but important details that were not noticed during previous projections. The motion picture can be kept for reference to refresh the memory or as a record of the motion at the particular time of the exposure.

A second use of the high-speed motion picture camera, perhaps more important than the first for engineering purposes, is its ability to permit making measurements of position as a function of time. The individual frames of the moving-picture film record the instantaneous position and form of the object being photographed with time interval between frames depending upon the rate at which the camera is run. The stroboscopic-light camera, when used for such work, may be arranged so that the time between flashes is accurately determined by a constant-frequency source of power instead of by the synchronizing commutator on the camera. The advantage of using an accurately timed flashing light lies in the fact that the speed of the film does not enter into the measurements. Needless to say, the pictures can not be projected, as they are not placed in the proper relationship to the sprocket holes. However, should it be desired to project them, they may be thrown upon a screen with respect to a stationary reference, and recopied frame by frame.

The velocity of a moving object may be determined from a motion picture film by measuring the difference in the position of the image between two successive frames and dividing by the time interval between the pictures. The accuracy of the results is influenced both by the accuracy of measurement of the displacement and the accuracy of determination of the time interval. Usually the former involves the larger error because of the difficulty of measuring the displacement on account of the smallness of the pictures, the blur if the exposure is long, and the size of the silver grains. The film shrinks as it ages, so that the photographs should have a distance reference upon them in order that the result of the measurement may be independent of the state of the film. The accuracy of determining the velocity is improved by taking close-up pictures, showing greater displacements between images. The short exposure time of the stroboscopic light is especially advantageous for velocity measurements, since the pictures are not blurred by motion of the object during exposure.

Acceleration measurements follow from the velocity determinations, since the acceleration is the change of the volocity with time. The slope of the velocity-time curve is therefore the acceleration, and the accuracy of the measurement depends upon the accuracy of measurement of velocity and time, and the additional difficulty of measuring the slope of the curve.

A very good example to illustrate the method of measuring velocities is the analysis[13] of a golf stroke. Fig. 3 is a series of pictures taken at a rate of 960 per second. The velocities of the ball and club are obtained by measuring the displacement between pictures and then multiplying by 960. Measurements of displacement by means of a comparator permit the determination of the velocities of the club and ball, both before and after impact, with an accuracy of about 2 per cent. An analysis of the photograph shown as Fig. 5 resulted in the following data:

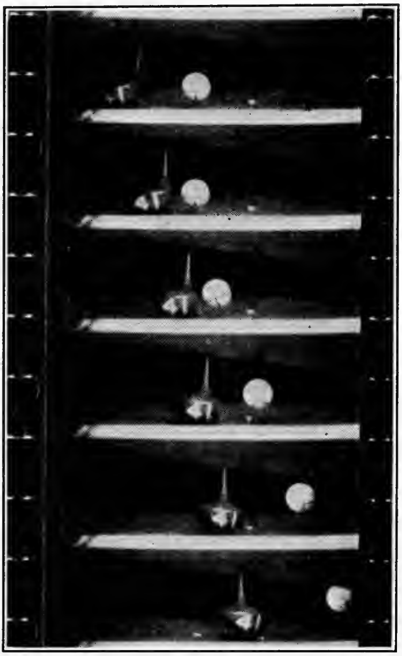

FIG. 3. Enlarged section of 35-mm. film made for the measuring velocities of golf club and ball. Interval of time between pictures, $^1/_{960}$ second.

Club velocity just before impact	151 ft./sec.
Club velocity just after impact	113 ft./sec.
Ball velocity	186 ft./sec.
Spin of the ball	5000 r.p.m.

As the mass of the ball and the club-head are known, there is sufficient information to calculate the energy lost by the club-head and the energy gained by the ball, as well as to calculate the energy stored in rotation. In addition, the pictures show definitely that the ball and club are in actual contact for less than $^1/_{1000}$th of a second, since the impact occurs during the interval between pictures.

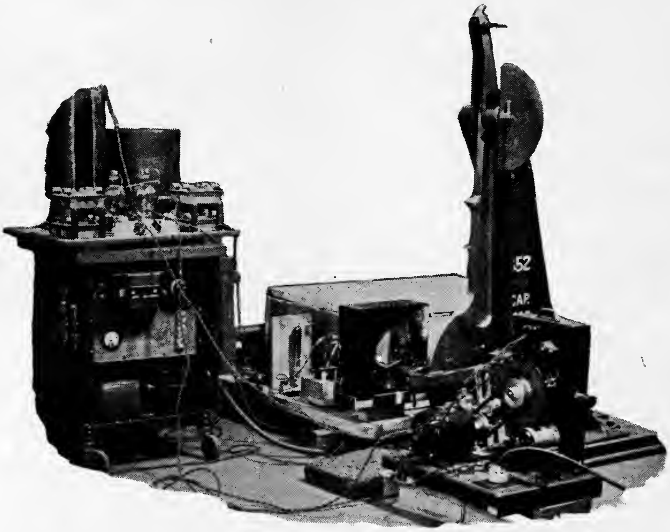

FIG. 4. Camera in position for taking silhouette pictures of index pointer on the pendulum of a Charpy impact-testing machine.

It is not possible to measure the accelerations of the club and ball from these pictures, since the acceleration of the ball was completed between frames.

The Charpy impact machine for testing materials has been studied by high-speed pictures taken at 6000 per second. Fig. 4 shows the camera arranged to take silhouette pictures of the impact pendulum. The arrangement of the light and camera is similar to that used by Bull[7] and Cranz[9] and offers many advantages in problems where a silhouette is sufficient. The depth of field is very great, corresponding to that obtained by a pinhole, and the utilization of light is efficient. The light source for the set-up shown in Fig. 4 is a spark gap, with brass electrodes spaced about 1 mm. The gap is connected in series with a mercury lamp which, besides timing the instant of flash, also acts as a rectifier to prevent the current from oscillating in the gap, as it normally does. A $^1/_2$-microfarad condenser charged to 1000 volts in this case furnished sufficient light to produce a good density on positive film with an exposure time of about 10^{-6} second. Fig. 5 shows some of the 6000-per-second pictures of a stationary reference point and a pointer on the moving pendulum. The pictures are only 8 mm. high, but extend across the entire 35-mm. frame, permitting the motion of the pendulum to be followed over a greater portion of its swing.

A few preliminary experiments have been made with a bow and arrow, using the high-speed camera to determine velocities and accelerations of the arrow. The arrow was provided with an accurate scale along its length, and the camera arranged to photograph about two inches of the scale. (See Fig. 6.) A close view is needed to attain sufficient accuracy in displacement measurements to enable the velocity and acceleration to be determined. The mercury lamp was placed close to the section to be photographed, reducing the power required to illuminate the subject.

FIG. 5. High-speed motion pictures taken with the set-up shown in Fig. 4 at 6000 per second, for determining the action of a metal during impact tension.

A photographic study of an automatic tapping machine furnished some interesting results indicating an advantage in increasing the speed of the cycle. Motion pictures at the rate of 1020 per second were taken of a light aluminum sectored disk about 4 inches in diameter attached to the chuck, making it possible to determine the speed of rotation as a function of time. The velocity-time curve of the cycle showed the manner in which the chuck was accelerated by the clutch, the decrease in speed during the time the threads were tapped, the deceleration period, and the withdrawal of the tap from the work.

The Aeronautical Engineering Laboratory of the Massachusetts Institute of Technology employed a high-speed camera to photograph the spray from solid injection Diesel jets. The mercury-arc lamp for this problem was shaped like a doughnut and fitted inside

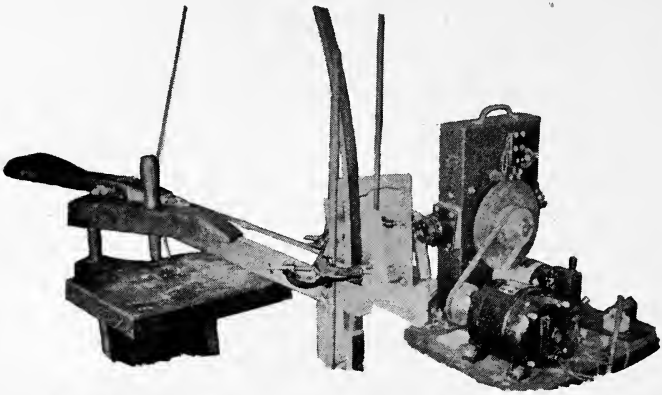

FIG. 6. High-speed camera arranged for a close-up of shot and arrow, for analyzing its motion.

a pressure chamber filled with carbon dioxide. In one end of the chamber was a heavy glass window through which the camera could be directed at the spray. The camera was operated at the rate of about 2000 pictures per second, and from the photographs it was possible to determine the velocities of various portions of the spray and to examine the form of the charge as it diffused through the chamber.

FIG. 7. Frames from 35-mm. film taken with ordinary camera, of vortices at the blades of an electric fan. A stroboscope was used for illumination, synchronized with the fan.

Rotary and vibratory motions of a repetitive nature too fast for the eye to see may be very effectively studied by means of the stroboscope,[12] and since the method is relatively simple it should be used instead of the high-speed camera, wherever possible. The use of the stroboscope depends upon the persistence of vision of the eye. Flashes of light are made to occur at the same frequency as that of the motion being studied. The eye, since it sees the object at only a single instant during each cycle, receives each view of the image at the same relative instant of the cycle; hence the object appears to be stationary. The motion of the object may be made to appear to pass through its cycle of events slowly by adjusting the frequency of the light to a value slightly different from what is required to stop the motion. It is thus possible to slow down the apparent motion. An ordinary motion picture camera may be used to make such a slow-motion record if the frequency of the stroboscopic light is sufficiently high to expose every frame of the motion picture film. Fig. 7 shows a section of a film taken in such a manner, showing the flow of air through a fan blade. Titanium tetrachloride was used to produce the smoke for rendering the filaments of air visible.

The examples described in this paper are examples of subjects to which the camera may be applied, and emphasize those types of problems for which the stroboscopic-light high-speed camera is especially adaptable.

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DISCUSSION

MR. ROSENBERGER: Can the mercury lamps be used to furnish stroboscopic illumination for a microscope?

MR. EDGERTON: The mercury-arc lamp is not very suitable for use as a source of illumination for a microscope, because its brightness is relatively low. However, we have used light from the end (looking down the axis) of a specially constructed tube with some success. A spark in series with a mercury-arc tube as a control element is quite a satisfactory method of taking high-speed motion pictures through a microscope, because the spark is a concentrated source of light and the instant of starting the spark is under control.

MR. MCGUIRE: Would it be possible to increase indefinitely the speed of taking motion pictures by the stroboscopic-light method?

MR. EDGERTON: Several factors limit the upper speed at the present time, but further developmental work will increase the upper value. One factor is the problem of accelerating the film and running it at a high velocity. Another is the tendency of the mercury tube to "hold-over"; that is, to fail to oscillate at high speed. The highest speed at which we have operated the camera described in this paper is 6000 frames per second, taking pictures having one-fifth the height of a standard 35-mm. frame.

A SWEEP OSCILLATOR METHOD OF RECORDING WIDE FREQUENCY-BAND RESPONSE SPECTRA ON SHORT LENGTHS OF MOTION PICTURE FILM*

J. CRABTREE**

Summary.—*A rapid small-scale method of determining frequency response characteristics, of particular application to cases in which a large number of conditions are to be compared.*

An important measurement frequently involved in the study of sound-film records is that of determining frequency response characteristic. The method usually employed is cumbersome, involving the use of long lengths of film. Enough footage of each frequency must be recorded and printed to enable a measurement of response to be made in the reproducer. At a reproduction speed of 90 feet per minute, at least 15 feet of film of each frequency will be required, involving for 6 frequencies a total length of film of about 100 feet. For processing such a length of film in a uniform manner, a continuous developing machine is essential.

In the Sound Picture Laboratory of Bell Telephone Laboratories it was desired to investigate in detail the possibility of improving the frequency response characteristic of recordings by modifying the processing, which is here meant to include the developing, fixing, washing, and drying operations. This involved the study of the influence of a number of different developers upon the frequency response characteristic; and, since the minimum volume of developing solution required for the processing machines in this Laboratory is 75 gallons, it was obvious that an extended investigation using the customary machine processing methods was not feasible.

It was decided to record the desired frequency spectrum on short lengths of film which could be processed in small trays, glass cylinders, or in a bench-model developing machine, and to determine the response characteristic by measuring the amplitudes of the developed record at the various frequencies in a recording microdensitometer.

---

* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

** Bell Telephone Laboratories, New York, N. Y.

Since the microdensitometer to be used accommodated a maximum length of film of $2^1/_4$ inches, the entire sound spectrum desired had to be recorded within that length. There were several methods by means of which that could be done. The one adopted was to rotate the rotor of a heterodyne oscillator at a suitable speed and record the output on film by means of the light-valve in the usual manner. The oscillator that was used had a frequency range of 20 to 9500 cycles, and was readjusted to a minimum frequency of 500 cycles, thus covering a range of 500 to 10,000 cycles. One revolution of the rotor varied the output continuously from 500 to 10,000 cycles.

FIG. 1. Developed image of a 500- to 10,000-cycle band on a $2^1/_4$-inch length of film.

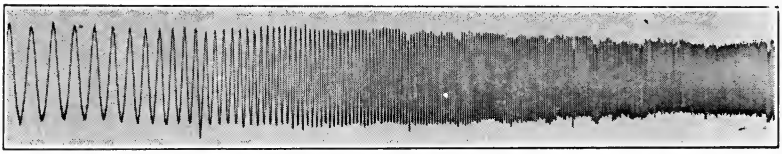

FIG. 2. Trace of image in Fig. 1 produced by scanning in a microdensitometer.

In order to record the 500- to 10,000-cycle band within the limits of the $2^1/_4$-inch length of film, it was necessary to rotate the oscillator rotor at 360 rpm. The developed image of the record had the appearance of Fig. 1. When scanned in the microdensitometer, it produced the trace shown in Fig. 2.

The response at any frequency is assumed to be indicated by the amplitude of the trace at that frequency, although, strictly speaking, that would be true only in the case of a print at reciprocal gamma or in the case of a "toe" record. However, as the records are used qualitatively, the assumption is permissible.

The wave-form is complex, for the reason that the frequency is constantly changing at a rapid rate. Purity of wave-form, however, is not an essential, the chief requisite being a range of frequencies easily and consistently reproducible at any time.

It will be noted that very little frequency loss is shown in Fig. 2, despite the constancy of the input to the light-valve. This is due to the fact that the high-frequency loss inherent in the film is equalized by valve resonance. It is possible to vary the high-frequency content of the record by suitably choosing the tuning frequency. In practice, the valve is tuned to 11,000 cycles, and a length of film recorded at a level below valve clash. The undeveloped film containing a large number of successive exposures is stored, and short lengths are detached as needed. The exposed lengths of film are subjected to various conditions to be studied, and the recorded image is scanned in the microdensitometer and the traces compared. It is possible in such a manner to conduct an investigation of the above type in a fraction of the time required for full-scale experiments. Promising leads may be selected and studied further on a large-scale basis.

PROGRAM OF FALL, 1934, CONVENTION
HOTEL PENNSYLVANIA, NEW YORK, N. Y.

MONDAY, OCTOBER 29th

10:00 a.m. *Salle Moderne.* **Business and Technical Session,** President A. N. Goldsmith, presiding.

Society Business; election of officers for 1935.

"Current Developments in Production Methods in Hollywood"; H. G. Tasker, United Research Corp., Long Island City, N. Y.

"The Use of Motion Pictures for Visual Education in the New York Schools"; Miss R. Hockheimer, Director of Visual Education, New York, N. Y.

Motion Picture: "Fundamentals of Acoustics"; Introduced by H. A. Gray, Erpi Picture Consultants, Inc., New York, N. Y.

"The Motion Picture Industry in Soviet Russia"; V. I. Verlinsky, Amkino Corp., New York, N. Y.

Report of the Standards Committee; M. C. Batsel, *Chairman.*

Report of the Non-Theatrical Equipment Committee; R. F. Mitchell, *Chairman.*

Report of the Historical and Museum Committee; W. E. Theisen, *Chairman.*

1:00 p.m. *Roof Garden.* **Informal Get-Together Luncheon.**

For members, their families, and guests. Speakers:

Mrs. Frances Taylor Patterson, Director of Photoplay Appreciation, Columbia University, New York, N. Y.

Mr. Martin Quigley, Quigley Publications, New York, N. Y.

Col. R. W. Winton, Managing Director, Amateur Cinema League, Inc., New York, N. Y.

2:30 p.m. *Salle Moderne.* **Photographic Session,** Mr. H. G. Tasker, presiding.

"New Developments in Micro Motion Picture Technic"; H. Rosenberger, Sandy Hook, Conn.

"Some Technical Aspects of Wild Animal Photography"; Martin Johnson, New York, N. Y.

"The Theatergoer's Reaction to the Audible Picture as It Was and Now"; Mordaunt Hall, New York, N. Y.

"Historical Notes on X-Ray Cinematography"; R. F. Mitchell, Bell & Howell Co., Chicago, Ill., and L. G. Cole, New York, N. Y.

"Roentgen Cinematography"; R. F. James, Westinghouse Lamp Co., Bloomfield, N. J.

"Application of X-Ray Photography in Industrial Development Work"; J. R. Townsend and L. E. Abbott, Bell Telephone Laboratories, Inc., New York, N. Y.

8:00 p.m. *Salle Moderne.* **Lecture and Motion Pictures.**

"Some Photographic Aspects of Sound Recording"; C. E. K. Mees, Eastman Kodak Co., Rochester, N. Y. Exhibition of Recent Outstanding Motion Pictures.

TUESDAY, OCTOBER 30th

9:15 a.m. *Salle Moderne.* **Sound Session,** Treasurer T. E. Shea, presiding.

"Piezoelectric Loud Speakers"; A. L. Williams, Brush Development Co., Cleveland, Ohio.

Motion Picture: "Sound Waves and Their Sources"; Introduced by H. A. Gray, Erpi Picture Consultants, Inc., New York, N. Y.

"Performance and Use of Wave Filters, and a Mechanical Demonstration of Their Characteristics"; C. E. Lane, Bell Telephone Laboratories, Inc., New York, N. Y.

"Applications of High-Speed Motion Picture Photography in Industrial Development Work"; H. I. Day, Electrical Research Products, Inc., New York, N. Y.

"Some Characteristics of 16-Mm. Sound by Optical Reduction and Re-Recording"; C. N. Batsel and L. T. Sachtleben, RCA Victor Co., Camden, N. J.

"The Need for Uniform Density in Variable Density Sound Tracks"; F. H. Richardson, Scarsdale, N. Y.

1:30 p.m. *Salle Moderne.* **Theater and Projection Session,** President A. N. Goldsmith, presiding.

"Possibilities of Engineering Developments in the Motion Picture Industry"; A. N. Goldsmith, New York, N. Y.

Report of the Projection Practice Committee; H. Rubin, *Chairman.*

Report of the Projection Screens Committee; J. H. Kurlander, *Chairman.*

"Proposed Architectural, Acoustic, and Optical Standards in Motion Picture Design"; B. Schlanger, New York, N. Y.; S. K. Wolf, Electrical Research Products, Inc., New York, N. Y.; and L. A. Jones, Eastman Kodak Co., Rochester, N. Y.

"Electronic Tube Control for Theater Lighting"; J. R. Manheimer and T. H. Joseph, E-J Electric Installation Co., New York, N. Y.

"Luminous Fronts for Theaters"; C. M. Cutler, General Electric Co., Cleveland, Ohio.

8:00 p.m. *Salle Moderne.* Eixhbition of Recent Outstanding Motion Pictures.

WEDNESDAY, OCTOBER 31st

9:15 a.m. *Salle Moderne.* **Photographic Session,** Mr. L. A. Jones, presiding.

"International Sensitometric Standardization"; W. Clark, Eastman Kodak Co., Rochester, N. Y.

Report of the Color Committee, C. Tuttle, *Vice-Chairman.*

Report of the Membership and Subscription Committee, E. R. Geib, *Chairman.*

"Some Factors in Photographic Sensitivity"; S. E. Sheppard, Eastman Kodak Co., Rochester, N. Y.

"Rear Projection for Process Photography"; G. G. Popovici, Eastern Service Studios, Inc., Long Island City, N. Y., and H. Griffin, International Projector Corp., New York, N. Y.

"The 16-Mm. Sound-Film Outlook"; W. B. Cook, Kodascope Libraries, New York, N. Y.

"The Non-Rotating High-Intensity D-C. Arc for Projection"; D. B. Joy and E. R. Geib, National Carbon Co., Cleveland, Ohio.

"The Stablearc-Unitwin Motor-Generator for the Non-Rotating High-Intensity D-C. Arc"; I. Samuels, Automatic Devices Co., Allentown, Pa.

2:00 p.m. Inspection Trips to the Plants and Laboratories of:
International Projector Corp.
Weston Electrical Instrument Corp.
Museum of Science and Industry
Eastern Service Studios, Inc.
De Luxe Laboratories, Inc.
Biograph Studios
Ft. Lee Laboratory of Consolidated Film Industries, Inc.

7:30 p.m. *Grand Ballroom.* **Semi-Annual Banquet and Dance.**

Address by Dr. F. B. Jewett, Vice-President of the American Telephone & Telegraph Co., and President of Bell Telephone Laboratories, Inc.

THURSDAY, NOVEMBER 1st

9:15 a.m. *Salle Moderne.* **Studio and Lighting Session, President A. N. Goldsmith, presiding.**

Apparatus Symposium
Moviola Co., Hollywood, Calif.
H. A. DeVry, Inc., Chicago, Ill.
Weston Electrical Instrument Corp., Newark, N. J.
Roy Davidge Co., Hollywood, Calif.
Akeley Camera Co., New York, N. Y.

"What Is Light?"; S. G. Hibben, Westinghouse Lamp Co., Bloomfield, N. J.

"High-Intensity Mercury and Sodium Arc Lamps"; L. J. Buttolph, General Electric Vapor Lamp Co., Hoboken, N. J.

"The Use of the High-Intensity Mercury Vapor Lamp in Motion Picture Photography"; M. W. Palmer, Motion Picture Lighting and Equipment Corp., New York, N. Y.

"Recent Developments in the Use of Incandescent Lamps for Color Motion Picture Photography"; R. E. Farnham, General Electric Co., Cleveland, Ohio.

"Reflecting Surfaces of Aluminum"; J. D. Edwards, Aluminum Co. of America, New Kensington, Pa.

1:30 p.m. *Salle Moderne.* **Laboratory Session.** **Vice-President J. I. Crabtree, presiding.**

"A Revolving Lens for Panoramic Pictures"; F. Altman, Hawk-Eye Works, Eastman Kodak Co., Rochester, N. Y.

"A New Method for the Control of Humidity"; F. R. Bichowsky, Surface Combustion Corp., Toledo, Ohio.

Symposium on Construction Materials for Motion PictureProcessing Apparatus:
International Nickel Co., New York, N. Y.
Carnegie Steel Co., New York, N. Y.
Synthane Corp., Oaks, Pa.

"A Roller Developing Rack for Continuously Moving the Film during Processing by the Rack-and-Tank System"; C. E. Ives, Eastman Kodak Co., Rochester, N. Y.

"Training Future Cameramen"; H. C. McKay, New York Institute of Photography, New York, N. Y.

SOCIETY ANNOUNCEMENTS

ATLANTIC COAST SECTION

At a meeting held at the Hotel Pennsylvania, New York, N. Y., October 10th, Mr. A. T. Williams, of the Weston Electrical Instrument Corp., Newark, N. J., presented a paper on the subject of "Photronic Exposure Meters," in which the many changes and improvements that have been made in those instruments during the past few years were discussed.

The meeting was well attended. Plans were announced for future meetings of the Section. Ballots for the election of Section officers and Managers for 1935 recently mailed to the voting membership of the Section included the following names:

Chairman:	L. W. Davee
	J. H. Spray
Sec.-Treas.:	D. E. Hyndman
Manager:	J. A. Norling
	H. Griffin

The Chairman and Secretary-Treasurer are to be elected for one-year terms; the Manager for a two-year term. The other Manager, whose term does not expire until December 31, 1935, is M. C. Batsel. Mr. H. G. Tasker, present Chairman of the Section, will remain a member of the Board of Managers, as Past-Chairman.

SOUND COMMITTEE

The results of calibrations of a Standard S. M. P. E. Sound Test Film in various sound laboratories were compared at a recent meeting and further plans were made for continuing and completing the work, with the view of eventually establishing a standard of sound recording that will permit direct comparison of recordings made under different conditions and in different studios on an invariable and mutual basis.

The Society regrets to announce the deaths of two of its members,

William V. D. Kelley

September 30, 1934

and

George K. Jenson

There's No Need To Gamble

ADAPTABILITY to every kind of shot . . . wide opportunity for creative artistry . . . dependable uniformity . . . Eastman Super-Sensitive "Pan" gives you all these. Results prove it every day. Just choose this famous Eastman film . . . and stick to it. There's no need to gamble.

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JOURNAL

OF THE SOCIETY OF

MOTION PICTURE ENGINEERS

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JOURNAL
OF THE SOCIETY OF
MOTION PICTURE ENGINEERS

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Published monthly at Easton, Pa., by the Society of Motion Picture Engineers
Publication Office, 20th & Northampton Sts., Easton, Pa.
General and Editorial Office, Hotel Pennsylvania, New York, N. Y.

Entered as second class matter January 15, 1930, at the Post Office at Easton, Pa., under the Act of March 3, 1879. Copyrighted, 1934, by the Society of Motion Picture Engineers, Inc.

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THE EFFECT OF APERTURE LENSES ON ILLUMINATION*

W. B. RAYTON**

Summary.—*The complexity of the geometrical optics involved in a motion picture projector leads to numerous proposals for improving illumination in some respect that look plausible at first glance but generally fail in practice. Among such proposals we might consider the addition of a small collective lens in the immediate neighborhood of the film gate. Careful study of the transmission of light from source to screen reveals the fact that in some reflector arcs such a lens can improve evenness of illumination and in some cases raise the general level, although the latter could have been taken care of in the design of the lamp. In a typical condenser equipment with the 13.6-mm. high-intensity arc no possibility of improvement was found either in an analytical study or in experimental tests.*

The illumination of a projected motion picture image for any given combination of light source, light collector, and projection lens is a subject so complex that any approach to full comprehension of all its details can be attained only after prolonged study. This fact may be responsible for the proposal of numerous schemes for improving illumination, either by increasing its total quantity or by improving its distribution, that at first sight look plausible, but do not always work out as expected. It is to the application of one such proposal in the projection of standard 35-mm. film that attention is here directed. It is a suggestion the principal aim of which is to improve evenness of illumination. Since relatively few have occasion to keep in mind all the details of motion picture illumination it seems advisable first to outline briefly the two types of illuminators in common use.

The ideal illuminator for motion picture projection would be a light source of uniform and sufficient brightness and as large as the aperture in the film gate, but not so hot as to damage film when placed practically in contact with it. If such a light source were available, a motion picture projector would reduce to the form shown in Fig. 1. Illumination would be even over the area of the picture except for two facts, one of which we shall ignore, and the other of which is

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

** Bausch & Lomb Optical Co., Rochester, N. Y.

demonstrated in the figure. It is much more convenient in studying this problem to think of the light sometimes as traveling from the screen to the film; at other times it may be more convenient to think of it as traveling from the light source to the screen, in the normal manner. The reversibility of a light path makes such a procedure entirely justifiable. At present we shall think of it as traveling from the screen toward the light source. In Fig. 1 two beams of light are shown, one focusing at the center and the other at the corner of the aperture. The one that focuses at the center of the film aperture fills the front of the projection lens, but the oblique beam does not. Any light belonging to the latter beam that falls on the front lens higher than the upper ray shown will be stopped by the mounting of the rear lens. In a few cases there may be none of this vignetting of the oblique beams but it is generally found in lenses of any considerable length. This reduction in the effective aperture of the lens for oblique beams results in a reduction of brightness at the margin as compared with the center, even if the source of light were ideal, as here assumed.

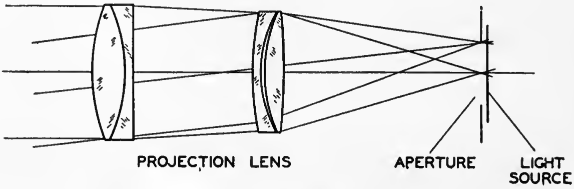

FIG. 1. Ideal projection system; source of light assumed large and bright enough to illuminate the whole aperture, and not so hot as to damage film.

Unfortunately, no source of light even remotely approaches such conditions. Available sources that are bright enough are not only tremendously hot, but are also too small, so the science of optics is called upon to make the available sources of light serve our purpose. To get away from the danger due to heat, it is obvious that it is necessary to move the source of light farther from the film. To overcome the difficulty due to the insufficient size of sources the well-known optical law is applied; stating, that by means of a collective element, such as a condenser lens or a concave mirror, a source of light can be made to behave as though it were of any desired size, without any more than a minor reduction in its intensity. With a given light collector, the maximum size the source may be made to appear is the diameter of the collector (condenser lens or mirror). In practice it is not always possible to make the light source appear as large as desired because practical considerations limit the size of the light-collector. The laws of optics set a definite limit to the size attainable in condensers and mirrors of a given focal length; and, generally, the laws of economic limitations become effective before the optical limitations do. Larger condensers and mirrors could be made and some improvement in illumination achieved thereby, but the cost would become prohibitive.

Since light collectors can not be made as large as they should be made, certain undesirable consequences follow, which will now be examined briefly. There are two cases. The simpler one is presented by customary practice in reflector arcs and will be considered first. Fig. 2 represents an assembly of a 5-inch projection lens of the Cinephor type, a standard aperture, an arc with an 11-mm. positive carbon, and an elliptical mirror 11.5 inches in diameter. The arc is imaged in the plane of the film or very near it. To study this case it is helpful again to consider the light as proceeding from the screen to the arc.

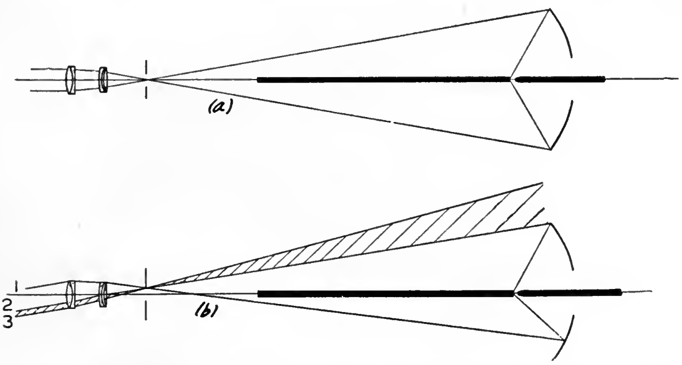

FIG. 2. Typical reflector arc; 5-inch projection lens, 11-mm. carbon, 11.5-inch diameter elliptical reflector: (*a*) central beam; (*b*) oblique beam.

Fig. 2*a* shows the beam of light involved in imaging the center of the picture and Fig. 2*b* an oblique beam that images a point at the corner of the picture. For the center of the picture the mirror is large enough to fill an area of the lens corresponding to a relative aperture of about *f*/2.8. A beam of light of that diameter entering the lens would focus at the center of the film aperture, diverge from the focal point, and just fill the mirror. Since film aperture and arc crater are conjugate foci, the beam after reflection by the mirror would come to a focus again at the center of the crater.

The oblique pencil of light is indicated by three rays *1*, *2*, *3*, which divide the beam into two zones. Ray *2* is a limiting ray, the position of which is found by joining the upper edge of the mirror to the corner of the film aperture. Ray *1* is another limiting ray, the highest ray that will pass through the projection lens at that angle. The two rays, and any that lie between them, will participate in imaging the corner of the aperture upon the screen, but they do not include the whole lens aperture. Rays between *2* and *3* are unavailable because the mirror is too small. The oblique beam is limited on one side by the size of the mirror and on the other by the construction of the projection lens. It is smaller than the central beam, and the illumination at the edge of the screen is correspondingly less than at the center.

It should be noted that an additional complication is introduced by the obstruction of light by the carbons and carbon-holder. As a consequence, both central and oblique beams have irregularly shaped holes in the center. The obstruction is slightly greater for oblique than for central beams. The difference is not great from the absolute standpoint, but inasmuch as the oblique beam is of smaller cross-section than the central one, the relative reduction is considerably greater in the former. If, as in this case, the arc is imaged at the film, the question of arc size is easily settled. If the image of the arc fills the aperture, it is large enough; otherwise it is not, and the margin of the picture will receive no direct illumination.

The question of arc size is not so easily disposed of in the next case, however, which is typical of all condenser combinations. Because of insufficient magnification, the source can not be imaged in the plane of the aperture but must be imaged at some distance ahead of it in order to get light to the margin of the picture, making the geometrical optics somewhat more complicated than in the case of the reflector arc. Illumination in the center of the field may be limited either by the size of the condenser or by the size of the light source; according to adjustment it will be one or the other, but not both. In the margin of the field both size of condenser and size of source are likely to be limiting factors. The conditions are brought out in Fig. 3, which shows the combination of a 5-inch Super-Cinephor projection lens, the most efficient condenser system in common use, 6 inches in diameter, and a 13.6-mm. high-intensity carbon arc as source. Fig. 3*a* shows the beam of light concerned in imaging the center of the field, Fig. 3*b* that concerned in imaging the corner of the picture. The drawings are made to scale. The lens has a relative aperture of *f*/2.3; the condenser, with reference to the center of the film aperture, of *f*/2.37. The condenser is, therefore, large enough practically to fill the aperture of the projection lens for the central point of the image. If we trace the rays limiting a beam of *f*/2.37 through the system, they fail completely to strike the crater of the arc, proving that the crater of the 13.6-mm. carbon is not large anough to utilize the full aperture of the projection lens. If we seek the location of the rays that just strike the edge of the crater of the arc, we find that they occupy the positions marked *B*, *B*, and that the beam of light they enclose corresponds to a relative aperture of *f*/4.8 in the plane of the drawing and *f*/6.7 in a plane at right angles to the drawing, the difference being due to the fact that the back lens of the condenser is a cylinder. It would seem from the drawing that all that would be required to utilize the aperture of *f*/2.37 would be to pull the arc back from the condenser to the point where the limiting rays *A*, *A* intersect. This is true, but it would leave the margin of the picture with little or no illumination. The position chosen for the arc is the result of a compromise between central and marginal illumination.

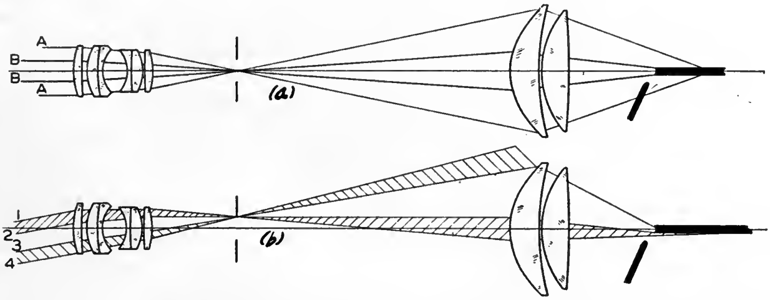

FIG. 3. Typical condenser illumination; 5-inch projection lens, *f*/2.3 6-inch diameter aspheric condensers, 13.6-mm. carbon: (*a*) central beam; (*b*) oblique beam.

To digress a moment, the dimensions of the actual source of light in the case of the high-intensity arc are rather indefinite. The diameter of the hottest central area for the 13.6-mm. carbon is 8 millimeters, as nearly as can be measured. This is surrounded by a ring about 2.2 millimeters wide which must also contribute considerable light, but is by no means as bright as the central area. The relative apertures just mentioned are computed for the central 8-mm. area from which most of the light emanates; but the figures do not represent the complete story, because zones of the lens not active according to this analysis actually do transmit light to the screen from the ring of carbon surrounding the central gas-ball. As experiment supports the conclusions drawn from a study of the problem in which the 8-mm. central area was regarded as the sole source of light, we can feel fairly safe in ignoring such light as is contributed by the outer ring of the crater.

Referring again to Fig. *3b*, four rays are shown. Ray *1* is the highest ray that can pass through the projection lens and arrive at the corner of the aperture. Continued through the condenser we find that it will not strike the crater of the arc; therefore it can not exist in actual projection. Ray *2*, after being refracted through the lens and passing the corner of the aperture, is refracted by the condenser to the lower edge of the crater. The useful area of the lens on the lower side is limited by the size of the crater. Ray *3* is determined by a line joining the corner of the aperture with the edge of the free aperture of the condenser. After refraction by the condenser it strikes the arc, and therefore it exists in actual projection. Any ray lower than *3*, such as ray *4*, fails to strike the condenser; therefore ray *3* limits the useful area of the lens on the lower side and ray *3* is determined by the size of the condenser. The zone between rays *1* and *2* is useless because the light source is not large enough, and the zone between rays *3* and *4* because the condenser is not large enough. This setting of the arc-to-condenser distance is found, however, to be about the best compromise between the desire for maximum illumination and even illumination. Such an adjustment will afford an illumination at the edge of the picture of approximately two-thirds that at the center. By pulling the arc back somewhat, the brightness at the center can be increased, but the brightness at the margin of the picture will suffer.

The ratio of the useful areas of the lens for central and marginal image points, is found, for this adjustment, to be practically the same regardless of the type of projection lens, at least for projection lenses as different in form as the Super-Cinephor, the Cinephor, and the type consisting of two widely separated cemented doublets.

It is practically inevitable under the conditions thus set forth that the illumination should be brighter at the center of the picture than at the edge. By suitable adjustment it is sometimes possible to approach equality of illumination over the whole screen area, but only by sacrificing in total illumination. Unevenness of illumination has been especially troublesome in projection from behind a translucent screen, where the center of the picture usually appears so much brighter than the edge that the question promptly arises as to whether something can not be done about it in the projector. Usually nothing can. The effect is almost entirely due to the character of the space distribution of light transmitted through the screen. With a screen that is a perfect diffuser no serious trouble would exist, but a perfectly diffusing screen would transmit so little light in any one direction that the image would appear too dark to be satisfactory.

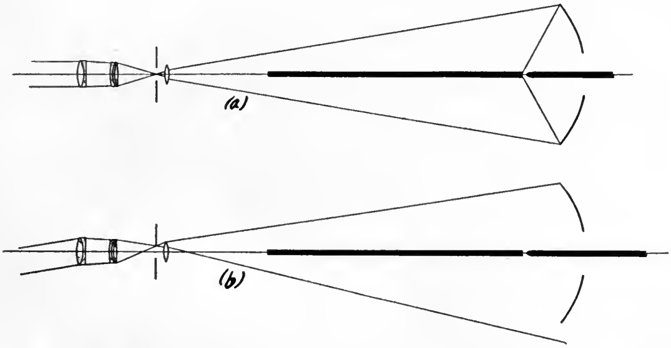

FIG. 4. Reflector arc with supplementary condenser at aperture (aperture lens); (*a*) central beam; (*b*) oblique beam.

One of the suggestions that have been made is to place a collective lens close to the film. Such lenses have been called aperture lenses. In so far as any effect on illumination is concerned, they might be placed ahead or behind the film with equal effect; but since, if placed ahead of the film, they would become essentially a part of the projection lens and have a bad effect upon the image quality, it is impracticable to place them there.

Fig. 4 shows the application of a lens of this kind to the optical system shown in Fig. 2. Two interesting results follow. In the first place, the angular aperture of the beam of light converging to the central point of the film aperture is increased, with the result that a greater area of the projection lens is used and there will be more light at the center of the screen. This is shown in Fig. 4*a*. This result is misleading, for it is accompanied by a reduction in the size of the image of the arc formed by the combined reflector and condenser. If that image were originally of just sufficient size to cover the aperture it would no longer cover it, and the distance from the mirror to the aperture would have to be increased to restore the arc image to the necessary size. The gain in illumination apparently attained would be lost by the readjustment. If the arc image were originally larger than necessary, the same gain in illumination might have been attained without the aperture lens, by decreasing the distance from the mirror to the aperture and re-focusing the arc, thus reducing the size of the arc image and increasing the angle of convergence of the beam of light. These effects are exactly compensatory, and the conclusion is that no gain in illumination at the center of the field is to be achieved by means of an aperture lens that could not have been attained by a different adjustment of the distances from arc to reflector and reflector to aperture. Since the necessary degree of freedom of adjustment may not be present in a given lamp, however, it would not be safe, in any particular case, to conclude that an aperture lens would not provide increased illumination.

A comparison of Figs. 2*b* and 4*b*, however, discloses an undeniable advantage in the use of the aperture lens. Whereas without the aperture lens the oblique beam, because of its inclination to the axis, in part fails to strike the reflector and in part fails to utilize other areas of the mirror, the addition of an aperture lens of appropriate power will deviate the entire beam, causing ray *4* (Fig. 2*b*) to strike the mirror and lowering the point of incidence of ray *1*. In fact, the whole area of the mirror may be made to contribute to the formation of the image of a point in the margin of the field; leading, therefore, to a level of illumination at the edge more nearly equal to that at the center. In addition to that effect, which is inevitable, there may be in some cases an increase in illumination at the edge of the field of the same nature as that described above as possible for the center of the field. Actual tests with an $11^1/_2$-inch elliptical reflector, an 11-mm. carbon at 70 amps., and a 5-inch Super-Cinephor projection lens led to an increase in average brightness over the entire area of the screen of 25 per cent.

On the other hand, the condition represented in Fig. 3 can not be improved by the addition of an aperture lens. By examining Fig. 3 it can be seen at a glance that a collective lens placed immediately back of the aperture could indeed change the direction of ray *4* and all other rays between *3* and *4* sufficiently to cause them to strike the condenser, whereas they now miss it completely. The gain, however, is offset by the fact that ray *2*, which is now a limiting ray of the active beam, determined by the fact that it is the highest ray that will actually strike the crater of the arc, will not meet the arc if an aperture lens be introduced. The highest ray that will strike the arc will be lower than ray *2*, and what is gained by an apparent widening of the useful beam on the lower side is compensated by a loss on the upper side. The only change is that we shall now be using a different area of the lens for imaging the corner of the picture.

The essential difference between the two typical cases is that in the first case the only limitation of the size of the beam of light, both at the center and at the margin of the picture, is imposed by the size of the light collector. In the second case, both the light collector and the light source are too small for the conditions under which they are used. In the former case an aperture lens improves evenness of illumination, and in case the light source is large enough it can increase the illumination over the whole picture more economically than by increasing the diameter of the reflector. In the second case, the introduction of an aperture lens does not appear profitable from theoretical considerations, a conclusion which is supported by experimental observations.

THE MICRODENSITOMETER AS A LABORATORY MEASURING TOOL*

W. R. GOEHNER**

***Summary.**—The microdensitometer is extensively used in studying a variety of problems of sound-film recording and reproducing: in studying the operating characteristics of light-modulating devices; in plotting variations of light transmission of sound-tracks in respect to the harmonic content of film records; in establishing correct operating technic in film processing; in studying the photographic characteristics of film as regards its ability to record high frequencies; and many other aspects of sound recording and reproducing.*

The commercially available microdensitometers are not well suited to making such studies unless proper means are taken to assure correct comparisons with data obtained with a calibrated reproducer. The present paper describes the modifications of a Moll microdensitometer that have converted it into a satisfactory instrument for sound-picture investigations.

Measured values of light transmission of photographic sound-films are used for evaluating and controlling various photographic and optical factors that influence the fidelity of photographic sound-records. Visual measurements of photographic density by means of a densitometer are satisfactory when relatively large areas of uniform density, such as provided by sensitometric exposures, are considered; but such measurements have little or no value when studying density variations of the sound-signal type. Recording densitometers are much more satisfactory because a greatly amplified record of the shape of the transmission wave of the signal is obtained. The resulting continuous record is more satisfactory for harmonic analysis than the measurement of the transmission at discrete points along the wave.

Devices for determining the light transmission of small areas of photographic images have been developed, particularly for determining the transmission and spacing of the lines of spectrograms. Many different kinds of apparatus have been described in the literature as microphotometers or microdensitometers. Several types

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

** Bell Telephone Laboratories, New York, N. Y.

are commercially available; in general, they provide a means of causing the photographic image to move in the plane of a narrow line of light. If variations of light transmission occur in the image, the light reaching the light-sensitive receiver will vary in proportion to the integrated value of the transmission over the area of the photographic film covered by the scanning image. The light-sensitive receiver converts the light fluctuations into electrical currents which actuate a sensitive galvanometer.

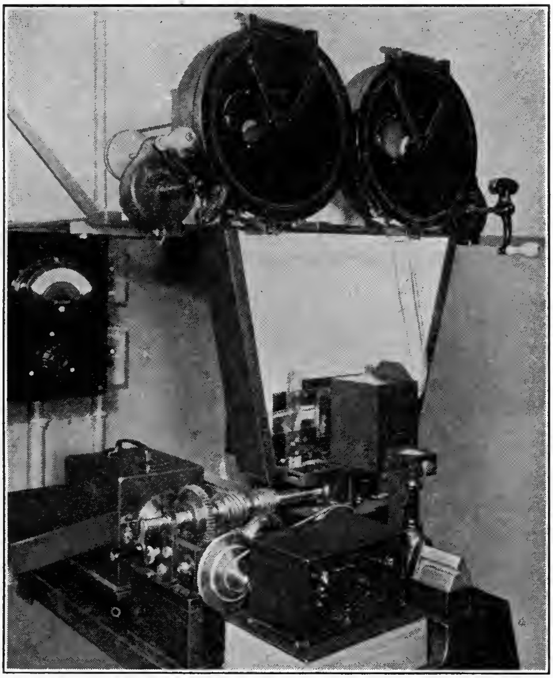

FIG. 1. The Moll Microphotometer, modified to permit direct readings in sound-film measurements.

In the recording microphotometer, the deflection of a galvanometer is recorded on a photographic paper, or film, which is moved accurately in relation to the record being scanned. The linear scale of the original is magnified 50 or more times by mechanical means, so as to spread out the wave envelope to a convenient size for inspection or measurement. It is evident that the mechanical linkage employed must be made very accurately to preserve the original wave-shape in the magnified record. One instrument maker guarantees an accuracy of 0.001 mm. for a film-driving screw having a pitch of 1.0 mm.; another has devised a film-propelling system employing a steel ribbon attached to rotating cylinders, which is independent of the precision of screws or gears.[1] Sandvik[2] has described a recording microdensitometer designed to record continuously the variations of transmission in a manner related to the projection characteristics of the standard reproducer optical system and photoelectric cell.

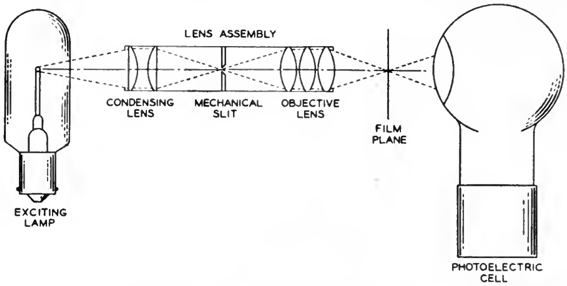

FIG. 2. Standard reproducing optical system, replacing the Moll optical system.

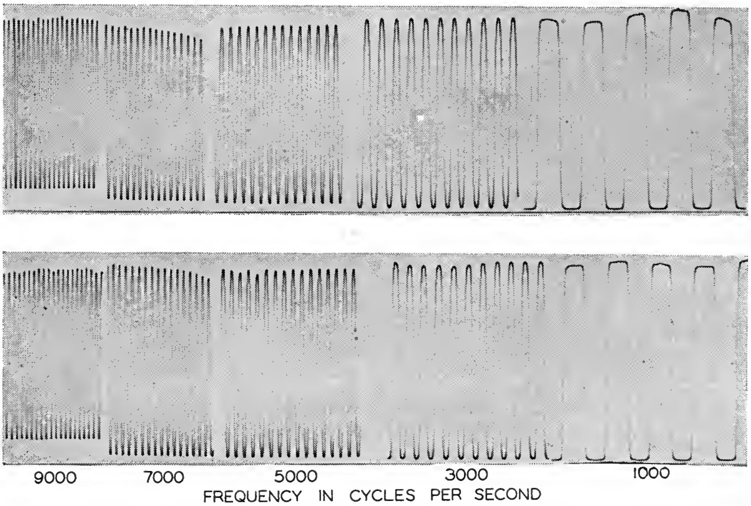

FIG. 3. Microdensitometric record of line-grating test-screen.

During the early development of the photographic method of

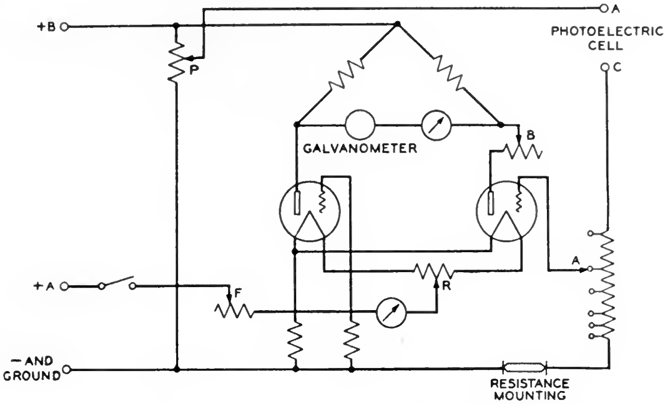

FIG. 4. Schematic circuit of d-c. amplifier between photoelectric cell and galvanometer.

recording sound at Bell Telephone Laboratories, density variations of photographic sound-tracks were analyzed by means of a microdensitometer used for spectrophotographic work. Correlation of

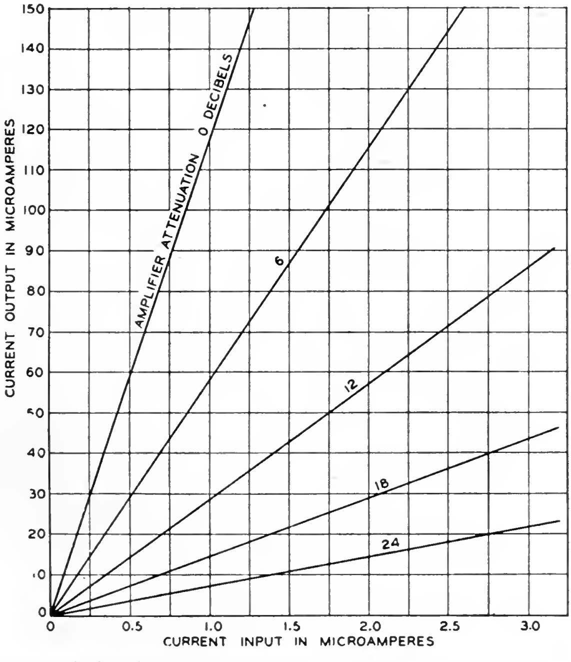

FIG. 5. Characteristic of d-c. amplifier for various photoelectric cell currents.

the resulting measurements with those of actual sound projection practice proved difficult because of certain fundamental differences between the analyzing instrument and the standard sound-film projection system. The principal differences were:

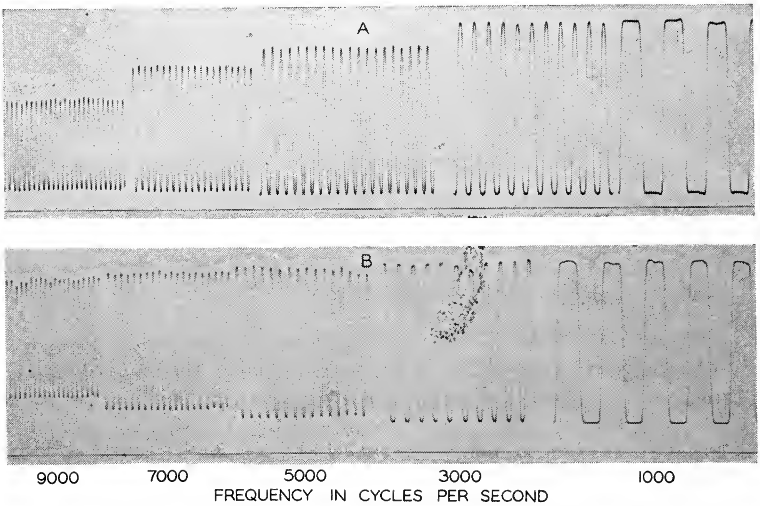

FIG. 6. (*A*) Microdensitometric record of line-grating frequency characteristic exposed on positive film; (*B*) photographic frequency characteristic of a grainless type of film, obtained by the line-grating test object method.

(1) The spectral sensitivity of the thermopile used in the microdensitometer differed from that of the projector photoelectric cell.

(2) The optical system of the microdensitometer accentuated the specular transmission of the film so as to increase the effective projection cotnrast factor.

(3) The recorded amplitudes for high-density films were inadequate.

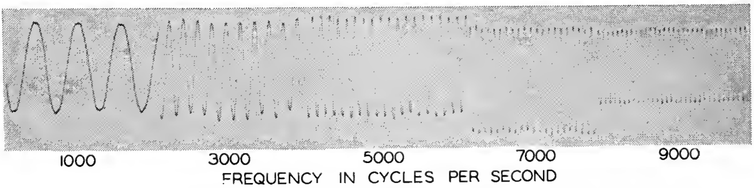

FIG. 7. Microdensitometric record of short section of positive print of a variable-density frequency record.

The difficulty of correlating data obtained with the Moll microdensitometer with those obtained with the standard projection system indicated that modifications were necessary to convert it into a direct-reading instrument for sound-film measurements. Fig. 1 shows the Moll microphotometer so modified. The magazines accommodate full reels of motion picture film so as to facilitate the handling of long lengths of film. The Moll optical system has been replaced by the standard Western Electric reproducing optical system (Fig. 2) consisting of an 8.5-volt 4.0-ampere lamp, a lens and slit assembly, and a No. *3-A* photoelectric cell. The standard lens and slit assembly provides a scanning image 0.001 inch wide. Stryker[3] has published values of reproduction loss at high frequencies due to the finite width of the scanning slit: an 0.001-inch scanning image introduces a loss of 5 db. at 10,000 cycles. In experimental work the desirability of maintaining high recording amplitudes at the higher frequencies led to a modification of the optical system to provide a scanning image having a width of 0.003 inch, reducing the

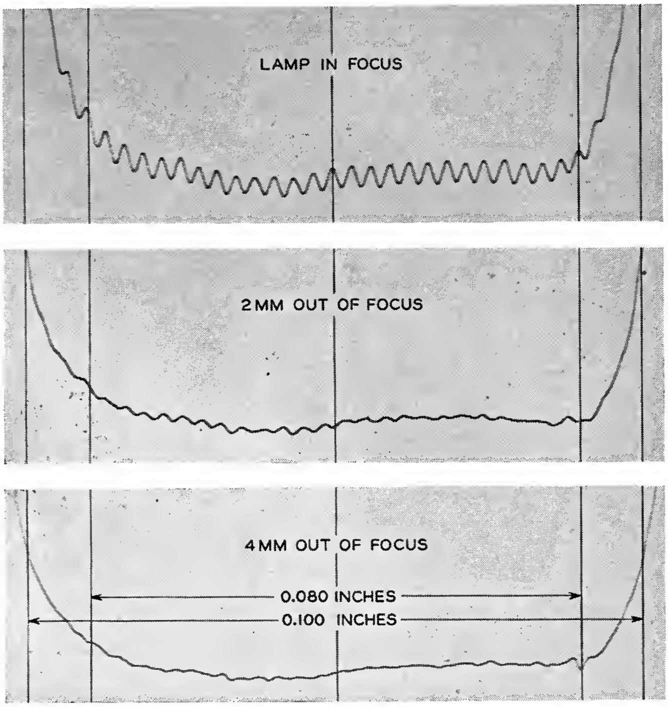

FIG. 8. Variations of transmission across sound-track recorded with experimental coiled filament recording lamp.

theoretical scanning loss at 10,000 cycles to approximately 0.5 db. In order to measure the loss introduced by the optical system, a specially prepared line grating test-screen was scanned in the microdensitometer in the same manner as for a sound film. The test-screen is a series of opaque lines ruled on a glass plate, spaced at intervals corresponding to wavelengths of 1000, 3000, 5000, 7000, and 9000 cycles per second. Fig. 3 shows the microdensitometric record obtained by scanning the test-screen; it will be observed that the relative amplitudes at 9000 cycles compared with those at 1000 cycles indicate a loss approximating the theoretical scanning loss determined for the 0.0003-inch scanning image. The adjustment of focus and azimuth of the slit and lens assembly must be accurately

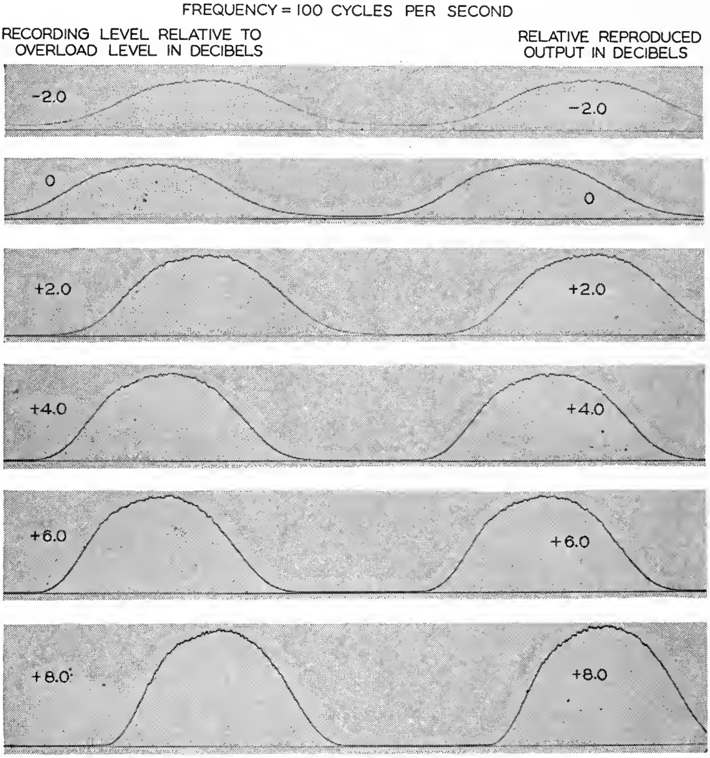

Fig. 9. Microdensitometric records of recordings made with several levels of input to the light-valve.

maintained to prevent false indications of loss at high frequencies. Provision is made in the film-supporting mechanism to maintain the focus and azimuth unaltered when films are interchanged.

By using the 0.0003-inch scanning slit the light input to the photoelectric cell was reduced by approximately 10 db., compared with the output obtained with the standard optical system, thereby reducing the galvanometer deflections to low values for high-density films. Larger galvanometer currents were attained by inserting a balanced d-c. amplifier between the photoelectric cell and the galvanometer. A schematic circuit of the amplifier is shown in Fig. 4. The maximum current amplification is 40 db., which is sufficient to cause a deflection of 1.0 cm. when a film having a transmission of one per cent is introduced into the scanning beam. The linearity of the amplifier for a range of cell currents is shown by Fig. 5.

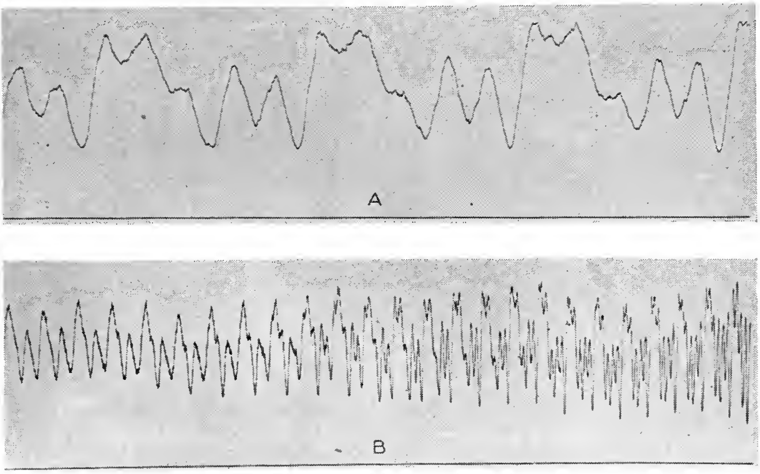

FIG. 10. Microdensitometric record of the letter *O;* (*A*) covering 0.017 sec.; (*B*) covering 0.123 sec.

The time-constant of the galvanometer system limits the speed of scanning, and the microdensitometer has been equipped with a galvanometer having a damped period of 0.2 second. It has been our experience that that speed is sufficient for scanning 2.2 inches of high-frequency film in ten minutes without permitting the results to be affected appreciably by galvanometer lag.

The microphotometer is arranged for two values of linear magnification. When the recording drum is connected to the high-speed gear the magnification is 50, so that a 15-inch record represents approximately 0.3 inch of film, corresponding to one wavelength of a 60-cycle constant-frequency film record. When the recording drum is connected to the low-speed gear, the magnification is approximately 7, so that the 15-inch record represents about 2.1 inch of film.

Microdensitometric records showing the characteristics of film materials in regard to high-frequency response have been made by scanning contact prints of the line-grating test object. The use of the line-grating test object in studying photographic frequency loss characteristics eliminates problems of optical definition and control of light modulation, which must be considered when the films are exposed in a standard recording machine. The line-grating test method has the further advantage of being able to cover the desired acoustical wavelength range in a film 2.25 inches long, whereas several feet of film are required for a single frequency recorded in the usual manner. It should be noted that the line-grating test object gives a square-topped wave of exposure which is not equivalent to the normal frequency recording but which does approximate a type of signal that is more difficult to record and reproduce—a steep wave-front signal. Fig. 6*A* is a microdensitometric record of a line-grating frequency characteristic exposed on positive film. The loss of amplitude at the high frequencies should be com-

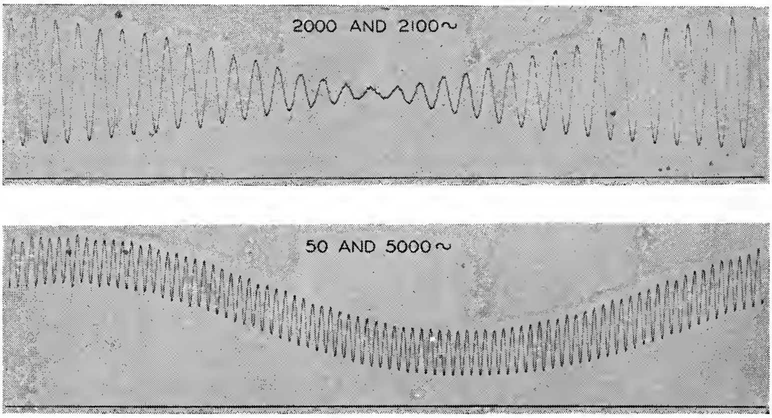

FIG. 11. Microdensitometric record of (*A*) recording made with equal levels of 2000- and 2100-cycle waves applied to the light-valve simultaneously; (*B*) of a similar record obtained with 50- and 5000-cycle waves.

pared with the loss obtained by scanning the line-grating test object.

Fig. 6*B* shows the photographic frequency characteristic of a grainless type of film, obtained by the line-grating test object method. The photographic sensitivity of the material is very low compared with the sensitivity of positive film, and it is evident, therefore, that difficulty would be experienced in recording a normal frequency record on that kind of material. The microdensitometer and the line-grating test object offer a convenient means for investigating the frequency characteristic of a wide variety of materials.

Fig. 7 is a microdensitometric record of a short section of a positive print of a variable-density frequency record. The negative was recorded in a standard recording machine; the record shows the wave-shape for sinusoidal exposure of the negative.

Problems relating to the illumination efficiency of recording and reproducing optical systems have been investigated by the microdensitometric method. Fig. 8 is the record of variations of transmission across a sound-track recorded with an experimental coiled filament recording lamp. The influence of coil spacing in producing striations on the sound track is shown by the peaks and valleys of transmission across the track when the lamp is operated "in focus."

Fig. 9 shows microdensitometric records of recordings made with several levels of input to the light-valve. The non-linear distortion resulting from light overload is indicated by the departure from the sinusoidal form as the level is increased beyond the overload point.

The microdensitometer may be used to study individual sounds selected from speech or music records. For example, Fig. 10 shows the scanning of the letter *O* taken from one of the character films used on the call announcer described by Matthies.[4] Record *A* covers a period of 0.017 second; record *B* covers 0.123 second; the total time taken by the complete letter *O* is 0.27 second. Fig. 11*A* is a record of equal levels of 2000- and 2100-cycle waves applied simultaneously. Fig. 11*B* is a similar record of 50 and 5000 cycles.

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A ROTATING MIRROR OSCILLOSCOPE*

R. F. MALLINA**

***Summary.**—When studying sound it is sometimes useful to project the wave-form of electrical or acoustical phenomena on a screen. A rotating mirror in combination with a vibrating mirror and a light source provide a convenient means of showing such waves. The problem of building an instrument for such a purpose is comparatively simple if a small screen is used in a dark chamber. However, when the screen is large enough to be viewed by a dozen or more persons, many difficulties arise.*

The paper describes how the various parts of the apparatus may be coördinated in order to produce a comparatively bright, clearly defined wave with a small incandescent lamp in a room of average illumination. The vibrator used in the apparatus may be so constructed that its response is either inversely proportional to or independent of the frequency.

One of the most instructive methods of demonstrating the characteristics of trains of sound waves, as of speech or music, is to project optically a corresponding wave on a screen. A cathode ray oscillograph is admirably suited for such demonstrations provided the wave is either steady or is viewed in short sections. If we wish to show the transitional states as well as the comparatively steady portions of such sound waves, we must project upon the screen a much longer section of the wave than can be displayed by the cathode ray oscillograph. In this paper the construction of a simple portable oscilloscope is described, with which relatively long trains of waves may be projected upon a screen so as to be visible to a group of persons in a room lighted in the ordinary manner. The various factors that should govern the design of such an instrument for best visibility of the wave will be emphasized.

The oscilloscope includes a vibrating mirror actuated electrically by a microphone and amplifier, and a scanning-mirror system rotating at a constant speed. The general arrangement of the mirrors and the screen is shown in Fig. 1, and is the same as that commonly employed in vibrating-mirror oscillographs. There are two principal forms in which a rotating-mirror oscilloscope may be

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

** Bell Telephone Laboratories, New York, N. Y.

built. The vertical arrangement (Fig. 1*a*) is preferable from the point of view of compactness, but unless the screen has a cylindrical form, the axis of the wave traced by the spot of light upon the screen will be distorted into an upwardly concave arc which may become objectionable when a wide screen is used. With the horizontal arrangement (Fig. 1*b*) this distortion is avoided. Theoretically, the screen should be spherical in either arrangement so that the light spot will be in focus at all times. However, since the distance from the vibrating mirror to the screen is great, as a rule, the change of focal length is small and can not be noticed.

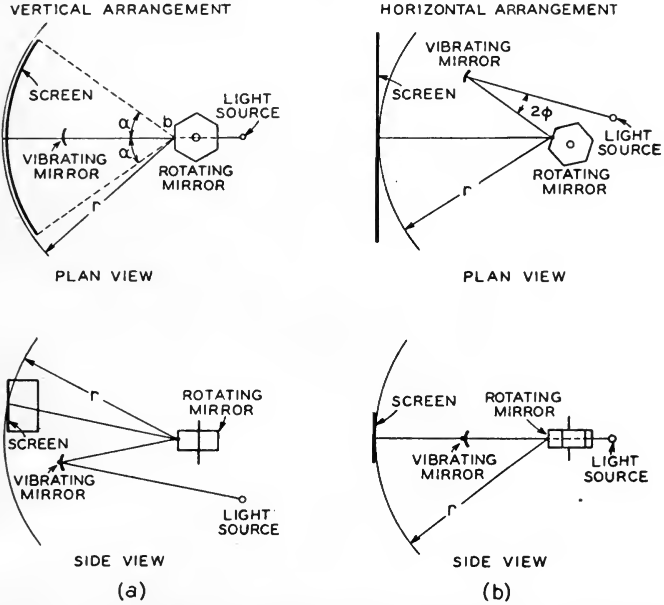


FIG. 1. (*a*) The path of the light ray in the vertical arrangement; (*b*) in the horizontal arrangement.

The Scanning Mirror.—Although the principle of an oscilloscope is quite simple, the function of the rotating mirror is sometimes not clearly understood. Assume for the moment that there is only one mirror in the rotating-mirror assembly and that the vibrating mirror has a sinusoidal motion. As the beam of light reflected from the rotating mirror passes across the screen we see a sine wave projected. The length of the visible wave will depend upon the angular velocity of the rotating mirror. If the angular velocity is such that the entire width of the screen is traversed in $^1/_{16}$ of a second, then we see the wave extend over the whole width of the screen, since the average time of persistence of vision is about $^1/_{16}$ of a second. If the velocity is less than that (say, the light beam covers only $^1/_4$ of the screen in $^1/_{16}$ of a second), the length of the observed wave is $^1/_4$ the width of the screen and we receive the impression that this short section of a wave sweeps across the screen.

In case of speech or music we are in general dealing with waves that are not steady but which vary continually with time. The traces produced by succeeding mirrors in the mirror assembly can therefore not be superposed, and if not more than a single trace is to be perceived upon the screen at a time, not more than one must be projected during the time interval of $^1/_{16}$ of a second; on the other hand, if the number of traces projected per second is much less than 16 a disagreeable flicker will be noticed.

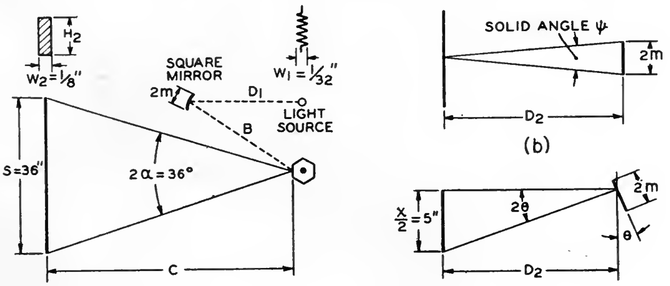
The question most frequently asked by persons observing an oscilloscope wave for the first time is, "What does one actually see upon the screen? Is it a wave such as one might see by observing the groove of a phonograph record passing beneath a microscope, or is it something else?" Probably the easiest way to simulate a rotating-mirror oscilloscope is to divide such a phonograph groove into lengths corresponding to $^1/_{16}$ of a second, and to photograph by means of a motion picture camera each successive length on each successive frame of the film. If the film were then passed through a motion picture projector we should see wave changes similar to those seen on the oscilloscope—not a wave bodily and continuously travelling across the screen, similarly to the wave of a phonograph record travelling beneath a microscope; but the wave in sections, each corresponding to a time-interval of about $^1/_{16}$ of a second. In other words, what we see on the screen at a given instant is what happened during the preceding $^1/_{16}$ of a second, and the wave we see at that instant is stationary and not moving across the screen.

The question is now, how many mirrors are required upon the rotating-mirror assembly. With one mirror it is obvious that the screen will be dark most of the time. If we increase the number of mirrors, forming a polygon of 5, 10, or 20 sides, the flicker caused by the change from a dark screen to a projected wave and *vice versa* will disappear gradually. The correct number of mirrors is the number that allows the pencil of light reflected from one mirror to appear upon the screen at precisely the moment when the one that was previously projected leaves the screen.

The requisite height of the mirrors is determined from the geometry of Fig. 1, as also their width, if the tolerable loss of illumination at the ends of the screen due to the cutting into the pencil of light by the edges of the rotating mirrors is specified.

The Optical System.—In choosing the optical system it is most important to project the maximum amount of light upon the screen for a given intensity of the light source and size of image. The simplest and most efficient arrangement is provided by a concave vibrating mirror for focusing the light source upon the screen.

In order to determine the focal length of the mirror the size of the image to be projected upon the screen must first be decided. This depends upon the highest frequency to be resolved. Assume that we wish to inspect a 3000-cycle wave upon a screen 36 inches wide, across which the beam of light will sweep in $^1/_{16}$ of a second. The wavelength on the screen will be approximately 0.2 inch, and the 3000-cycle wave will be fairly well resolved if the width of the image is about 0.1 inch.



(a) (c)

FIG. 2. (*a*) The limiting condition for sweep angle 2a; (*b*) the solid angle subtended at the screen; (*c*) the limiting condition for the mirror tilting angle θ.

Experience shows that for inspecting waves of speech and music the most satisfactory wave is one the average slope of which is comparatively great, say about 70 degrees. Such being the case, we may choose an image of considerable height, say four times the width. By so doing more light is obtained upon the screen than would be obtained with a square or round spot.

The 32-cp. automobile headlight is a convenient source having such proportions. The height of the filament is $^1/_8$ inch and its width is $^1/_{32}$ inch. Since the width of the light spot upon the screen is to be about $^1/_{10}$ inch, or say, $^1/_8$ inch, the optical magnification should be 4.

At the beginning it was assured that the width of the screen was to be 36 inches, the width of the image $^1/_8$ inch, and the filament $^1/_{32}$ inch. One more factor must be considered: the sweep angle 2α (Fig. 2). If the screen is to be visible to a large group of persons it should be substantially flat or, at the most, slightly concave. To keep the image in focus on a flat screen the sweep angle 2α must not be very much greater than about 36 degrees. The following values are therefore known: S, W_2, W_1, and α. From the relation $E = B_\psi$,

$$E = 16\,Bm^2\left(\frac{\tan\,\alpha}{S}\right)^2 \qquad (1)$$

where E is the illumination or the flux per unit area of the spot, B is the brightness of the light source, and ψ the solid angle subtended by the mirror at the screen. The formula shows that the only means of increasing the illumination is to use a brighter light source and a larger mirror. It can be shown also that no other optical system can increase the efficiency beyond that obtained by a single lens or a concave mirror.

Assuming now that a single concave mirror is used in the optical system, and the distance D_1, Fig. 2, between the light source and the concave mirror, and the magnification M, may be obtained from:

$$\frac{W_2}{W_1} = \frac{C + B}{D_1} = \frac{D_2}{D_1} = M \qquad (2)$$

and the focal length f from:

$$\frac{1}{D_1} + \frac{1}{D_2} = \frac{1}{f} \qquad (3)$$

From Fig. 2(a) it is apparent that the sweep angle 2α is a limiting condition. Fig. 2(c) shows that an additional limiting condition is imposed by the angle θ through which the mirror oscillates, and by the maximum double amplitude x of the projected wave, which was assumed to be 10 inches. If the angle θ is too great, mechanical stresses occur in the drive and distortion results. Equation (4) shows that the illumination is again a function of the brightness and the mirror area, this time being expressed as a function of the angle θ and the amplitude x; *viz.*,

$$E = 16\, Bm^2 \left(\frac{\tan 2\,\theta}{x}\right)^2 \tag{4}$$

Assuming the sweep angle 2α to be the limiting condition, it was found that θ is sufficiently small to cause no excessive stresses; in other words, the limiting condition is α rather than θ.

In order to facilitate the choice of the variables in the equations, they were plotted for a number of focal lengths, as shown in Fig. 3. Four boundaries limit D_2 and H_2. The first is the resolving power of the eye (R), which limits the ratio of the size of the image to the distance D_2. For a given image there will be a distance D_2 beyond which the eye can not resolve the high frequencies.

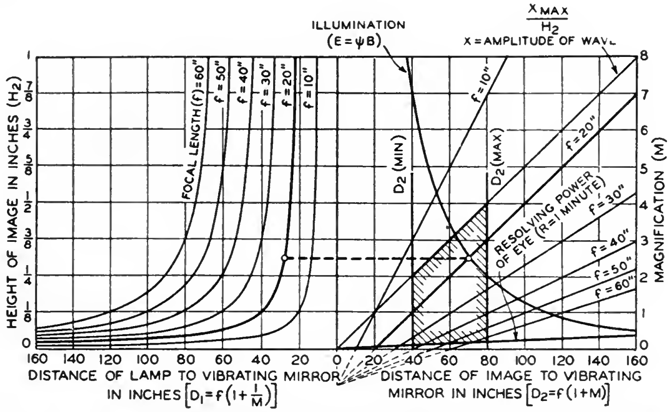


FIG. 3. Curves showing the relations between f, D_1. D_2, M and H_2, and boundaries for H_2 and D_2.

The second boundary is the ratio of the maximum amplitude X of the projected wave to the height of the image H_2. If the size of the image relative to the amplitude is too large, the high frequencies will not be resolved.

The third boundary is the minimum distance D_2 between the vibrating mirror and the screen. In general, the minimum limit for D_2 is the distance at which the size of the oscilloscope begins to be large as compared with the size of the screen, thereby obstructing the view.

A boundary that is more difficult to establish is the maximum distance D_2, which depends largely upon the illumination in the room. In a dark room D_2 can be made quite large, but in a light room the screen must be quite close to the oscilloscope to perceive a distinct wave. The curve E shows how rapidly the illumination decreases as D_2 is increased.

It is well known that the image formed by a spherical mirror is astigmatic except for perpendicular incidence. For both the arrangements shown in Fig. 1, (*a*) and (*b*), the angle of incidence is quite large. A cylindrical lens may conveniently be placed in the path of the light in such a position and of such focal length as to correct the astigmatism and afford an appreciable improvement in definition.

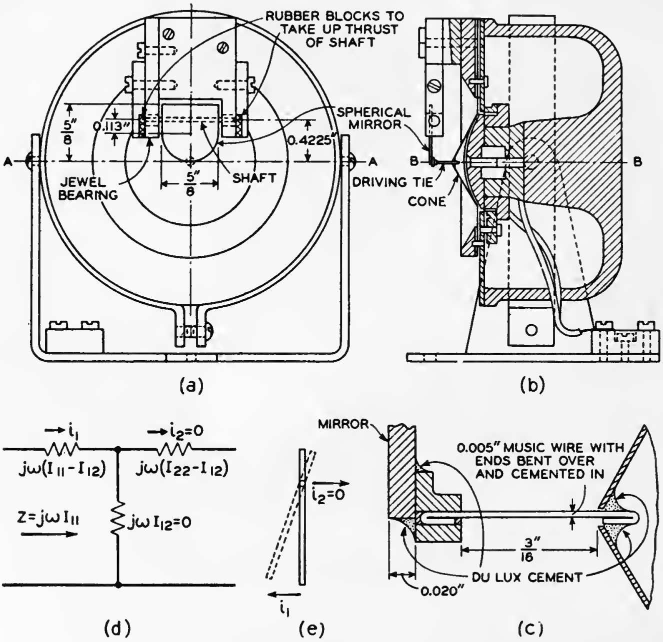


FIG. 4. (*a*) Front view of vibrator; (*b*) cross-section; (*c*) tie connecting mirror and diaphragm cone; (*d*) analogous circuit for determining axis of spontaneous rotation; (*e*) end view of mirror.

The Vibrator.—The driving mechanism for the vibrating mirror of a portable oscilloscope should be rugged, free from resonances, free from variations due to atmospheric conditions, and capable of imparting sufficient angular motion to the mirror. A modified form of the moving-coil microphone described by Wente and Thuras[1] best fulfills the conditions, the application of which is shown in Fig. 4. The mirror is attached along its axis of spontaneous rotation to a thin shaft supported in jewel bearings, and is driven at the center of percussion (Fig. 4 (*c*) and (*e*)). Mounting the mirror in this manner reduces the possibility of resonance vibrations. To reduce the possibility of such vibrations still further, the mirror is made semicircular at the driven end.

In order that the efficiency of the drive may be a maximum, it is necessary to determine what dimensions the driving coil should have relatively to the size of the mirror. A convenient expression for the efficiency η (at a given frequency) is $\eta^2 = x^2/i^2R$, where x is the amplitude of the mirror displacement, i the maximum current that the coil will withstand, and R the resistance of the coil. At high frequencies the device is mass-controlled, and we have the relation

$$Bli = \omega^2 x(M_d + M_m) \tag{5}$$

where B is the flux density, l the length of the coil, $\omega/2\pi$ the frequency, M_d the mass of the diaphragm and coil, and M_m the effective mass of the mirror at the point at which it is driven. Assuming, then, that in changing one dimension all other dimensions are changed proportionally, the efficiency is

$$\eta = C\frac{r^3}{k_1 r^3 + M_m} \tag{6}$$

where C and k_1 are constants, $k_1 r^3 = M_d$, and r is the radius of the coil. This equation shows that η is a maximum when $k_1 r^3 = M_m$; in other words, when the effective mass of the diaphragm and coil is equal to the effective mass of the mirror. Assuming now that a certain displacement of the mirror is required for a given displacement on the screen, the size of the driving coil and diaphragm can be calculated.

It was mentioned before that the illumination on the screen is proportional to only two factors; the brightness of the light source and the solid angle subtended on the screen ($E = B\psi$). In order to increase E it is conceivable that the vibrating mirror might be moved very close to the screen, thereby increasing ψ. This naturally would increase the sweep angle 2α (Fig. 2). Instead of employing a rotating mirror, the oscillograph could have been so designed that the horizontal movement of the spot of light upon the screen is produced by a bodily movement of the vibrator across the screen.

To determine whether the illumination E increases as the distance D_2 is decreased, the following argument may be employed: The kinetic energy K of the mirror is $I\dot{\theta}^2/2$, where I is the moment of inertia and $\dot{\theta}$ the angular velocity of the mirror, and where the illumination E is again B_ψ. For a square mirror $I = k_1A^{5/2}$, where k_1 is a constant and A the area of the mirror. It is assumed here that the ratio of the thickness of the mirror to its area remains constant. The angular velocity θ of the mirror is k_2/D_2 where K_2 is a constant and D_2 the distance from mirror to screen. Solving these equations for the illumination E in terms of the distance D_2 we obtain $E = k_3/D_2^{6/5}$, assuming that the kinetic energy K and the brightness B are to remain constant. In other words, the nearer the vibrator is moved to the screen the greater is the illumination. However, there are four factors that limit the shortening of the distance D_2:

(1) If D_2 is not large, compared with the maximum amplitude traced upon the screen, the spot will not remain in focus.

(2) As mentioned before, the angle θ, through which the vibrating mirror is tilted, can not be made very large without straining the tie connecting the diaphragm and the mirror.

(3) The maximum amplitude of the vibrator is limited by the depth of the air chamber behind the diaphragm.

(4) If a driver of a certain power capacity is assumed, the distance D_2 will attain a value such that θ becomes so large that the coil will be burned out.

Using a moving-coil drive as described in this paper, the limiting factor is the amplitude of the diaphragm. It would be possible, of course, to drive the mirror through a larger leverage; but as long as the axis of spontaneous rotation is to remain within the area of the mirror, a substantial increase of leverage can not be achieved. The best that can be done is to use the conjugate values of the point of percussion and the axis of spontaneous rotation. According to the design followed out in this paper, factor 2 above is not very close to a limiting condition, as the angle θ is quite small. Factor 4 is rather far removed from the limiting condition so long as the effective mass of the mirror is equal to the effective mass of the diaphragm assembly. But even if it were possible to bring the vibrator close to the screen, the mechanics of moving it across the screen would greatly complicate the machine, and this method was therefore not considered in the final design of the oscilloscope.

The driving structures may be designed either for constant velocity or for constant amplitude per unit of force over a wide frequency range. With a high-quality microphone and amplifier, if the drive is constant velocity, the projected wave will represent the displacement of the air particles of the sound wave; whereas if it is constant amplitude, the wave will represent the pressure. Although the latter case may possess greater physical significance for demonstration purposes, the former type of wave is generally to be preferred as it is more easily followed. The measured response of a vibrator designed for constant velocity is shown in Fig. 5.

The Screen.—The visibility of the wave largely depends upon the reflection characteristics of the screen. The same conditions apply here as for a motion picture screen. When a maximum lateral angle of view has been decided upon, a screen should be chosen that will reflect the greatest amount of light throughout that angle. With such a screen an appreciably brighter image will be obtained throughout the viewing angle than would be the case if a completely diffusing screen were used.

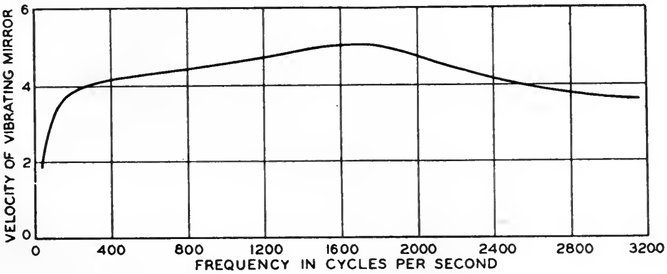


FIG. 5. Measured characteristic of vibrator.

If the oscilloscope is to be operated in a lighted room, a considerable improvement in visibility will be achieved if the screen is surrounded by a hood to shield it from direct rays. An oscilloscope designed according to the general principles outlined here may be used for exhibiting distinctly visible waves of speech and music to a group of 20 or 30 persons. When the room illumination is decreased, the visibility improves rapidly, so that the waves may be observed by much larger groups.

REFERENCE

[1] WENTE, E. C., AND THURAS, A. L.: "Moving Coil Telephone Receivers and Microphones," *J. Acoust. Soc. of Amer.*, **III** (July, 1931), No. 1, p. 44.

SOME TECHNICAL ASPECTS OF THEATER OPERATION*

H. M. WILCOX AND L. W. CONROW**

Summary.—*The various technical phases of theater operation, grouped under the headings (1) projection, (2) sound, (3) light, power, and heat, (4) building maintenance, are discussed. Particular attention is paid to means of effecting savings in the cost of operation, such as by properly choosing the type and voltage of lamps; burning the proper size carbons in the proper manner; keeping lamps, reflectors, optical systems, and screens free from dust and dirt; selecting the proper kind of fuel for the heating system, and properly firing it; paying close attention to the maintenance of the theater building, particularly the roof, a rain hazard; and the various fire hazards.*

There has been considerable literature on the various phases of the technical part of theater operation, much of it very excellent. Most of such matter, however, has been devoted to specific details of projection, sound reproduction, air conditioning, *etc.;* and while instructive and helpful to some particular theater employees it is not particularly helpful to the theater managers. In this paper we shall endeavor to give an inclusive but brief outline of the technical problems of theater operation with which every capable theater manager should be familiar.

There is an old adage, "If you want a thing done right, do it yourself"; but in this highly specialized age this should probably read, "If you want a thing done right, hire someone who knows how." This may be all very well for the larger theater chains comprising, say, ten or more theaters, but these constitute less than thirty per cent of all the motion picture theaters in the United States, and the managers of the other seventy per cent are in the difficult position of being responsible for the proper operation of highly technical equipment without being in the financial position to employ technical assistants.

The first requisite of a good theater manager is showmanship, which implies ability to select programs that will please his clientele,

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* Presented at the Fall, 1934, Meeting at New York, N. Y.

** Electrical Research Products, Inc., New York, N. Y.

advertise these programs, and get people into his theater. Compared with this requirement, the mechanical and technical features of operation are relatively small, but not relatively unimportant by any means. The smart retailer packs his goods in neat packages and displays them attractively. In the show business the picture's the goods, the theater's the show window.

Suppose we start with the purchase of a ticket for admission to a "movie" show. Ostensibly we have purchased the right to enter the theater and occupy a seat to see the show. As a matter of fact, we have purchased considerably more than that. Suppose, for example, that after we are comfortably seated in this theater we notice that the picture is not clear and there is an objectionable flicker; we have to strain to understand the dialog; after a while the sound stops; then the screen becomes dark for a minute or so; the picture resumes with possibly part of it left out; before long we commence to get drowsy on account of bad air. Under such conditions, even if the picture were good, we wouldn't like it.

Obviously we have bought something besides the mere right to enter the theater and see the show. We have bought the right to see the show comfortably, undisturbed, and presented in such a manner that we are practically unaware of the mechanics or mechanisms by which the show is presented. Annoying distractions detract greatly from the value of the picture.

Let us take a trip behind the scenes and meet some of the problems that confront the theater manager in operating his theater so that his patrons will receive the maximum satisfaction and enjoyment from the entertainment without distracting annoyances. We shall assume that the pictures and the program have been bought and paid for, and delivered to the theater; furthermore, that the prints are satisfactory both as to picture and sound. The theater, as a machine, must be ready for their presentation on time and to the satisfaction of the audience.

The various technical phases of theater operation may be grouped under the following general headings:

(1) Projection.
(2) Sound.
(3) Light, Power, and Heat.
(4) Building Maintenance.

Each of these will now be discussed in turn.

PROJECTION

The ultimate in projection is to make the patron become mentally a part of the story of the picture, with total absence of either conscious or unconscious eye-strain. The creating of the illusion of reality requires making the two-dimensional scene on the screen assume the illusion of three dimensions, and with proper screen illumination this effect can be secured to a remarkable degree.

The screen should appear to be evenly illuminated from every seat, and the amount of reflected light should fall between certain definite limits. When the reflected light is too great the eye becomes "overloaded"; the pupil contracts, and there is a resulting loss of the fine gradations of contrast. When too little reflection occurs, the eye responds oppositely and the picture becomes "flat," losing contrast and whatever stereoscopic effect may be created by careful lighting. Either under- or over-illumination may cause physical discomfort and possible damage to the eye and its associated nerve system. Not infrequently you hear people state that "movies" always make them sleepy. In many cases this is the result of improper projection.

We have recently made a study of screen illumination in a large number of theaters. This study consisted of the measurement of the amount of light which is projected to the screen by each projector and the measurement of the amount of light reflected from both the right-hand and the left-hand side of the screen, using the light source of each machine. Tests were also made of the maximum point of focus, for travel-ghost, and for spherical and chromatic aberration, and for the proper curvature of lens by use of the standard lens measure.

Not in one single case was it found that the screen illumination from the two projection machines was the same, and variations between machines were found to be as high as 50 to 100 per cent. These results were caused mainly through incorrect calibration of ammeters, generator commutators scored or having high mica, ballast resistor connections imperfect, improperly adjusted shutters, faulty optical alignment, pitted reflectors or condensers, or dirty projection lenses.

Another matter of considerable importance is picture size. Sight-lines and viewing angles must be given careful consideration in determining the size and the placing of the screen. Quite a usual fault in small theaters is the use of screens that are too large. This tends to dilute the intensity of the light on the screen with a resulting impairment of definition, or else an unnecessarily high current consumption in order to increase the light intensity. Also, the larger the picture the more apparent are defects of projection, such as jump, weave, graininess, and other film imperfections.

The condition of the screen is, of course, an important factor in maintaining a satisfactory degree of illumination of the picture. In this regard the screen manufacturers have a great opportunity for developing a screen material with an adequate reflecting surface at a price which will enable exhibitors to replace screens at more frequent intervals than is the case at present. Some sacrifice of initial reflecting power would be permissible if screens could be obtained at a low enough cost to permit more frequent changing, thereby raising the general average of screen illumination.

The complete projection system is a combination of mechanical and electrical equipment. The various working parts of such a system are designed to operate most efficiently when adjusted and maintained within the limits prescribed by the manufacturer. The wear and tear on a projection machine is abnormally high under constant use due particularly to the intermittent mechanism and the large amount of current used, with resulting high temperatures.

The condition of the intermittent mechanism should be watched closely as worn intermittents not only reduce the life of the projector head but also the life of release prints. The cost of release prints runs into millions of dollars a year, and even a 10 per cent increase in their life would mean a substantial saving which eventually would accrue to exhibitors, because they, after all, are the ones who foot the bill for the entire cost of pictures. The proper maintenance of the power generating equipment is an important factor in maintaining projection at a high standard of excellence.

The theater personnel assigned to the operation of the projection equipment should be trained men; definite routines should be established for the maintenance of the equipment, and certain standards established against which actual performance can be checked from time to time. The Projection Practice Committee of the S. M. P. E. have made substantial progress in the establishing of standards. The task now appears to be to get exhibitors to adopt these standards and to establish simple methods by which theater managers can check the performance of their projection equipment against the standards.

SOUND

The picture is enlarged from the film to the screen a few hundred times. Sound, on the other hand, is amplified several million times from the initial impulses at the photoelectric cell to the time it is projected from the loud speakers. As a consequence, any imperfections entering into the reproducing apparatus have a much greater effect in deteriorating the quality of sound reaching the audience than is the case with picture projection.

In order to have a full appreciation of the importance of adequate maintenance of sound equipment, which is the most highly technical device of any theater apparatus, it is desirable to have some knowledge of the nature of sound.

When you hear a note struck on a piano you know that it is a piano. The same note on a violin would sound differently. What is it that makes it possible for you to recognize whether the tone originates from a piano or a violin?

Sound has its origin in vibrating bodies. The atmosphere exerts a definite, uniform pressure on all bodies with which it is in contact. When vibrations have been communicated to the atmosphere they cause rapid fluctuations in this pressure, and these changes of pressure striking the ear-drum result in the sensation which we know as sound.

The rapidity with which these vibrations strike the ear causes the sensation which is known as tone or pitch. The intensity with which these vibrations strike the ear causes the sensation which is known as volume or loudness. You may perhaps remember how, as a boy, walking along the street you might drag a stick lightly along a picket fence; if you would start to run, the sound would immediately go up in pitch; if you pressed the stick harder against the fence it would become louder.

If you have ever noticed the piano keyboard you will remember that it is divided into a number of uniform sections comprising eight white keys and five black keys. Each of these sections is identical to the other except that the pitch or tone of each adjacent section is what is known as one octave higher or one octave lower than the next one. The perfect human ear can hear sounds over a range of approximately ten octaves. Technically this is known as the sound spectrum, and the audible spectrum encompasses a range of from 16 vibrations per second to 16,000. One of the highest pitched sounds which the ear can hear is the tinkling of keys, while the rumbling of the lowest organ note is about the lowest pitched sound which the ear can detect.

Variations of loudness range from the faint rustling of leaves up to artillery fire; that is, to the point where the sensation changes from one of hearing to one of feeling. In terms of energy this is a variation of many million times.

When one note is struck on the piano, say, middle *C*, which is a pitch resulting from the vibrations of the piano string of about 250 times per second, a strange thing happens. You hear not only the tone represented by 250 vibrations per second but you hear also some of 500, some of 1000, some of 2000, some of 4000, some of 8000, and perhaps some of 16,000. These are known as overtones or harmonics. The reason that you could determine that a certain tone came from a piano or a violin is the fact that there were different combinations and intensities of these harmonics or overtones which struck your ear drum. It is this fact which gives character to sound. If any of these overtones are missing or over-accentuated the sound will not be natural.

Any mechanical or electrical device must be capable of recording and reproducing a sufficient range of vibrations to make the reproduced sounds appear to be natural. Bearing in mind that the ear can hear a range of about ten octaves the apparatus which records the sound and which reproduces it must have the capacity of handling this range for the sound to be completely natural. The old mechanical phonograph of ten years ago could handle about four octaves. The electrical phonograph of 1925 could reproduce about five octaves. You perhaps remember in the early days of talking pictures how frequently the characters seemed to lisp. This was caused by the inability of the machine to reproduce the sibilants which are sounds of relatively high frequency or vibrations per second.

Since the introduction of sound pictures commercially about eight years ago there has been a continuous improvement in both the tone range and the volume range of sound recording and reproduction, so that today the standard of sound reproduction in theaters represents about 80 per cent of all that the ear can hear.

Fortunately, in sound reproducing apparatus there are few moving parts, so that there is relatively little mechanical wear and tear. In maintaining a high quality of sound, cleanliness is next to godliness. Probably the most vital part of the apparatus is the optical system and exciting lamp which generates the initial power entering into the sound reproducing system. A very small amount of dirt on the exciting lamp or the optical system, or a very small maladjustment of its alignment or focus can have a very serious effect on the quality of the sound reproduced.

It is very necessary that the film travel at a smooth uniform speed through the exciting lamp beam, otherwise objectionable flutter will appear in the reproduced sound. Consequently, the film-driving mechanism of the projector and sound head must be kept in first-class condition.

In the amplifying system the photoelectric cell and the vacuum tubes are the equivalent of moving parts, but the motion is electrical and not mechanical. However, this electrical motion taking place within the photoelectric cells and vacuum tubes does cause wear and tear, and these should be watched closely for condition. As a rule, deterioration of vacuum tubes takes place very gradually up to a certain point and then becomes exceedingly rapid. In general, properly manufactured vacuum tubes of high quality will last a theater running 60 hours a week for over a year.

Troubles from defective loud speaker units are usually not immediately apparent, particularly where there are two or more units in use. It is advisable occasionally to run one reel on each machine and listen to the reproduction from each speaker unit with the others cut out.

The exhibitor owes it to his audience to deliver faithfully all that the producer of pictures is delivering to him on the sound record. To a considerable measure the reproducing apparatus in theaters is an extension of the recording apparatus in studios. The producers are continuously striving for improvement in sound recording, and it is highly important that the reproducing apparatus be kept in step with recording technic in the studios, to the end that the efforts of the producers in improving their product will be translated into increased box-office receipts.

LIGHT, POWER, AND HEAT

A periodic survey of the light, power, and heating plants will provide a substantial saving in the cost of operation. We recently completed a survey in 14 theaters belonging to a chain which maintains relatively high operating standards. The following summarizes the reports on the actual conditions found in these theaters, and refers to facts that are of distinct interest to theater managers generally:

"The average indicated net saving per theater in current, carbon, and lamp replacement costs, expressed in terms of a percentage of the respective annual light and power bills, is 13.4 per cent. This represents a total first year saving, after deduction of the cost to affect the savings, of $12,884.

"The average indicated net saving per theater in fuel consumption and fuel costs is 23 per cent. This represents a total first year saving, after deduction of cost of necessary indicating instruments, of $5873.

"These estimates are conservative. Recommendations are restricted to those considerations involving little or no initial expense. No attempt has been made to alter existing policies in regard to amount of light and heat used. Considerations effecting reductions in power consumption by motor overhaul, adjustment, and lubrication also effect equipment savings by reducing fire hazard, avoiding equipment breakdown, and minimizing equipment replacement costs."

Reduction in current consumption for lighting is based upon the following considerations:

The light output per watt of standard incandescent lamps increases with increase in wattage size of lamps. One 100-w. lamp produces 42.6 per cent greater light than is produced by four 25-w. lamps, while one 75-w. lamp produces only 1.3 per cent less light than do four 25-w. lamps. It is possible, where consistent with appearance and effect, to produce the same amount of light at a lower current consumption by substituting a smaller number of higher wattage lamps. Reduction in the number of lamps in use reduces the cost of lamp replacement.

The actual wattage consumed by a lamp, its life, and its light output depend upon the voltage of the circuit on which it is operated. A 120-v. lamp used on a 110-v. circuit consumes only 88 per cent of its indicated wattage, lasts 320 per cent as long, and gives only 73 per cent as much light as it would on a 120-v. circuit. A 110-v. lamp used on a 120-v. circuit consumes 115 per cent of its indicated wattage, lasts only 30 per cent as long, and gives 135 per cent as much light as it would on a 110-v. circuit. The determination of lamp voltage thus depends upon the cost of lamps as compared with cost of current; for it is possible to save on lamp replacement cost by selecting lamps of a voltage greater than the voltage on which they are to be used, or to save on current cost by selecting lamps of a voltage lower than that of the supply voltage. In most theaters, the cost of current outweighs the cost of lamps, and lower voltage lamps are more economical.

Not only must the supply voltage be considered, but also the voltage of individual circuits. The voltage of heavily loaded lines will be lower than the supply voltage, as will all dimmed circuits. It may be necessary for a theater to use lamps of three or four different voltages. Standard lamps are supplied for 105, 110, 115, 120, 125, and 130 volts.

Effective light may be as little as 1 per cent of the light actually produced. A lamp distributes light almost equally in all directions. Unless satisfactory reflecting surfaces are used to redirect light in the desired direction, much of the light produced is wasted. Reflecting surfaces include ceilings, walls, and floors, as well as reflectors. The efficiency of light reflection of these surfaces depends upon the inherent character and brightness of the surfaces and upon their condition and cleanliness. The most striking example of waste of light is found in theater dome coves. The surfaces at the sides and bases of vertically mounted lamps in coves are often rough concrete, covered with heavy accumulations of dust. The lamps are covered with dust, and the light that finds its way through the tip of the tinted lamp is redirected to the auditorium by means of the curved surface of the dome, the paint of which is dull with age. Beginning with a loss of 30 or 40 per cent due to tinting, another 75 per cent of what remains is absorbed by the dust-covered reflecting surfaces. Of the little remaining light, part is obstructed by dust on the lamp, and as much as 80 per cent of the remainder may be absorbed by the dull reflecting surfaces of the dome.

Reflectors are available with efficiencies as high as 95 per cent, while the efficiency of flat white painted surfaces may be as high as 85 per cent. In the above example, clean lamps in clean, efficient reflectors suited to the lamps in use, directed into a white dome, would deliver to the auditorium more than 60 per cent of the light produced.

Reflectors should be used wherever possible to avoid waste. Reflecting surfaces, marquee, soffit, space behind attraction letters, coves, ceilings, walls, and even floors should be kept as clean and bright as possible. Light-transmitting media such as globes, fixtures, panels, attraction letters, and the glass of the lamps should be kept clean and free of dust.

Tinted lamps cost more, produce less light, and burn fewer hours than standard lamps. Light effects may be produced by using color caps, by tinting the glass of fixtures, panels, *etc.*, by using variously colored overlays, and by using colored drapes.

Some theaters in this circuit use tinted 25-w. lamps behind tinted glass in exit fixtures. The use of a tinted lamp in this way causes a loss of light equal to the difference between a 25-w. lamp and a 15-w. lamp. This is a loss of 40 per cent in current and 20 per cent in lamp replacement cost.

The majority of lamps in use in these theaters are bare, low-wattage, tinted, 120-v. lamps, operating on circuits between 110 and 115 volts. If these lamps could be replaced with fewer, properly reflected, higher-wattage clear or white frosted, 110-v. or 115-v. lamps, current consumption for all lighting would be reduced 40 per cent.

Other considerations effecting reductions in current consumption include reduction of line loss in overloaded circuits and dimmed circuits; replacement of high-wattage lamps in exit lights and indicators; reduction of the number of units on one switch; location of switches conveniently to encourage turning off lights; and replacement of inefficient fixtures, such as the channel type of attraction sign letter, which is costly in current consumption and lamp replacement cost.

Projection accounts for a large part of power consumption. Considerations affecting current consumption are, type, size, condition, and cleanliness of screen; type, adjustment, condition, and cleanliness of reflectors and lenses; size, kind, adjustment, and operation of carbons; condition and operation of feed motors, jaws, contacts, feed rollers, *etc.* Type of screen is determined by the shape of auditorium and angle of projection. Size of screen affects light density per unit area. Condition and cleanliness affect reflectivity of screen and consequently affect the necessary light production at the arc. Reflectivity of a new screen is from 77 to 85 per cent. The normal loss in reflectivity in one year is 50 per cent. This represents a current consumption loss at the arc of from \$15 to \$65 a month, where the average cost per kilowatt hour of current is $3^1/_2$ cents. Types of reflectors and lenses are governed by the length of throw and the size of picture on the screen. Adjustments of reflectors and lenses affect adjustments of carbons. Condition and cleanliness of reflectors and lenses affect efficiency of light transmission. Size and kind of carbons affect current and carbon consumption. Oversize carbons increase current consumption and reduce carbon consumption, but increase carbon consumption cost. Undersize carbons increase current consumption and increase carbon consumption and carbon costs. Adjustment of carbons affects current consumption greatly. An out-of-position adjustment of $^1/_8$ inch may increase the current and carbon consumption 10 per cent. A common fault is reducing the arc-gap between positive and negative carbons. This increases the light, but causes excessive current and carbon consumption and burning of carbons and reduces the voltage at the arc. This, in turn, causes faulty operation of the carbon feed motor. Irregular feed produces irregular light on the screen and necessitates periodic, inefficient hand adjustment.

Electrical contacts, jaws, rollers, motors, *etc.*, must be kept clean and in good operating condition to avoid losses in current and carbon consumption. Projecting single reels instead of double reels increases the current and carbon costs at least 5 per cent.

Light and power billing rate schedules should be given constant consideration. Billing depends not only upon the amount of current consumed, but also on the manner in which it is used. Alternate rate schedules are usually available, and should always be considered in any change in policy affecting current consumption. A theater on an annual demand rate may find it to its advantage to elect to have applied to its billing a flat rate when its operating policy establishes a high demand for only a short period during the year. On the other hand, the theater may so adjust its policy as to maintain a fairly constant demand and so control its billing.

Heating efficiency depends largely upon the selection of fuel for which the boiler was designed and the complete combustion of the fuel in the presence of the heating surfaces. Complete combustion depends upon the proper mixture of fuel and air. It is possible, by means of an Orsat apparatus and a thermometer so to adjust air mixture and draft as to produce nearly complete combustion. Fuel should always be purchased on specifications.

Except where burners were found defective, it was possible to attain combustion efficiency of 75 per cent for oil-burning and coal-stoker installations. Hand-fired furnaces depend so much upon the ability and interest of the fireman, that although high efficiencies were attained during tests, the anticipated savings were based upon much lower efficiencies. A small bonus to the fireman based on fuel consumption with maintenance of proper temperature in the auditorium may be an effective economy.

Other considerations for which savings are indicated but not readily calculable are insulation of piping, shielding of radiators, improving condensate return systems, *etc.*

BUILDING MAINTENANCE

Building maintenance needs less frequent attention than any other parts of theaters, and consequently the tendency to neglect is greater. Being a place of public assembly, safety and comfort of patrons is the first consideration. Such things as exit doors, fire-escapes, stairs, carpets, fire extinguishers, and electrical apparatus and wiring should be inspected at regular and fairly frequent intervals. An excellent plan is to have a check list of all such items and a regular time set each week or each month for a building inspection. An hour or so is all that would be necessary except in the very largest houses, and there is considerable advantage in the manager making these inspections personally. He could check the housekeeping, such as cleanliness, condition of plumbing, decorations, *etc.*

Twice a year, in spring and fall, there should be a thorough inspection of roof, gutters, and drains. Roof deterioration is insidious, and water damage inside the building is apt to be very costly. In a recent case an organ was almost ruined from a leaky roof which suddenly developed during an exceptionally heavy rain and wind storm. Roof repair or reconditioning should be made on definite specifications, and in general the highest bidder will probably prove the most economical in the long run. Every fall there should be a thorough inspection of the heating system, including cleaning of flues with special reference to fire hazards.

As we consider each of the many problems which a theater manager must deal with, it is quite evident that to handle the more involved technical problems of maintenance efficiently he must look for assistance and advice of an engineer or group of engineers. He can, of course, secure information from many individual sources, but he can not be certain that the information he receives applies to his individual problem. Only a careful investigation and study of conditions in the theater will produce the best and most economical solution. The question is, how much will maintenance of this character cost. It will cost something, of course, but in the long run the savings from efficient handling of maintenance will result in a reduction of direct operating expenses, longer life of equipment, and satisfied patrons, and will make the net expenditure a very small percentage of the cost of operation.

PROBLEMS IN MOTION PICTURE ENGINEERING*

A. N. GOLDSMITH**

Summary.—*After defining motion picture engineering as the production of an acceptable semblance of reality, there are discussed the functions of the engineer and the artist, as well as certain aspects of parts engineering, including the improvement of the film, the camera, lenses, studio lighting, sound recording, laboratory processes, theater monitoring and maintenance, sound reproduction, theater architecture, and other allied matters. An open mind and a determined attempt favoring continuous evolution of the art are urged.*

The problems of any branch of engineering depend upon the aims of that branch. While it would be most difficult, if not impossible, briefly to define the aims of mechanical or electrical engineering, for example, it is fortunate that a reasonably acceptable definition can be contrived for motion picture engineering. It is the presentation of a real or imagined happening to the audience in such approach to perfection that a satisfactory illusion of actual presence at the corresponding event is created. Briefly, it is the production of an acceptable semblance of reality.

It might be objected that exact replicas of reality will not give a desired dramatic or comic effect, and that is quite true. On another occasion, I defined the motion picture industry as "vendors of illusion and sellers of glamour." This definition need not be changed. However, the task of the engineer is to create the illusion of reality. It is for the playwright, the director, the actor, and any other artists who are involved to provide the glamour by intensifying or subduing or otherwise modifying the reality to be recorded and reproduced so that the most satisfactory audience response shall be achieved. It is well for the industry to keep this point in mind. If we desire in the theater suppressed or heightened impressions, those who provide the raw material for the engineer to work upon must arrange for this and specify the desired effects clearly. The engineer can help greatly, but it is not his function to control tempo, the aesthetics of lighting, the tone of the actors, and the multitude of other necessary

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* Presented at the Fall, 1934, Meeting at New York, N. Y.

** Consulting Engineer, New York, N. Y.; *President,* Society of Motion Picture Engineers.

artistic factors. Occasionally there will be found an engineer who is also an artist, but in general it is well, as a practical proposition, for the two groups of workers to "stick to their own last" and to become more nearly perfect in their respective tasks through specialization.

In considering the further problems of motion picture engineering, there must not be assumed any implied criticism of the fine work which has been done in the past. The results already available are a convincing testimonial for what has been done by the technicians. Yet the motion picture industry can not stop at that point. No industry that hopes to retain public patronage on so vast a scale can afford to be smug and self-satisfied. We have not yet reached our goal—and perhaps we never shall.

Motion picture engineering falls into two broad divisions—system engineering and parts engineering. Historically the latter generally comes first. Individual parts of the complicated series of devices necessary for the final presentations to the public are invented; are built in crude form; are tested and found wanting in some respects; and are improved in a series of steps toward an acceptable performance. But parts engineering is not enough. By coördinating each device with the others, and by fully appreciating the way in which each part fits into the entire structure, greater effectiveness of operation, superior results, and marked economies generally result. We may safely assume that every device now used by motion picture engineers can be improved, that new devices for functions not yet filled can be contrived, and that the relation of each part of the system to the whole system of audio-visual recording and reproduction requires study and consequent technical development.

In the brief presentation which is the subject matter of this paper, only parts engineering can be conveniently considered. Even so, the subject is so vast that only a brief and partial summary can be given. It is obvious that present and possible future problems can be listed but that their solutions can not be given—to do so would be to overleap human mental and time limitations.

Considering first the raw material and very foundation of this branch of engineering, namely, the photographic film, we can fairly ask whether the present film materials are the best that can be expected. Are they as durable, as economical, as well adapted to high-speed projection and intense heating, and as free from dimensional changes with time as may be desired? Has graininess been reduced to a completely satisfactory minimum (even for such special applications as process shots), and has speed been raised to the point where the cameraman is practically untrammeled in his work even under such unfavorable conditions as frequently challenge the newsreel worker? Can we be said to have film that is suitable for color photography—that is, for the reproduction on the screen of the full colors of the photographed scenes? Has film susceptibility to other forms of energy than light been reduced to a minimum? Can we add to the already great accomplishments along these lines?

The engineer, contemplating the awkward structure of a blimped or sound-proofed camera (the camera itself being an object of considerable size and weight), wonders whether something more convenient can be contrived. Silence in operation, compactness, continual accessibility of all adjustments and simplification of such adjustments, and generally increased mobility present attractive possibilities. Some workers are prepared to accept the theory that the optics of photographic lenses are not capable of basic improvement, but if some way to diminish the large number of lenses that are required in the studio for close-ups, medium, and long shots could be contrived, it would be a step forward. Zooming by more convenient and automatic means is desirable. And the present methods of achieving angle shots, following shots, and the like leave room for improvement, as any one must admit who has watched the operation of the mammoth cranes and dollies now in use.

It may also be fairly assumed that the last word has not been spoken in studio lighting. Could not studio lighting be so arranged that each set does not require inevitably the shifting of practically every lighting unit? Could not a semi-standardized lighting plan be adopted under which the lighting could be controlled by manipulating a modern control board rather than by dragging tons of equipment around the studio? The control of the direction of incident light, its amount, its diffision, and its color (where that factor is of importance) all present to the engineer matter for further consideration. Closely associated with such problems are those of make-up, set construction and finish, and costuming. It is possible that new materials will be found for set construction which will present a more desirable combination of optical, mechanical, and acoustical characteristics than those now available.

The recording of sound is well done, considered as a young art.

But the evolution of more compact and lighter recording equipment, the use of more economical recording methods, the development of more convenient and simpler methods of editing and rerecording or "dubbing," and methods of recording that enhance auditory perspective are desirable.

When the processing of film by the laboratory is considered, it seems clear that a group of methods will be evolved whereby the precision and uniformity of the product can be further increased. Automatic processes are entirely in order in dealing with the vast quantities of film that are handled by a laboratory, and one may look forward to the time when everything, from exposure time and developer concentration and temperature to the condition and packing of the finished film, will be handled and controlled automatically. The devices for the purpose may even be provided with "checking controls," indicating when the control device in question is out of order and then providing a corresponding alarm.

By a simple extension of the thought, one can imagine film exchanges wherein the inspection of film and the repair of at least some defects can be automatic or semi-automatic. Considering the way in which film is sometimes mistreated by the user, one might facetiously add that there is need for a device that automatically charges the delinquent user for the damage he has done *and* also collects the full amount promptly and relentlessly.

Closely related to some of the problems mentioned are those of the theater. Present methods of monitoring both picture and sound leave something to be desired. Substantially complete silence in the projectionists' room is needed if convenient monitoring through large open ports is to be possible. In the meantime, a type of port that lets out light without absorption, but not sound, may be developed. Screen illumination remains inadequate in some cases, and no standardized method of checking the condition of screens as often as may be desirable has been worked out. A simple and automatic method of so doing would be a help to the exhibitor whose entire salable output passes through the proscenium arch. The color of the projector illuminant and its stability and economy are under active study and merit such attention. The reduction of film wear by appropriate construction of projectors and by automatic or semiautomatic supervisory methods presents a real problem. And, needless to say, film breakage during projection is, in the engineering sense, entirely inexcusable. The projection of color pictures will bring in a number of new problems of projector construction, of screen surfacing, theater lighting, and other arrangements. If ever three-dimensional pictures are to be available, it is likely that a number of radical changes in theater construction and equipment will be involved.

The reproduction of sound in theaters has also steadily improved. Problems of increasing further the dynamic range of reproduction, of establishing *and maintaining* reproduction of improved fidelity, of achieving stereosonic reproduction (*i. e.*, sound reproduction with auditory perspective), and of reproducing speech and sound with equal satisfaction assuredly exist and invite further effort. Closely associated with all the preceding is the general question of motion picture theater construction. Some architects skilled in the related problems have vigorously maintained that the present forms of theater design are not technically sound, and have proposed other more or less plausible substitute constructions. Speaking for a moment as a theatergoer, something is certainly to be desired to permit the blinking and half-blind patron, entering a darkened theater from a sunlighted street, first to accomplish the difficult feat of locating an unoccupied seat and then to reach it with minimum damage to the footwear, other impedimenta, and good nature of the seated occupants of that row. And, as has been clearly pointed out recently by a profound thinker, there is need for solving the old problem of the theatergoer who enters at the middle of a picture and has the weird experience of "enjoying" a slice of life that begins with the death of a character and ends with his birth. Perhaps even that puzzle has a partly technical answer.

As may have been gathered, all the preceding discussion is really more a plea for an open mind, willing effort, and resourcefulness on the part of the engineer than a complete technical summary of problems in the motion picture field. If you are satisfied that much has been accomplished and that much remains to be done, the purpose of this discussion will have been achieved. In that event, motion picture engineering will continue to be the loyal friend and tireless servant of the industry and the public, and will always, as now, deserve to be fostered and encouraged by the industry and the public alike.

DISCUSSION

MR. RICHARDSON: You mentioned only camera lenses and various problems in connection with them. There is another lens that deserves attention. I am more and more impressed with the fact that the condenser is by no means what it should be, and that due to that fact we are wasting a great deal of light.

MR. SCHLANGER: The difficulty of being able to find one's seat in the motion picture auditorium has been largely overcome. In the past, direct and spot illumination was used, and during the performance it was necessary to switch off the lights because of the distraction they caused in competing with the screen illumination. The proper intensity and color of evenly distributed indirect light will afford ample illumination for getting about the theater, and will not in any way interfere with screen definition or the ability to view the screen comfortably. Low chair, stair, and wall lights below the line of vision are effective also for auditorium illumination.

The problem of adjusting the eyes to the sudden change of intensity from that of the street to that of the auditorium is soluble in two ways: first, by a higher permissible intensity of light in the auditorium proper; and second, by having at least two intermediate stages of light intensity between the street and the auditorium, using the lobbies, foyers, or other spaces in the same way as compression chambers are used in under-water construction.

MR. BLIVEN: I am quite interested in the reduction of sound through the projection port, and particularly of the audience's reaction to the noise of the projectors and the sound of the monitoring speaker. Serious work should be done on that problem, taking into consideration the dimensions of the ports and projection room noises.

MR. RICHARDSON: If the wall of the projection room is thick enough, say, 8 inches, and if the two sides of the port are faced with sound-absorbent material cut to the size of the light-beam, the sound should be considerably reduced. Such a scheme has been tried in a number of theaters, and has proved quite satisfactory.

MR. BLIVEN: I have tried that, at the same time lining the interior with sound-absorbing felt, but it was not entirely satisfactory.

MOTION PICTURE APPARATUS

A SMALL DEVELOPING MACHINE*

H. R. KOSSMAN**

It is the purpose of this paper to describe a small developing machine especially suitable for research work and for such cases wherein it is desirable to duplicate the conditions that exist in the largest film printing and developing establishments. In designing the machine, the first thought was compactness; not only for the purpose of saving space, but primarily to make it possible for the operator of the machine to watch at all times all the phases of development from the time of feeding the film into the machine to the final rewinding after the film leaves the drying cabinet.

The machine consists of the following units:

(1) The developing, hypo, and washing tanks.
(2) The cabinet, containing the motor drive, motor ventilator, high-pressure blower, electrical heating unit for the drying air, air filters, and a complete switchboard for all the thermostat relays and starters for the circulation pump motor.
(3) Drying cabinet.

In addition, there is a small unit containing the constant level tank, the circulation pump, and the coil and reheating unit controlling the temperature of the bath.

The dimensions of the smallest machine are 7 feet long, 6 feet high, and 3 feet wide. Its capacity, necessarily small, is 650 feet of film per hour, for a developing time of four minutes. A slightly larger machine has an output of 1300 feet per hour. The machine can be used for developing either positive or negative film.

The change from positive to negative bath can be effected in two different ways: The circulation pump can drain the positive developer from the developing tanks and return the bath to the storage tank. Then the negative storage tank would be connected to the circulation circuit. Another way to change the positive to a negative bath is to change the developing tubes. The tubes are instantly interchangeable, and such procedure may be preferable in many cases especially when it is intended to try various developing solutions as for picture and sound.

The temperature of the developing solution is thermostatically controlled. The film passes from one developing tank to the other with the least possible exposure to the air. The developing time can be regulated from 4 to 16 minutes, by changing from one to the other of the two speeds provided in the machine and by lengthening or shortening the film loops in the developing tanks. The developing time can be changed in each individual developing tank so that if it is

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

** Andre Debrie, Inc., New York, N. Y.

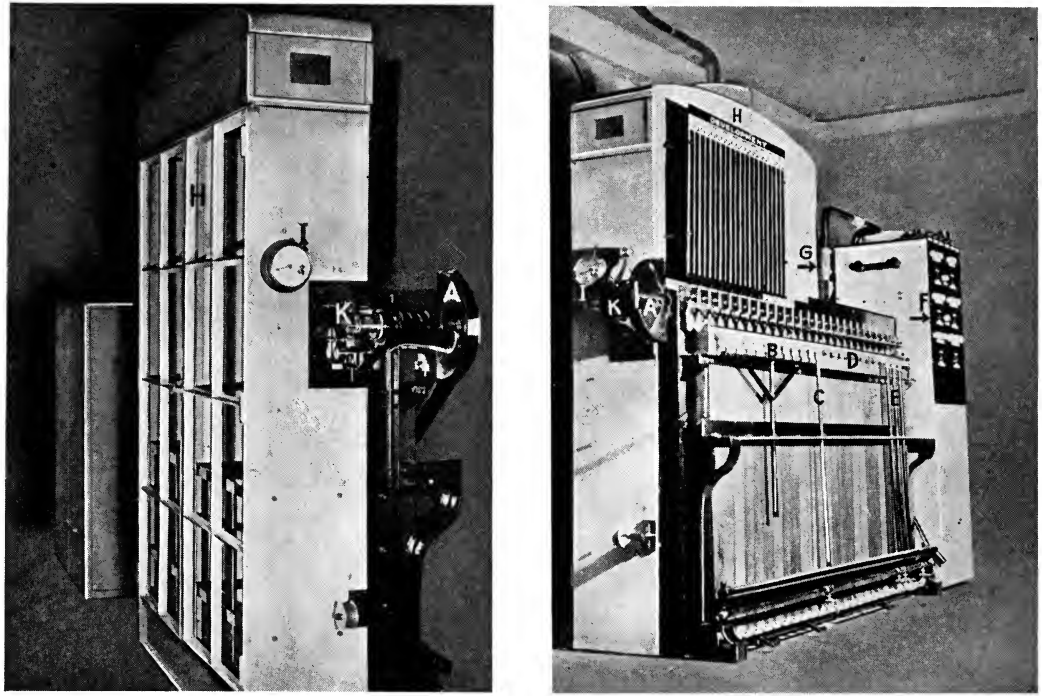

FIG. 1. (*Right*) Rear of developing machine; (*Left*) front view; (*A*) film feed; (*B*) developing tanks; (*C*) washing; (*D*) hypo tanks; (*E*) washing tanks; (*F*) cabinet containing air filters, motor ventilator, motor drive, air-heating unit, switchboard for motor circulation pump, and relays for thermostats; (*G*) blower; (*H*) drying cabinet; (*I*) thermostat; (*K*) film rewind.

discovered in the first or second developing tank that the developing time is either insufficient or excessive, it is possible to compensate for the condition in the last developing tank.

In the smallest model there are five developing tubes, followed by one washing tube, and finally by five hypo tubes and three washing tubes. At this point the film leaves the tubing, its direction of travel is changed, and it is immersed on the opposite side of the machine in three additional washing tubes. After leaving the last washing tube and before entering the drying cabinet, the film passes a high-pressure blower, which is so constructed that the water is blown off entirely without causing the undesirable spots produced by the so-called "squeegees." The film then enters the drying cabinet, forming four loops. The temperature of the drying cabinet is also thermostatically controlled. After leaving the drying cabinet, the film is rewound exactly at the same point where it was fed into the machine.

The machine is equipped with a system for filtering the air before heating it for the drying. For locations where it is necessary to control the humidity of the air, as is especially the case in the tropics, a refrigerating system and closed air circuit are provided. The air is cooled; the excess moisture is eliminated; it is then heated and passed through the drying cabinet, the same air being returned to the refrigerating unit. Such a procedure makes it possible to condition the air perfectly with a comparatively small refrigerating unit.

The temperature control of the bath, the circulation pump, and the constant-level tank are built in one unit. By a pipe connection, preferably of rubber or lead, the developing solution passes into the constant-level tank by gravity, the tank being so arranged that it automatically refills the developing tanks if the developing solution is reduced by evaporation or by being carried over into the washing and hypo tanks by the film. The tank supplies only fresh developer. Below the constant-level tank is the temperature control tank, which also contains the circulation pump. The temperature of the bath is controlled by a copper coil, which uses either city water or, if conditions make it necessary, artificially cooled water. This unit is equipped also with a heating unit and a very sensitive thermostatic control so that the temperature can be maintained constant within $1/2$ degree.

The machine has been designed so as to require a minimum of labor in installing it. Normally, the plumbing for the water system, and the pipe connections for the storage tanks and circulation unit must be provided by the purchaser. However, in the latest design, all connections to and from the storage tank and circulation unit are made by rubber pipes delivered with the machine, a procedure that greatly reduces the cost of installation. Only one feed line for the electrical current to the switch-board is necessary.

The material used in this machine is Monel, Allegheny, and hard rubber. The tanks are made of ebonite, and are easy to clean and, as mentioned above, to interchange.

THE NEW KLIEGLIGHT*

H. KLIEGL**

Twenty-five years ago the Klieglight was used extensively and successfully in indoor photography, following which came the high amperage arc spotlights. Then, for a long time the only developments that occurred were improvements in the general design of the equipment then in use, principally mechanical improvements. With sound came incandescent lighting and high-wattage lamps; and the principle of sun arc was widely adopted and is now universally used.

Chief among the disadvantages of the latter are its size, and the requirement of using "niggers" and "gobos" for subduing false light and for shaping the beam, and of "cellos" to render the field of light more uniform—a costly means of control. In 1932 a great deal of experimenting was done with differently shaped and designed reflectors, leading ultimately to the new Klieglight.

The rhodium reflectors that were used proved extremely successful. The accuracy of these electrolytically deposited reflecting surfaces was far greater than that of spun or cast surfaces, and far greater durability was achieved. The reflection factor was about 74 per cent, and the surface could withstand the heat of a 2000-watt spotlight bulb, in any kind of hood designed for that size of lamp. Fig. 1 shows the original now popular down-light employing a 250-watt bulb, the main reflector of which is elliptical in design.

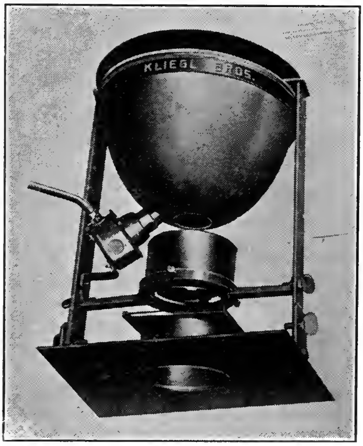

FIG. 1. The original unit, employing a 250-watt lamp and elliptical reflector.

In the elliptical reflector the light emanating from the lamp filament is collected and then projected to the conjugate focus. In the new unit, however, the rays are intercepted by a flat rhodium mirror reflector placed at the exact center of what would be the completed ellipsoid, as shown in Fig. 2.

The action is as follows (Fig. 2): light ray *A* passes from the lamp to the reflector, then to the flat mirror, then back through the lamp, and out through the exit hole in the reflector—a two-reflection ray. There are, in addition, any number of four-reflection rays, as, for example, ray *B*, which missed the exit opening and had to travel through another series of reflections before emerging from the unit.

Upon leaving the reflector the rays are picked up by a set of lenses which

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* Presented at the Spring, 1934, Meeting at Atlantic City, N. J.

** Kliegl Bros. Stagelighting Co., New York, N. Y.

converge the rays into a crossing beam, permitting the light to pass through an opening in the ceiling only 4 inches in diameter. The unit has an efficiency of 24 per cent, approximately three times that of the standard spotlight.

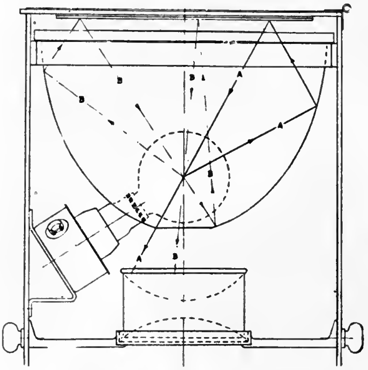

FIG. 2. Reflection of light rays in the unit shown in Fig. 1.

Fig. 3 shows the next step in the design of the Klieglight, which is practically a reversal of the down-light. The output of the exit hole is placed at the center of the reflector, which is located exactly as described before, and the lenses are placed beyond the conjugate focus. The exit hole is large enough to permit maximum pick-up by the lens —of the beams suffering only one reflection. The remainder of the light, missing the lens, is redirected by the mirror back into the reflector, which, in turn, sends it eventually out the exit hole into the lens. The efficiency of the unit is approximately 30 per cent as compared with 24 per cent for the previous lamp.

However, difficulty was encountered in attempting to employ lamps of higher wattage, containing larger filaments and entailing a corresponding loss of light because of the size of the filament, which difficulty, however, was solved by using lamps with filaments of the biplane type. However, the lamps had to be burned base downward, and an additional hole had to be made in the top of the reflector in order to be able to insert the lamp in the socket. While studying the output of the lamp it was found that if the filaments were faced toward the sides of the reflector, the pick-up of the latter would amount to nearly 90 per cent of the light emitted by the filament, all of which is directed by the reflector in one reflection to the lens. It is actually a fact that in the same reflector 40 per

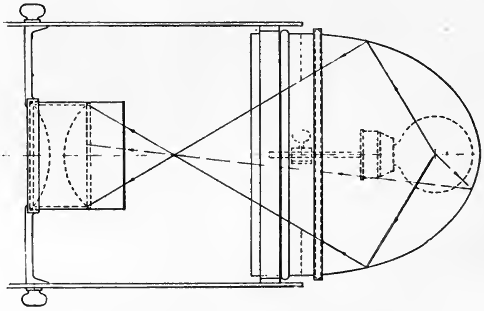

FIG. 3. A development of the Klieglight, practically a reversal of the down-light.

cent more light enters the lens when the filament faces the sides of the reflector than when it faces the lens.

A 1500-watt *bipost-base up-burning* lamp, with a biplane filament in the *T-24* size bulb, was then developed, and the hood of the lamp was again redesigned, as shown in Fig. 4. The bulb is designed to operate at any angle within 45 degrees of the vertical, and by off-setting it in the fashion shown a full 90-degree down-tilt is permitted. The filament is placed far down in the tip of the lamp, resulting in two advantages:

(1) There is very little glass inside the reflector system.
(2) All the blackening of the bulb occurs near the top of the neck, outside the reflector, enabling the system to retain its initial efficiency over a much longer period of time.

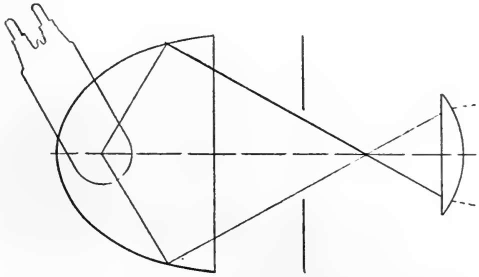

FIG. 4. The final arrangement of the spotlight, employing a 2000-watt bi-post up-burning lamp operated 45 degrees from the vertical.

The lamps are made in both the 1000- and 1500-watt sizes in a *T-24* bulb, and a 2000-watt size in a *T-30* bulb. The centering of the filaments of all three lamps is the same. Both the square and iris adjustable shutters are used, as well as the single-lens pick-up and control system. The flat mirror reflector has been omitted, because the increase of light effected by it was found to be very slight in proportion to the direct pick-up. The shutters are at the focal point of the lens, and the spread is determined by the distance of the lens from the conjugate focus of the reflector. By using lenses of various focal lengths the divergence of the beam can be changed.

In order to illustrate effectively the performance of the new lamp, comparative measurements of the intensity of the spots and floods of the three spotlights indicated in Table I were made.

Note that the intensity of the spot cast by the standard Klieglight is about the same as that of the flood, which is to be expected as the lens position is unchanged, the size of the beam being regulated by the shutter. It is an interesting feature of this type of lamp, that the field intensity remains constant while the beam is varied. The unit lends itself readily to lenses having any degree of spread, either circular or in only one direction.

TABLE I

Comparative Tests of Spot and Flood Intensity
(51-Ft. Throw)

Spotlight	Standard	Klieglight (Fig. 4)	Model *F*
Lens	8″×16″	6″ × 8″ (Single Lens)	Combination of Two Lenses
Reflector	5$^1/_4$ Rhodium Spherical	Rhodium Elliptical (No Front Mirror)	
Control		Shutter	Shutter and Adjustable Lenses
Lamp	2000-w. Monoplane 115-v.	2000-w. 200-hr. Biplane 115-v.	2000-w. 200-hr. Biplane 115-v.
Spot Intensity (6 ft.)	24	32	70
FloodIntensity (20 ft.)	11	32	32

Referring again to Fig. 4, a unit of such type is very suitable for proscenium lighting, balcony-front units, ceiling floods for illuminating stages and orchestra pits, for general spotlighting on the stage, and for indoor and outdoor floodlighting—anywhere where a sharply cut-off beam of high intensity without spill is required. Lenses can be had for beam-spreads varying from 49 to 5 degrees.

The Model *F* Klieglight resulted from the further development of the present standard, the variation of the intensity and spread of the beam being effected by adjustment of the lenses—without dimmers. Two lenses are used in combination, the shutters remaining fixed, by which means the total luminous output of the lamp is utilized at all times. Although the intensity of the illuminated area decreases as the area increases, the minimum intensity, which occurs in the flood position, is about the same as the intensity of the standard Klieglight. The maximum, which occurs in the spot position, is more than three times as great. The shutters can, of course, be adjusted during the alteration from flood to spot or *vice versa*, so that any intensity within the range of the lamp may be achieved. The transition from spot to flood is effected much more gradually than is possible with a dimmer. The most important features of the new spotlight are the method of controlling the beam, the absence of spill light, and the attendant reduction in the lighting expense and operating cost.

THE FALL CONVENTION

NEW YORK, N. Y., OCT. 29—NOV. 1, 1934

HOTEL PENNSYLVANIA

Approximately two hundred members and guests of the Society attended the various sessions of the Fall Convention at New York. The Convention opened on Monday morning with a general session, including reports of Committees, election of officers of the Society for 1935, and action on a proposed amendment of By-Law 1, Sec. 3(d), as described in *Society Announcements.*

At noon of the opening day, an informal luncheon was held for the members and guests. A short introductory address was given by President Goldsmith, followed by addresses by Mrs. Frances Taylor Patterson, Director of photoplay Appreciation of Columbia University; Mr. Martin Quigley, Publisher of the *Motion Picture Herald;* Col. R. W. Winton, Managing Director of the Amateur Cinema League, Inc.; and Mr. Homer G. Tasker, the president-elect for 1935.

The program of papers and presentations, as actually followed at the sessions, was published in the November issue of the JOURNAL. At the Semi-Annual Banquet, held on Wednesday evening, the members were addressed by Dr. F. B. Jewett, President of Bell Telephone Laboratories, Inc., who traced the important and parallel connection between the art of telephonic communication and that of producing and projecting sound motion pictures. Dr. Jewett was appropriately introduced by President Goldsmith.

In recognition of Dr. Goldsmith's unbroken attendance at the meetings of the Projection Practice Committee during the past three years, and his unselfish and invaluable contributions to the work of that Committee the members of the Committee presented to Dr. Goldsmith, at the banquet, a solid silver combination fountain-pen and pencil. The presentation was made on behalf of the Committee by Mr. J. J. Finn, and was followed by a few words of appreciation by Mr. J. I. Crabtree, on behalf of the Board of Governors, for Dr. Goldsmith's untiring and very successful administration of the Society's affairs during the past two years.

Credit for the success of the Convention, which might be measured in terms of an increased general interest of the motion picture industry in the affairs of the Society was largely due to the efforts of Mr. W. C. Kunzmann, Convention Vice-President, Mr. J. I. Crabtree, Editorial Vice-President, Mr. J. O. Baker, Chairman of the Papers Committee, and Mr. H. Griffin, in charge of projection and other technical facilities. Others to whom credit is due were Mr. H. Heidegger, Mr. Griffin's assistant; the officers and members of Local No. 310, I. A. T. S. E., for furnishing the projectionists for the film programs and technical sessions; Mrs. O. M. Glunt, for attanging an attractive and interesting program of entertainment for the ladies visiting the Convention; Mr. and Mrs. H. Griffin, for arranging a tea and fashion show for the ladies at Wanamaker's department store;

Mr. J. Frank, Jr., Chairman of the Apparatus Exhibit Committee; Mr. W. Whitmore, Chairman of the Publicity Committee; and Mr. M. W. Palmer for his assistance in arranging the banquet facilities.

The sound and projection equipment used in the meetings and at the banquet was supplied and installed by the International Projector Corp.; Bausch & Lomb Optical Co; National Carbon Co.; Bell & Howell Co.; Raven Screen Co.; Electro-Acoustic Products Co.; National Theater Supply Co.; RCA Victor Company, Inc.; and Motion Picture Lighting & Equipment Co.

Courtesy passes were provided to the members and guests by the Radio City Music Hall, Warner's Strand Theater, and the Paramount Theater. The floor show at the Banquet was provided through the kind offices of Mr. J. H. Spray and Mr. H. Rubin. Passes to several broadcasts were provided for the Ladies Committees by the National Broadcasting Co.

Monday and Tuesday evenings were devoted to film programs as follows: *Timereel,* Fox Film Corp.; *Old Kentucky Hounds,* Paramount Pictures, Inc.; *Grandfather's Clock,* Metro-Goldwyn-Mayer; *Gay Divorcee,* RKO Pictures, Inc.; *Transatlantic Merry-Go-Round,* United Artists; *St. Louis Kid,* Warner Bros. Pictures, Inc.; *So You Won't Talk* and *Baby Blues,* Vitagraph Corp.; *A Dream Walking,* Paramount.

HIGHLIGHTS OF THE TECHNICAL SESSIONS

Among the interesting presentations on Monday was a paper by H. Rosenberger, describing the recent developments in the technic of cinephotomicrography or micro motion pictures. This was followed by a symposium of three papers on x-ray cinematography; one by R. F. Mitchell, in which the history of cinematography with x-rays was traced; another by R. F. James, dealing with the principles of Roentgen cinematography, and another by J. R. Townsend and L. E. Abbott, describing the applications of x-ray cinematography in industrial development work.

On Monday evening, preceding the motion picture show, an illustrated lecture by Dr. C. E. K. Mees entitled "Certain Photographic Aspects of Sound Recording" was presented by L. A. Jones. The presentation constituted a valuable résumé of the large amount of research work carried out by various experimenters to date.

The paper by A. L. Williams on the piezoelectric loud speaker, followed by a demonstration of the performance of such a speaker, stimulated much discussion and interest. The reproduction of the orchestra, singers, and speakers at the banquet on Wednesday evening was through a piezoelectric microphone operating according to the same principles.

C. E. Lane repeated his demonstration of the mechanical analogue of electric wave filters, which he had originally presented at the Atlantic City Convention last spring, in a more detailed and elaborate form.

On the afternoon of Tuesday, Dr. Goldsmith discussed at quite some length the possibilities of engineering developments in the motion picture industry, in which many fertile fields for research and investigation were pointed out. This paper prompted considerable discussion and suggestions for further study and improvements in motion picture technic.

Perhaps the outstanding session of the Convention was that devoted to the theater and projection, on Tuesday afternoon, which was opened by Dr. Goldsmith's presentation. The report of the Projection Practice Committee was followed by a vigorous and interesting discussion on the merits of reflector guards for projection machines, and the paper by D. B. Joy and E. R. Geib described a non-rotating high-intensity arc, which operates more efficiently and provides a quality of light comparable with that obtained from the conventional high-intensity arc.

The report by Messrs. Schlanger, Wolf, and Jones, outlining in a very interesting manner the architectural and acoustical features of motion picture theaters, was based on information assembled with the view of subsequently presenting it before architectural societies.

The way in which the lighting of the Centre Theatre, Rockefeller City, New York, is controlled by means of electronic tube devices formed the subject of an interesting presentation by J. R. Manheimer and T. H. Joseph.

On Wednesday morning Dr. S. E. Sheppard, in his paper on photographic sensitivity, outlined the various theories proposed to date explaining the reason for the sensitivity of the photographic emulsion to incident light; and some of the mysteries of rear projection for process photography were explained by G. G. Popovici and H. Griffin, their presentation representing a valuable contribution to studio practice.

In the afternoon of Wednesday inspection trips were conducted to various studios, laboratories, and manufactories in the New York district, which were well attended and apparently greatly appreciated by the members, judging from the large turnout for each trip.

"What is Light?" constituted an extremely interesting presentation by S. G. Hibben, which was accompanied by illuminating demonstrations. The author predicted an increasing application of light sources such as the sodium, mercury, and zinc vapor lamps. Also on Thursday, J. D. Edwards, of the Aluminum Company of America, displayed samples of polished aluminum electrolytically treated so as to attain an extremely high reflecting power.

A new method for controlling humidity, by passing the air to be conditioned through a saturated solution of lithium chloride, was described by F. R. Bichowsky.

An innovation of the Convention was a symposium on "Construction Materials for Motion Picture Processing Apparatus," in which Dr. LaQue of the International Nickel Company described the new alloy, Inconel, and Mr. Foote, of the Synthane Corporation, Oaks, Pa., described the various molded bakelite products. Dr. Mitchell, of the Carnegie Steel Company, mentioned a stainless steel containing molybdenum in addition to chromium and nickel, which should display greater resistance to corrosion than the usual 18-8 stainless steel alloys.

"A Developing Rack for Continuously Moving the Film during Processing by the Rack-and-Tank System" was described by C. E. Ives. With this mechanism it is possible to produce an equally uniform degree of development as is attainable with the larger processing machines.

SOCIETY ANNOUNCEMENTS

BOARD OF GOVERNORS

At a meeting held at the Hotel Pennsylvania on October 28, the day preceding the opening of the Fall Convention, plans were laid for holding the Spring, 1935, Convention at Hollywood, Calif., May 20–24, inclusive. The status report presented by Mr. O. M. Glunt, Financial Vice-President, indicated that the fiscal operations of the Society during the current year were progressing very satisfactorily; in view of which the Board voted to increase the number of pages published in the JOURNAL, beginning with the January issue. Various designs for the Progress medal were submitted by Mr. J. I. Crabtree, and work has been begun on a design of the Journal Award Certificate which this year is to be conferred, posthumously, upon Dr. Peter A. Snell.

A Code of Administrative Practices, prepared by a committee of board members and presented by Mr. O. M. Glunt, was adopted by the Board. This code formulates the current administrative procedure of the Society, as directed by enactments of the Board extracted from the mintues of the meetings, that are now in effect. The Code is to be brought up to date periodically, so that each new Board, as it is elected, will be aware immediately of what enactments still remain in force.

Among the actions taken by the Board was the abrogation of the charge for exhibiting apparatus at conventions of the Society. No charge will therefore be levied at the Hollywood Convention, and it is hoped that a large number of exhibitors will take advantage of this enactment and assist in making the Hollywood exhibit a notable one.

In order to clarify a point that has been discussed in the past, the Board ruled that all Committees of the Society shall be appointed annually, their terms corresponding approximately with that of the President of the Society. In other words, the term of office of all members of the various Committees of the Society will coincide with the calendar year, since, according to the recently revised Constitution and By-Laws, the President's term also coincides with the calendar year.

A committee of Board members was appointed to confer with Mr. J. W. McNair, of the American Standards Association, regarding the selection of the organizations to be represented upon the recently authorized Sectional Committee on Standardization. This Committee will prepare and render its specific recommendations to the Board at the next meeting which is to be held on Friday, December 14.

ATLANTIC COAST SECTION

At a meeting held at the studio of RCA Photophone, Inc., New York, N. Y., on November 14, a paper entitled "An Improved System for Noiseless Recording" was presented by Mr. G. L. Dimmick of the RCA Victor Company, Inc. The paper, which was followed by an interesting demonstration of noiseless recording, enlarged upon the information contained in previous papers upon the subject, and the demonstration indicated that means have been found of increasing the volume range of reproduction considerably without introducing distortion or ground noises.

AMENDMENT OF BY-LAW I, SEC. 3 (D)

In accordance with By-Law XI, outlining the method of amending the By-Laws of the Society, the following proposed amendment was introduced at the Fall, 1934, Meeting at New York, N. Y., over the signatures of ten members of Active or higher grade:

"Applicants for Associate membership shall give as reference at least one member of higher grade in good standing. Applicants shall be elected to membership by the approval of at least three-fourths of the Board of Governors, *or, at the discretion of the Board, this authority may be delegated to a Committee on Admissions appointed by the Board.*"

The amendment consists in adding to the end of the second sentence the clause printed in italics.

JOURNAL AWARD

An award of fifty dollars, to be accompanied by an appropriate certificate, was provided for by the Board of Governors some time ago, to be granted to the author or authors of the most outstanding paper originally published in the JOURNAL of the Society during the preceding calendar year (1933). The Journal Award Committee, appointed to study the contributions to the JOURNAL and make their recommendations for the Award to the Board, reported as follows:

AWARD

P. A. Snell, "An Introduction to the Experimental Study of Visual Fatigue;" May, p. 367.

HONORABLE MENTION

H. E. Ives, "An Experimental Apparatus for the Projection of Motion Pictures in Relief;" Aug., p. 106.

J. Crabtree, "Sound Film Printing;" Oct., p. 294.

W. Garity, "Production of Animated Cartoons;" April, p. 309.

W. N. Goodwin, "A Photronic Photographic Exposure Meter;" Feb., p. 95.

O. Sandvik, V. C. Hall, and J. G. Streiffert, "Wave Form Analysis of Variable Width Sound Records;" Oct., p. 323.

In view of the untimely death of Dr. Snell some months ago, the Award will be granted posthumously to his widow. Announcement of the Award was made at the Semi-Annual Banquet of the Society on October 31.

PROJECTION SCREENS COMMITTEE

At a meeting held on October 9 plans were suggested for forming a Committee representative of the various phases of screen illumination, in order to initiate a comprehensive study of that subject. Such a Committee would include representatives of the Projection Practice, Screens, and Theory Committees, Committee on Laboratory Practice, and Sound Committee, so that the problem could be studied from the standpoints of screen design, projection, film density, and sound reproduction.

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