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JOURNAL

OF THE SOCIETY OF

MOTION PICTURE ENGINEERS

Volume XXXVII **July, 1941**

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JOURNAL
OF THE SOCIETY OF
MOTION PICTURE ENGINEERS

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Twenty-Fifth Anniversary

SOCIETY OF MOTION PICTURE ENGINEERS

Incorporated at Washington, D. C.
July 24, 1916

Incorporators

C. Francis Jenkins	Washington, D. C.
Donald J. Bell	Chicago, Ill.
Paul H. Cromelin	New York, N. Y.
C. A. Willatt	Boston, Mass.
Francis B. Cannock	New York, N. Y.
W. Burton Westcott	Boston, Mass
Paul Brockett	Washington, D. C.
E. Kendall Gillett	New York, N. Y.
Herbert Miles	New York, N. Y.
J. P. Lyons	Cleveland, Ohio

The object of the Society shall be . . . *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.*

Membership of the Society

The membership of the Society at the first meeting, held at the Hotel Astor, New York, N. Y., October 2–3, 1916, numbered twenty-six persons, as follows:

C. Francis Jenkins
Donald J. Bell
Paul H. Cromelin
C. A. Willat
Francis B. Cannock
W. Burton Wescott
Paul Brockett
E. Kendall Gillett
Herbert Miles
Carl E. Akeley
H. T. Wilkins
R. G. Hastings
H. B. Coles
Harvey M. Wible
H. A. Campe
R. E. Vom Saal
Barton A. Proctor
M. D. Copple
F. H. Richardson
H. T. Edwards
Max Mayer
Wm. C. Kunzmann
A. S. Victor
E. M. Porter
N. I. Brown
Hermann Kellner

From this modest beginning the Society has grown to nearly 1300 members distributed all over the world, a tribute to its success in fulfilling the object stated on the previous page. Every branch of the motion picture industry, including both the artistic and the scientific aspects of photography, processing, distribution and projection is well represented in the Society, not only by those directly engaged in these professions but by chemists, engineers, and research workers interested in perfecting the apparatus and materials involved.

Presidents of the Society

C. Francis Jenkins	1916–1918
H. A. Campe	1919–1921
Lawrence C. Porter	1922–1923
Loyd A. Jones	1924–1925
Willard B. Cook	1926–1928
Lawrence C. Porter	1929–1930
John I. Crabtree	1930–1931
Alfred N. Goldsmith	1932–1934
Homer G. Tasker	1935–1936
S. K. Wolf	1937–1938
E. Allan Williford	1939–1940
Emery Huse	1941–

SALUTE TO THE SMPE

WILL H. HAYS

When your Society was founded twenty-five years ago, the motion picture, with slow and faltering steps, was just beginning to grope its way into the hearts and affections of the public. The pioneers of that seemingly far away period had enthusiastic confidence in this youngster among the arts, but the world at large too often looked down its nose at the "movies." The child grew and developed, soon was taking prodigious strides, until today the motion picture is the most democratic of the arts of our century, and the universal entertainment of all the people everywhere.

Will H. Hays.

Of the past, with its heartaches and its exhilarations, with its defeats and its unparalleled triumphs, we can be justly proud, but it is the present and the future that now concern us most.

If we are going to develop this art-industry to its fullest potentialities, as I know we are, then the work in no small measure will have to be done by the technicians and engineers of your group. In a basic sense, the motion picture is a mechanical art, the product of technical wizardry. During my long years of association with the industry, I have never ceased to have a feeling of awe on learning of each fabulous scientific advance that has come from the laboratories and workshops, from the minds of men seeking constantly to improve the art. How many times have the unknowing said, "Well, this is it. . . . nothing more is possible!" And then some Aladdin among you has rubbed a magic lamp and brought forth a new wonder to dazzle and stun the imagination.

You have given the screen voice, color, undreamed-of realism. Knowing what you have done, what you are capable of, I won't even hazard a guess what the motion pictures will be twenty-five years from now when the Society of Motion Picture Engineers celebrates its Golden Jubilee. But I do know this: whatever the future holds you will contribute greatly to its course.

The motion picture is a collaborative art, requiring many minds and many hands. Some 275 arts and crafts and professions participate in the making of a single film in our studios. It is this coöperation of talents, harmoniously integrated, which has made the screen one of the greatest constructive forces of modern times. Our industry must always combine depth of human interest and human understanding with foresight, tenacity, sound judgment, and unswerving devotion to the public welfare.

The entire industry rejoices to extend greetings and best wishes on this occasion of your Society's 25th Anniversary.

WILL H. HAYS,
President, Motion Picture Producers
and Distributors of America

ANOTHER MILESTONE

EMERY HUSE

President

July 24, 1941, marks the Twenty-Fifth Anniversary of the Society of Motion Picture Engineers. In 1916 when a group of twenty-six technical men, headed by Mr. C. Francis Jenkins of Washington, D. C., met with the idea of formulating a motion picture engineering society, little did they realize what might come of their idea. The Society as a mere infant passed through the First World War with only a few scars. As the years passed the Society grew in membership and in strength until it eventually became a nationwide organization. Some years after its inception it began to reach out into the world for membership and as a result of its far-reaching activities it has become without question the outstanding motion picture engineering society in the world today.

Some idea of the growth of the Society, particularly during the past ten or twelve years, can be had if one knows that in 1928, at the time the Pacific Coast Section of the Society was organized, the total membership of the national organization was less than the current membership of the Pacific Coast Section alone. The Society is now made up of two Sections in addition to that on the Pacific Coast—the Mid-West Section, located in Chicago, and the East Coast Section, with headquarters in New York. The East Coast Section is fundamentally the parent body of the Society. From the standpoint of membership from all over the world, the Society now boasts of approximately thirteen hundred motion picture engineers.

It is most unfortunate for the affairs of men that the world today is in such a state of turmoil, but it is the purpose of the Society of Motion Picture Engineers during these trying times to maintain its normal activities as far as it is possible to do so. It is firmly believed that in times of war, peacetime activities and efforts must go on and the Society must remain a worthy outlet for the accumulated knowledge in the minds of men doing peacetime work, or even war work, provided the latter is connected with motion picture engineering. If we are able to live up to these worthy desires it seems certain that when this period of emergency is over the importance and prestige of the Society will be maintained, and we believe we will have laid a firm foundation upon which a better peacetime program in the field of motion picture engineering may be built.

This issue of the JOURNAL of the Society of Motion Picture Engineers, which is dedicated to the Twenty-Fifth Anniversary of the Society, marks a definite milestone in the accomplishments of the Society. It must be proved that these accomplishments have not been made in vain, and it is up to each and every member of the Society to dedicate himself to the perpetuation of the ideals of this Society. This can be done best by looking ahead to the Fiftieth Semi-Annual Convention of the Society which will take place in New York City, October 20 to 23, 1941. We must all put our shoulders to the wheel and see to it that this Convention is the most outstanding ever held by our Society.

Emery Huse

President

TWENTY-FIVE YEARS OF SERVICE

F. H. RICHARDSON

Historically speaking, twenty-five years is an infinitesimal portion of time, but in relation to the motion picture industry, twenty-five years covers almost the entire period of birth, growth, and adolescence of the industry. Twenty-five years ago I sat at a meeting with twenty-five other men who had somehow chosen "moving pictures" as their interest and livelihood, and we put this Society to work for us.

We had no idea the Society was going to last for twenty-five years or that it would grow to the technical importance it now holds for the entire industry. We had a job to do, and we set about to do it, and the formation of the Society was one means of helping us to do it.

The Society grew slowly at first, because the industry was floundering about, trying to find itself; but soon it grew more rapidly as the movies began to expand into the enormous industry we have today; and when sound came into the picture.... It is needless to go into details. Today the Society's influence encompasses the entire world; it has members in all important countries of the world; and constitutes the most important source of information on the up-to-date progress and technical developments of motion picture engineering.

I am proud to have been one of the founders of the Society, and all through the years I have tried to contribute whatever I could to the betterment of the industry and of the Society. Projection has been my principal interest, because I started as a projectionist—or "operator," in those days—and I am indeed happy in the fact that, with the aid of a few others, I have been helpful in arousing the interest of the Society in the humble art of "operating moving picture machines."

I trust and feel confident that the Society will continue successfully this work begun so many years ago, and I can but repeat that I am proud to have had a part in all this work. May the Society prosper and find success in all its endeavors.

F H Richardson

RECENT ADVANCES IN THE THEORY OF THE PHOTOGRAPHIC PROCESS*

C. E. KENNETH MEES**

Summary.—*A photographic film consists of a layer of gelatin coated on cellulose base in which are dispersed a great number of very small silver bromide crystals. When exposed to light, electrons are liberated in the crystals and these collect at certain points, where they are neutralized by silver ions which deposit atoms of metallic silver. This metallic silver deposited in definite specks forms what is known as* the latent image, *which makes possible the development of the crystal. The surface of each silver bromide crystal in the gelatin layer of an emulsion immersed in the developer is protected by charged layers of bromide and potassium ions. The development of the grain is initiated by the break in this charged layer caused by the presence of the silver latent image. When the developer acts on the silver bromide crystal, metallic silver is produced in a ribbon-like form, a tangled mass of which forms the developed silver grain.*

Behind all our technology there lies the basic theory of the photographic process—the chemistry and physics of the formation and structure of the photographic material, its reaction to light, its behavior in the developer when the image is produced, and the properties of that image.

The science of photography is founded on the two great sister sciences, chemistry and physics, and it was only as our knowledge of these grew that progress could be made on the problems of photographic science. Until recently, photographic science tended to consist of a chaos of observations, some of them of real value and others of very doubtful value, with little in the way of theories to connect them properly. It is only within the last few years that fact after fact has been falling into place in an ordered network. At the present time we can say that while much remains to be done, we have a very clear and definite science of photography—something which can be written out and generalized upon and to which the missing parts can be added as more work is done.

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received May 6, 1941.

** Kodak Research Laboratories, Rochester, N. Y.

Strictly speaking, many light-sensitive substances could be used for making photographic images, and the science of photography should be co-extensive with photochemistry itself; that is, with the chemistry and physics of light-sensitive substances. But in practice, this is not the case, and the art of photography is almost entirely confined to the use of silver salts, so that the science of photography is necessarily preoccupied with the very complex system of silver halide crystals dispersed in gelatin. Information as to the reactions which go on in the simpler systems used in photochemical investigations throws little light on the photographic process.

If we enlarge a photographic film under a microscope to about the limit of resolution of the microscope; that is, to some 2500 diameters, we shall find that it consists of a very complex system. On the base, which is cellulose nitrate or acetate, there is coated a layer of gelatin containing silver halide crystals. These silver halide crystals are composed of silver bromide containing a small amount of silver iodide, and they may be dyed to sensitize them to the longer wavelengths of light. The crystals vary considerably in size but are of the same general shape. They are triangles and hexagons, which are the natural forms of silver bromide, and they are held in photographic gelatin (Fig. 1). Analysis would show that the film also contains a number of materials—glycerine, hardeners, and other things adapted to control its properties. When this film is exposed to light, the silver bromide crystals are affected in some way by an extraordinarily small amount of light, and they suffer some change. That change must take place in two steps and not quite instantaneously, although it occurs in a very short fraction of a second. The reason for this conclusion is that the amount of change produced depends somewhat upon the rate at which the light is supplied. This is what is known as the "reciprocity effect." If the light is supplied rapidly, somewhat more effect is produced than if the light is applied very slowly—as if, for instance, a faucet were running into a bucket and the bucket had a small hole in it. But the analogy is not good because when the exposure is over, the change that has occurred is permanent; the image will keep for long periods. When Andre's photographs were found at the Pole thirty years after his balloon fell on the ice and were developed, they were quite satisfactory, the latent image having been preserved by the cold in spite of immersion in sea water.

The silver bromide crystals in the emulsion depend for their sensitivity upon the gelatin in which they are suspended. Emulsion makers have known for many years that some gelatins were active and would give sensitive emulsions and that others were inactive. In an arduous research, this was traced by Sheppard to the presence in the gelatin of traces of free sulfur compounds, which are presumably derived from the plants which the calves and their mothers ate. When gelatin is made from little animals, like rabbits, which avoid the hot-tasting plants, such as mustard, which contain sulfur, the gelatin does not contain these sulfur compounds, so that it was not improper to state that "if cows didn't like mustard we wouldn't have any movies!" The sulfur compounds in the gelatin react with the silver bromide and produce specks of silver sulfide. These specks of silver sulfide in some way increase the sensitivity of the silver bromide crystal to light.

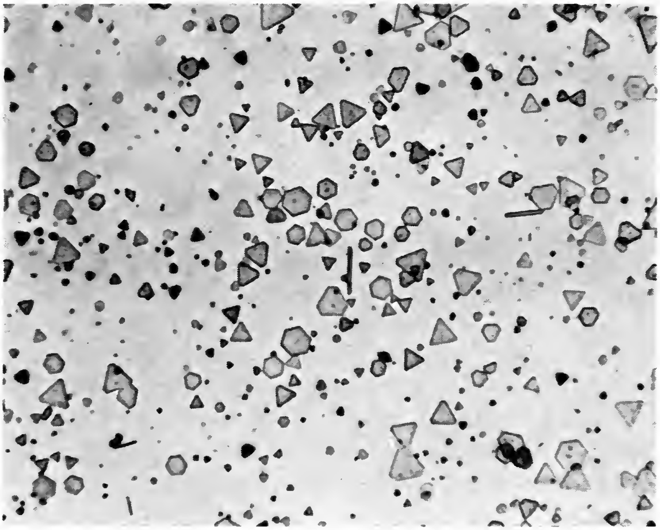

FIG. 1. Silver bromide grains in a photographic emulsion.

Recently, a thoroughly consistent theory of the effect of light upon the silver bromide grains has come out of the work of our laboratories and from Professors Gurney and Mott of Bristol, England. In the first place, if we consider the energy diagram (Fig. 2) of a silver bromide crystal, we shall find that we have two energy levels, the S and

P levels, in which the electrons may be situated. The *S* band is normally empty and is referred to as a "conduction band." The *P* band is normally completely filled with the electrons. Upon exposure of a silver bromide crystal to light which is absorbed in the long-wavelength end of the characteristic absorption band, the electrons are transferred from the lower *P* band to the *S* band, and the crystal becomes conducting. This property is well known in other materials, as well as in silver bromide, as "photo-conductance," and the silver bromide crystal exposed to light may be imagined to be filled with a sort of gas of conducting electrons. Also, when light is absorbed by the silver bromide, electrons are released. This is the primary photographic process—the thing that happens instantly when light falls on the crystal. The electrons move about with great speed inside the crystal and will very frequently reach the boundaries of the crystal, but when they reach a sensitivity speck, they will be trapped by it and the sensitivity speck will become negatively charged by the electrons that it has absorbed. Naturally, the sensitivity specks will themselves be giving out electrons slowly if they are at normal temperatures, just as does any other solid body. During an ordinary exposure, the amount of electrons given out by the sensitivity specks will be very small; while those which will be absorbed from the electrons freed by light will be very great. After the formation of the free electrons by light, therefore, the sensitivity specks acquire a negative charge by the absorption of these free electrons.

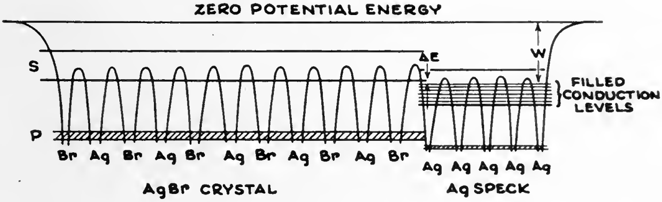

FIG. 2. Energy diagram of the silver bromide crystal.

In a crystal, there is always available, of course, a certain amount of silver ions which are formed inside the lattice. As soon as the sensitivity specks acquire negative charges, these silver ions are attracted to the specks, each negative charge neutralizes one silver ion and produces a deposit of a silver atom at the sensitivity speck, so that every electron freed by the original light exposure is eventually transformed into a silver atom deposited on a sensitivity speck.

This theory of the effect of exposure was suggested by Sheppard and Trivelli of our laboratory over ten years ago under the title of "the concentration speck theory," but they were unable to give a satisfactory mechanism for the formation of the concentration speck although they saw that in some way the effect of light must be to produce a silver deposit at the sensitivity specks. The new theory of Webb and Gurney and Mott shows that the effect occurs in two stages: first, the release of free electrons, which occurs instantaneously; and then the transformation of the free electrons by neutralization through the silver ions into silver atoms at the sensitivity specks. This accounts for the reciprocity effect. When the light acts, free electrons are formed and go to the sensitivity specks, but the sensitivity specks are continually losing electrons and, consequently, if the light is weak, there will not be as many silver atoms deposited at the sensitivity specks as there should be. A certain minimum concentration of electrons must be built up in the crystal before the electrons begin to be trapped by the sensitivity specks. This explanation is shown to fit the facts because, when the loss of electrons from the sensitivity specks is reduced by greatly lowering the temperature, the rate at which the light is supplied no longer affects the resulting image.

The action of light, then, on the silver halide crystals is, first, to produce instantaneously a charge of free electrons. Then these electrons are attracted to the sensitivity specks, and their charge is neutralized by silver ions, with the result that metallic silver is deposited around each sensitivity speck and forms the permanent nucleus which we call the "latent image."

The great efficiency of the photographic process is due to the very small amount of work which is done by light in forming an image and the very large amount of work which is done by the chemical developer.

A photographic developer is a reducing agent; that is, it is a substance which is itself oxidized by silver bromide and, in being oxidized, reduces the silver bromide to metallic silver. The matter is, however, very complicated, and we are only beginning to understand the behavior of photographic development. In the first place, not all reducing agents, by any means, are photographic developers. If the reducing agents are too strong, they reduce the unexposed silver bromide and the whole of the film turns black, no image being formed. If the reducing agents are too weak, they will not reduce the silver bromide after exposure. In order that the substance may be a developer, it must have a certain power of reduction or, as we should say in electrochemical terms, a certain "reduction potential." But there are substances which fall in the correct range of reduction potentials, so far as we can measure it, which still are not photographic developers. There are others which are photographic developers in the sense that they show an image on an exposed film but are not useful photographic developers because they do not develop satisfactory images in a reasonable time.

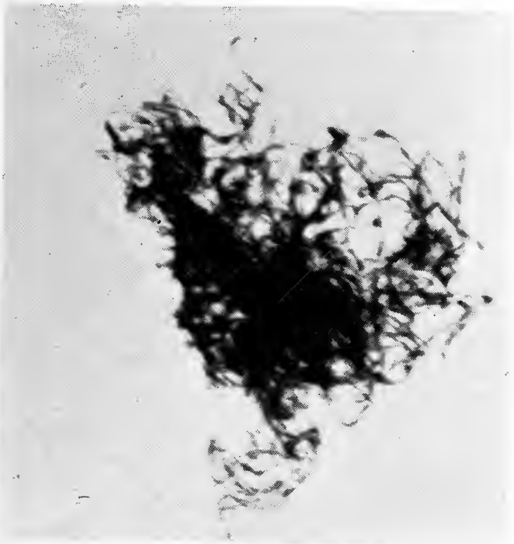

FIG. 3. Filamentary structure of a silver grain (×40,000).

Our knowledge of the mechanism of development has been greatly assisted by the information as to the structure of the developed silver obtained by the use of the electron microscope. The grains of developed silver show little structure under the highest magnification of the ordinary microscope. It was obvious that they could not be compact masses of silver since their volume is much too great for their mass if the structure was compact, and it was generally thought that the grains had a spongy structure, somewhat similar to that of

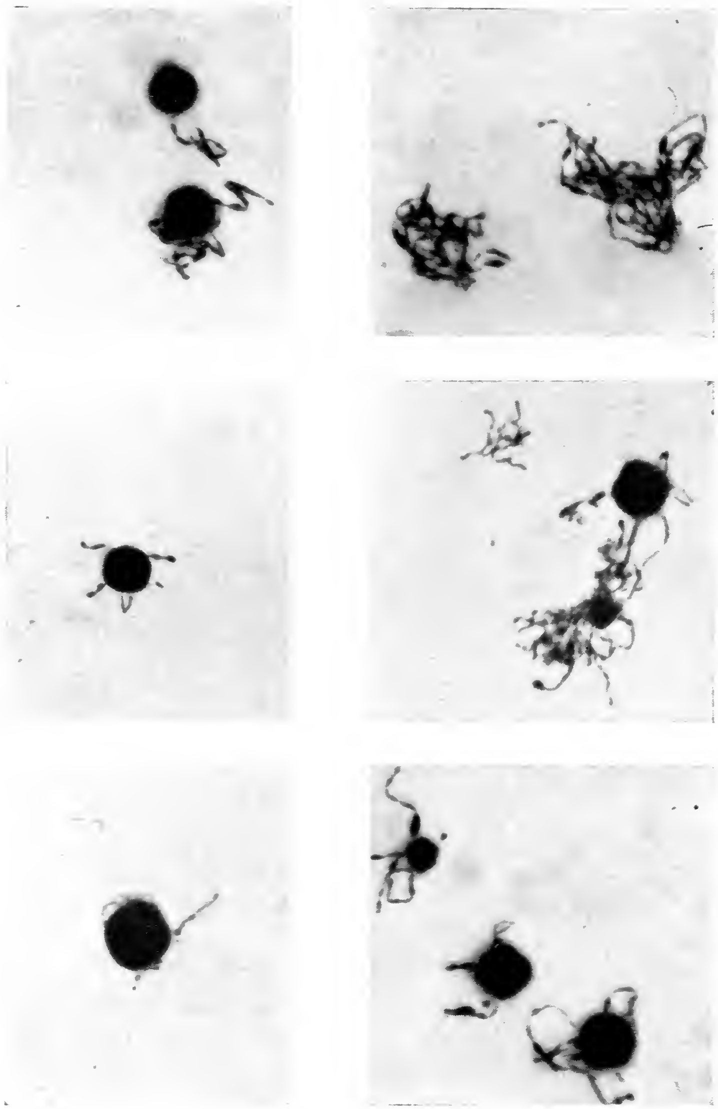

FIG. 4. Stages of development in grains (×25,000).

coke. The electron microscope enables photographs to be taken with equally good definition at magnifications about twenty times higher than those which are possible with the ordinary microscope, and when this instrument was applied to the photomicrography of developed silver, it was found that the silver had a most unexpected ribbon-like structure, so that the grains appear like masses of seaweed (Fig. 3). This filamentary structure of developed silver is very surprising, and the fact that it is so unusual makes possible some deductions as to the formation of silver. It might be thought that the ribbons were produced by the formation of silver in interstices in the silver halide grains, but this is seen to be impossible when we examine the development of extremely small silver bromide grains, such as those which are used in emulsions of the Lippmann type. Each single crystal turns into a filament of silver, which is much longer than the diameter of the crystal, so that it is evident that filamentary silver must be ejected from the crystal when development occurs. A series of pictures showing the stages of development of grains are very instructive (Fig. 4). The grains were deliberately selected to be very small and the photographs show clearly the ejection of the ribbons of silver and their growth from the grains until the whole grain has been converted into a spongy mass of silver filaments. It seems to be clear, therefore, that the old idea that the grains dissolved in the developer and then silver was precipitated and coagulated around the exposed crystalline grains is quite incorrect. Instead, we have to imagine that the developer reacts with the exposed silver bromide grain and from it forces filaments of silver arising presumably from the silver silver-bromide interface. As more silver is produced, new spots in the grain become the sources of development until the whole grain is converted into silver.

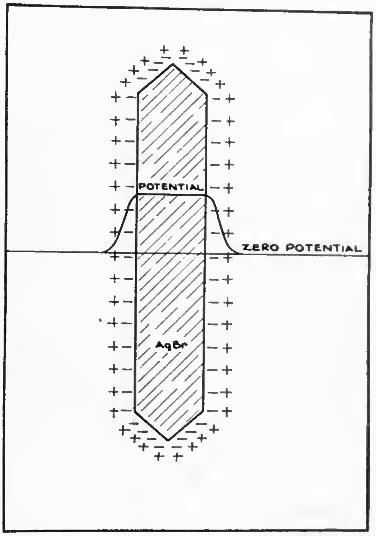

FIG. 5. Diagram of grain with protective double layer.

In a study of the initiation of development, it must be remembered that the problem is not why an exposed grain develops, so much as why an unexposed grain does not develop. If silver bromide is precipitated in the presence of an excess of silver nitrate, it is spontaneously developable without exposure to light. Moreover, silver bromide even in the absence of free silver and without exposure to light is readily reduced in a developing solution if it is precipitated in the absence of gelatin, and there is no doubt that the adsorption of gelatin to the silver bromide protects it from the action of the developer. This protection may be considered to be due to a negatively charged electric layer which surrounds the silver bromide grain formed with an excess of bromide, the function of the gelatin being to protect the charged layer. Dr. J. H. Webb depicts the exposed silver halide grain as a plate, as shown in Fig. 5 in which the charged condition around the grain is represented schematically. The surface of the silver bromide grain itself has an excess of bromide ions which give rise to a negatively charged surface. However, just outside this negative charge, a positive layer of potassium ions must be present to neutralize the negative charge. Without such a neutralizing layer of positive ions, it would be impossible for the surface of the silver bromide grain to be covered with negative bromine ions, since the amount of such a charge in so small a region would give rise to explosive forces. A double charge layer, consisting of negative bromine ions on the grain and positive potassium ions in the gelatin just outside, may be considered to exist around the surface of each silver bromide grain. Grains with such a double layer (in solution) would move under an electric field as negatively charged bodies, since the negatively charged grain would be forced in one direction by the field, and the surrounding movable positive ion layer in the opposite direction, but as at any point in the liquid there would be positive ions to form the surrounding positive shell, the double charge layer would be maintained. That the surface charge on the particles and surrounding charge layers do neutralize each other in the manner outlined is proved by the fact that the colloidal suspension does not possess a net charge of either sign, but is neutral as a whole.

It may be assumed that a grain, with its double charge layer, behaves toward outside charges and also toward charges located inside the grain as a neutral body. An electron placed inside such a double charge layer would experience no force nor, in the same way, would an electron placed outside such a double layer. However, there is a marked difference in potential between the inside and outside of the grain, and the total jump in this potential occurs in the region between the two charge layers. The potential gradient between these charge layers accordingly gives rise to a strong electrical force between the layers, and an electron placed between them would experience a force toward the outside. It is considered that the double charge layer acts in this way as an effective potential barrier to the entrance of an electron into the silver bromide grain of the emulsion and prevents the charged ions of the developer from attacking the grain.

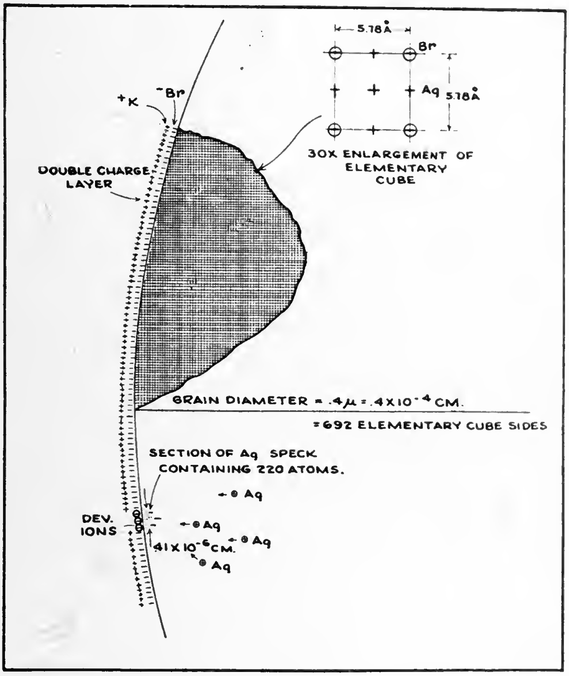

FIG. 6. Diagram of grain with latent image.

The condition existing in the exposed grain containing a latent image silver speck may be seen in Fig. 6. This shows a greatly enlarged scale model of a charged grain surface with a clump of silver atoms on the surface, which is supposed to represent the latent image produced by exposure to light. The clump shown includes 220 atoms, with approximately the correct spacing. This size was chosen as representing a fair mean of the values given by various workers.

It is assumed that development of a grain is initiated by the break in the double charge layer caused by the silver speck, permitting the negative developer ions to reach this silver speck. The latent image speck is viewed as an electrode penetrating into the grain. The tendency on the part of the developer ions to release electrons to the silver causes electrons to pass to the electrode and charge it negatively. This occurs if the electrons of the developer ions are situated in levels above the highest occupied energy levels of the silver metal. The penetration of this negative electrode into the silver bromide grain upsets the neutral electrical condition previously existing in the grain, and there arises an attractive force for the positively charged silver ions in the neighborhood of the latent image speck. Some loose positive silver ions always exist in the crystal lattice owing to temperature motion, and these diffuse to the speck under the attraction of the negative charge there and enlarge the silver speck. Thus, it is supposed that the original silver speck of the latent image commences to grow by this mechanism. As this proceeds, the protective double layer is more and more ruptured, and a rapidly increasing area of the silver halide grain is exposed to the attack of the developer. The reduction of the grain therefore proceeds at an ever-increasing rate, and the grain is very soon reduced throughout to metallic silver. In the initial stages of development only, is a silver bromide grain protected from a developer; after the barrier is once penetrated, it rapidly approaches the status of an unprotected grain, which, as pointed out, is developable very rapidly.

This is only a very preliminary sketch of the action of development. Undoubtedly, the adsorption of the developer to the developing grain plays some part in the reaction. It concentrates the developer ions at the point where they are required and undoubtedly also the actual reaction of the developer with the grain, and its behavior as a reducing substance is catalyzed by the silver of the latent image.

A great change has taken place in the technic of the motion picture studio in the last twelve years as a result of the application of panchromatic films. Negative films in motion picture work are now invariably panchromatic, and their greatly improved quality compared with the earlier materials is due to the advances that have been made in the preparation of sensitizing dyes. These sensitizing dyes are what are known as "polymethine" dyes, most of them being the class of dyes which are known as "cyanines." There are basic dyes in which the two nuclei are linked by a chain of CH groups. Since many different nuclei can be used, the chain can be of different lengths and various substituents can be inserted in a molecule, so that very many dyes are available, and since they all have properties peculiar to their structure, a wide range of sensitizing can be obtained. The cyanine dyes show very beautiful crystals. They have bright colors, and many of them are pleochroic, so that they show iridescent effects.

In addition to the advances in practical photography which have followed the use of the sensitizing dyes we have achieved a considerable knowledge of the way in which they work. It seems clear that the optimum concentration for the sensitizing of a silver halide grain is a single layer of dye molecules attached to the whole surface of the grain, as if the flat plate of silver halide were covered with a little velvet pile of dye molecules, all of them firmly attached to the silver halide lattice, but free to resonate to the light which they absorb. The dye molecules appear to be arranged edge-on, so that for the best sensitizing the surface is covered with leaf-like molecules piled edgewise in as close packing as is compatible with their own structure and the structure of the crystal, forming a parallel pile or edge-on layer one molecule thick. The new surface of the crystal with the dye on it has no affinity for water, but there is an attraction between the molecules oriented in this way, so that colliding particles may tend to aggregate and precipitate. Dyes which otherwise might be sensitizers may fail to sensitize because their molecules are so shaped that they can not form this flat leaf-like structure, and the best sensitizers are presumably those which form the structure easily. When the light is absorbed by the dye molecule, it must liberate an electron, but it is not yet possible to decide whether this electron itself acts to form the latent image in the silver bromide or whether the energy is transferred to the silver bromide which liberates the electron into the conduction band.

There are many obscure points which still require elucidation in the theory of the photographic process, but very rapid progress has been made recently and we are beginning to understand the fundamentals of the process by which pictures are made.

RECOMMENDED PROCEDURE AND EQUIPMENT SPECIFICATIONS FOR EDUCATIONAL 16-MM PROJECTION*

A REPORT OF THE COMMITTEE ON NON-THEATRICAL EQUIPMENT

MAY, 1941

This report has been prepared in response to a request from the Committee on Scientific Aids to Learning, of the National Research Council.

The report is in three parts. Part I is a general discussion of the problems that enter into the selection and use of 16-mm motion picture equipment for educational institutions. It includes recommendations for such comparative tests of equipment as can properly be made without testing laboratory facilities.

Part II is a report on the optical characteristics of the screens available at the present time for non-theatrical projection.

Part III consists of a set of detailed technical specifications defining acceptable performance of 16-mm projection equipment for educational uses. The character of these specifications is necessarily such that they can be interpreted and applied only by a fully equipped testing laboratory.

Committee on Non-Theatrical Equipment

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PART I

GENERAL RECOMMENDATIONS

Objectives.—In the selection of motion picture equipment for classroom use, the object should be to provide a picture that can be viewed to good advantage by everyone in the classroom. Likewise,

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received May 27, 1941.

equipment should be selected to provide good reproduced sound in every part of the classroom.

Standards of quality in educational projection ought, if anything, to be higher than those in the theatrical motion picture field. The pupil does not come to the classroom to be entertained, but to learn. In order to learn from the screen, he must watch it diligently, even though he may happen to be seated in a position that affords him only an oblique and distorted view of the picture. In order to learn from the sound, he must be able to understand reproduced speech without effort, and he must be able to obtain a true impression of the character of natural sounds and of the tone qualities of musical instruments when these are used in the films.

In a motion picture theater, if one has to sit in an unfavorable location, as a rule he is subjected to this annoyance for only a single performance. In the schoolroom, however, he may be required to keep the same seat day after day. If this seat does not give him a good view of the picture and a good opportunity to hear the sound, he is under a permanent handicap.

It is because of these considerations that in several instances this report recommends narrower limits than are commonly accepted in theatrical projection practice. The Committee believes that in the educational field there should be no compromise with respect to the conditions that are necessary to secure substantially equal performance for all persons in the classroom.

Basic Steps in Equipment Selection.—Intelligent selection of equipment means a great deal more than the mere selection of high-quality equipment. It means the coördinated selection of equipment items in relation to the conditions under which they are to be used. The projector, the unit on which most attention is generally focused, should, as a rule, be the last to be selected.

The first consideration, and one of the most important, is the size of the screen to be provided. This is determined primarily by the maximum distance from which the picture will be viewed by the students.

After the picture size has been determined, the right type of screen surface must be selected, as determined by the shape of the room, or, rather, by the seating arrangement of the spectators in the room.

The picture size and the type of screen surface, together with the degree to which light can be excluded from the room, determine the light output required from the projector. The selection of the projector should be made from those types which provide as nearly as possible the correct light output.

A similar requirement exists with respect to the power-handling capacity of the sound-reproducing system, in relation to the acoustic properties of the classroom. Fortunately, the power output of the sound-reproducing system can be controlled more conveniently than the light-projecting system of the projector; therefore it is sufficient to ascertain by practical test that the maximum sound power output of the projector selected is sufficient for the room in which it is to be used.

Complete equipment for the projection of films in a classroom includes a suitable stand for supporting the projector firmly in the proper location. Facilities for darkening the room during projection are also needed.

Recommendations with respect to each of these problems will be given, in the general order in which they have been mentioned.

Picture Size.—In the past the Society of Motion Picture Engineers has conducted an extensive survey of theaters[1] to determine, among other things, the most desirable picture size in relation to the distance from the screen to the farthest spectators. The result of this survey agrees well with the conclusion that follows theoretically from a study of the ability of the average human eye to see fine details under the conditions of watching a motion picture. It is found that a distance equal to 6 times the width of the screen is the greatest at which all of the details in the picture can be seen easily. *It is recommended, therefore, that a picture width equal to $^1/_6$ of the distance from the farthest row of seats to the screen position be adopted for classroom projection.*

Other considerations dictate a minimum viewing distance. If the observer is sitting too close to the screen, even though the screen image is focused as sharply as possible, it will appear to be out of focus, because it does not contain enough fine details to appear sharp at that distance. Under this condition the spectator experiences a type of eye-strain caused by the instinctive attempt of the brain and the eye muscles to focus a sharper picture than is present on the screen. Since this is impossible, the eye muscles are kept in continuous activity, and there is nervous as well as physical fatigue. It is also a matter of common observation that when one sits too close to a motion picture, the eye movements needed to follow the action on the acreen are excessively rapid, and may result in eye-strain.

It is recommended that no pupils be seated closer to the screen than twice the picture width. In most classrooms this requires the placing of the screen on or near the front wall of the classroom, in order to have it far enough from the front row of seats.

In order to adjust the size of the projected image exactly to fill the screen, the projector rather than the screen should be moved. The ideal arrangement is to provide a fixed stand for the projector at the correct distance from the screen. If this is not done, a stand on wheels which can be locked in position when the right location has been found should be provided with each projector. A description of one suitable type of stand will be found in the booklet entitled "Projecting Motion Pictures in the Classroom," Vol. IV, No. 5, of the series entitled "Motion Pictures in Education," published by The American Council on Education, Washington, D. C. A stand not differing greatly from this design is available from at least one equipment manufacturer.

If the projector is equipped with the usual lens of 2-inch focal length, the screen will be filled when the distance to the projection lens is $5^1/_4$ times the screen width. Thus the correct location for the projector is a little more than $^5/_6$ as far from the front wall of the classroom as the farthest row of seats. While in some cases it is more convenient to have the projector at the rear of all of the rows of seats, it should be placed in this location only if the resulting picture width is not greater than $^1/_2$ the distance from the front row of seats to the screen.

Projection lenses of several focal lengths greater than 2 inches are available for use with 16-mm projectors. These are useful in cases where the construction of the room or auditorium makes it necessary to place the projector in a location that would give too large a picture with the 2-inch lens. The lens of longer focus gives a smaller picture in the ratio of 2 inches to the focal length of the lens used.

In general, however, it is best to use the 2-inch lens and obtain the correct picture size by locating the projector correctly. Structural limitations in most of the projectors now available make it necessary to reduce the angular aperture, or "speed" of the longer focus projection lenses in order that they may be mounted on the machine. This reduction of lens aperture reduces the light transmitted to the screen. If the amount of light obtained is still within the limits recommended later in this report for the size and type of screen used, performance will be satisfactory. The need for a lens of long focal length is most likely to arise, however, in an auditorium or lecture room where the amount of light required is already equal to the maximum that can be obtained from the projector. In such a case the sacrifice of optical efficiency that is involved in the use of a lens of long focal length and reduced relative aperture should be made only when there would be real difficulty in locating the projector correctly for the use of the 2-inch lens.

It may reasonably be inquired whether or not there is a best location from which to view a motion picture. This question receives a definite answer from a consideration of the perspective relationships in the viewing of the picture. It can readily be demonstrated[2] that the perspective in a projected picture will be entirely correct from the standpoint of the observer only when the observer's distance from the screen bears the same relation to the distance from the projector to the screen as the focal length of the lens used to take the picture bears to the focal length of the lens used to project it. Since most 16-mm motion pictures are photographed with 1-inch lenses, and the result obtained by reducing films from the 35-mm size is almost exactly the same as if the pictures had been taken in the 16-mm size with a 1-inch lens, it follows that whenever 16-mm films are projected with the usual 2-inch lens, the best position from which to view the picture is half way between the projector and the screen. In this location the spectator's judgment of the relative sizes of objects near and far from the camera will be correct. All those sitting closer to the screen receive the impression that the more distant objects in the picture are too large. Those sitting farther from the screen receive the impression that the near objects in the picture are too large.

The above considerations relating to perspective are not of vital importance, as may be seen from the fact that they are frequently neglected in motion picture theater construction. Nevertheless, they indicate that whenever a picture slightly wider than $^1/_6$ the distance from the screen to the farthest row of seats can be used without making the width greater than $^1/_2$ the distance to the nearest row of seats, it is just as well to use this larger picture, since this practice results in placing the point of best perspective rendition more nearly in the center of the audience. It should be remembered, however, that a larger picture requires more light from the projector.

Limitation of Viewing Angle.—All those spectators who view the picture from positions near a line drawn perpendicular to the center of the screen see a nearly undistorted picture. As the observer moves away from this line toward the side of the room, his view of the picture becomes distorted. When the viewing angle approaches 40 degrees the screen appears square instead of oblong. Careful tests made by Tuttle[3] demonstrated that this amount of distortion is definitely objectionable, even to spectators who see the picture under conditions such that they are unaware of the cause of the distortion.

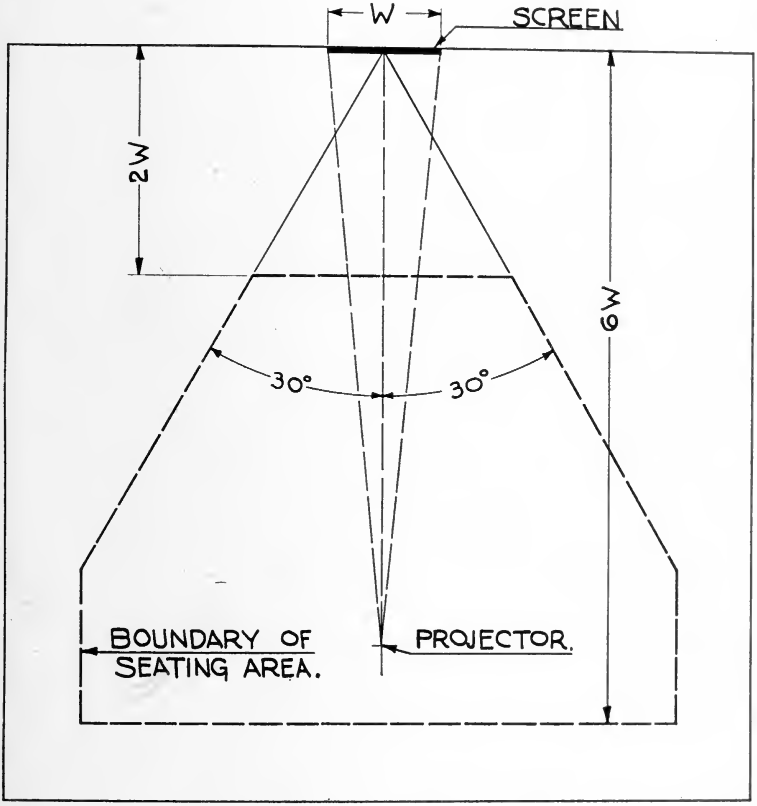

FIG. 1. Recommended seating area for wide room, with matte type screen.

This Committee recommends that for school projection the viewing angle be limited to 30 degrees. This condition is approximately fulfilled when no row of seats is longer than its distance from the screen. In a nearly square classroom or auditorium this recommendation calls for the seating arrangement shown in Fig. 1. Any seats outside the limits indicated should not be occupied during the projection of motion pictures.

Selection of Screen Surface.—Screens fall into three general classes as to the manner in which they reflect light. First is the matte-surface type, coated with flat white paint or consisting of fabric or rubber so treated as to reflect light in the same manner as white paint. These screens reflect the light that falls upon them in such a way that their brightnesses are approximately the same at all angles of view. A picture projected on such a screen is almost as bright when viewed from an angle of 30 degrees, or even from an angle of 60 degrees, as it is when viewed perpendicularly.

The reflecting power of screens in different directions is customarily expressed in terms of a theoretical screen which reflects all the light falling upon it in such a way as to be equally bright at all viewing angles. Taking the coefficient of reflection of such a screen as 100 per cent in every direction, a good matte-surface screen will have a coefficient of reflection of 85 per cent along the perpendicular to the screen surface, and a coefficient of reflection of between 75 and 80 per cent at an angle of 30 degrees.

The second type of screen has a surface covered with small glass beads. These beads have the property of reflecting the light internally, and at the same time directing it by refraction in such a way that the largest proportion of the light is sent back in the direction from which it came. This is true even when the light strikes the screen at an angle. Because the beaded screen sends most of the light back toward the projector, those sitting along the centerline of the classroom see a much brighter picture than would be provided even by the perfectly reflecting theoretical screen described above. The brightness along the axis of projection corresponds to a coefficient of reflection (as defined above) of about 350 per cent. At greater viewing angles, however, the picture is much less bright. At an angle of 22 degrees the picture brightness is the same as is obtained with an average matte surface screen, and at all greater viewing angles it is considerably less.

The third type of screen is coated with fine particles of metal, usually aluminum, which reflect the light like so many little mirrors. Screens of this type show a pronounced "hot-spot," which is near the center of the screen for those sitting near the centerline of the room, and moves over to one edge as the spectator moves away from the centerline. The condition is particularly bad for those sitting near the ends of the front row of seats. In this location one side of the picture may appear as much as ten times as bright as the other side.

Metal-surfaced screens are necessary for certain types of projection in which polarized light is used, but they should not be used in classroom projection of motion pictures. This recommendation is made regardless of whether the screen surface is of smooth or rough texture. The rough textured screens diffuse the light more than the smooth surfaced types, but none of the surfaces examined by the Committee showed sufficient diffusion to avoid the difficulties mentioned above.

The choice between the matte-surface type of screen and the beaded screen depends upon the maximum viewing angle. *When the classroom is nearly square*, requiring a maximum viewing angle of 30 degrees (that is to say, a seating arrangement similar to that shown in Fig. 1), *only the matte-surface type should be used. If the classroom is oblong, with the picture at one end, so that the maximum viewing angle can be limited to 20 degrees, the beaded type is the best,* because of its ability to concentrate most of the reflected light within this narrow angle and thus furnish a bright picture with less light from the projector.

An easy rule to follow is that *with the beaded screen no row of seats should be longer than $^2/_3$ of its distance from the screen.* In many oblong classrooms this condition can be met by not using the seats in the extreme front corners of the seating space during the projection of motion pictures. *A beaded screen should not be used if the viewing angle for any large number of spectators will exceed 20 degrees.* The proper arrangement of the spectators is shown in Fig. 2.

It has been mentioned that the beaded screen sends most of the reflected light back in the direction from which it came, even when that direction is not at right angles to the screen. For this reason, *whenever a beaded screen is used, the projector should be located only just high enough for the projected beam of light to clear the heads of the spectators.* If, as is sometimes done, the projector is located in the balcony of an auditorium or gymnasium, far above the heads of the spectators, it can readily be seen that the beaded type of screen is entirely unsuitable, since it sends most of the light back to the neighborhood of the projector where there are relatively few spectators. Meanwhile, all those seated on the main floor of the room see a relatively dim picture.

It should be emphasized that the above paragraphs apply to the selection of screens from among the types commercially available at the time of this report. It is entirely possible that new types will be developed that will provide brighter pictures than the present matte screens over the range of viewing angles up to 30 degrees without exhibiting the "hot-spot" difficulty now experienced with the metal-surfaced screens.

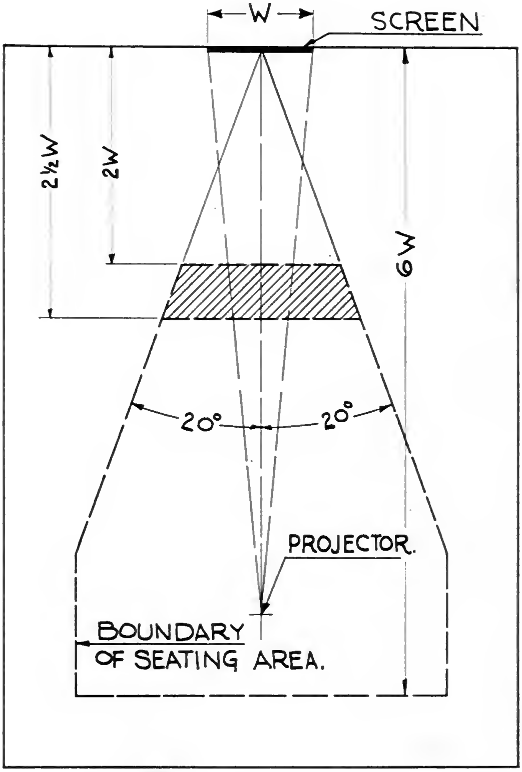

FIG. 2. Recommended seating area for narrow room, with beaded screen. Note—seats in the shaded area are the least desirable.

Representative reflection distribution curves for screens of the three types that have been discussed will be found in Part II of this report. That part of the report also contains a much more detailed discussion of the relations that exist between the reflecting properties of the screen and the appearance of the picture as viewed from various angles and distances.

Need for Replacement of Old Screens.—An unfortunate aspect of the screen problem is the fact that screens deteriorate with age. If left exposed to the air, both the matte and beaded types darken rather rapidly from the accumulation of dust and soot. If rolled up in protective cases when not in use, they remain in good condition longer, but tend eventually to turn yellow.

Some screen surfaces can be cleaned, but this should be attempted only on the advice of the manufacturer.

A matte screen that has deteriorated until it appears dark in comparison with a sheet of clean white writing paper placed against it should be replaced, since it is wasting from $^1/_4$ to as much as $^1/_2$ of the light from the projector. A beaded screen that has become noticeably yellowish should not be used, especially for the projection of color films.

An especially bad practice is to continue the use of a screen after it has acquired a mottled appearance. It is, of course, impossible to view a motion picture with any satisfaction when a splotchy pattern of lights and shades due to the screen itself is superposed on the lights and shades of every scene. The apparent movement of the pattern on the screen when objects in the picture move is especially distracting.

Picture Brightness.—Another question that has been investigated in detail by the Society of Motion Picture Engineers is that of the proper brightness of the picture on the screen.[4] It has been established that there is a fairly definite minimum picture brightness necessary to permit the eye of the spectator to function at full efficiency. When films are printed so as to obtain the best rendition of lights and shadows that can be obtained with present photographic materials, this desirable value of picture brightness corresponds to a brightness of 10 foot-lamberts as measured on the illuminated screen with the shutter of the projector running, but without film. Values of screen brightness are customarily stated in this way, for convenience in measurement.

It will be noticed that in this discussion the *foot-lambert*, a unit of *brightness*, is used. The *foot-candle*, which has been used frequently in the past in this type of discussion, is a unit of *illumination*. The light falling upon the screen may be measured in foot-candles, but this is only a partial and inaccurate measure of the brightness of the picture, since it takes no account of the reflecting properties of the screen.[5,6]

When the projector does not furnish sufficient light, picture quality suffers, and those sitting farthest from the screen find it difficult to see all the details in the picture. The medium densities of the picture merge with the blacks, and the highlights are weak and unreal. On the other hand, it is definitely possible, though perhaps rare in practice, to have too bright a picture in 16-mm projection. Under this condition the shadows become light gray, and any graininess in the film becomes unpleasantly noticeable. If the picture contains a wide scale of tones the highlights become dazzling, and flicker may appear.

In order to avoid these two undesirable conditions of excessive screen brightness and inadequate screen brightness, *the Committee recommends that projectors be selected to provide, in conjunction with the screens used, picture brightness not greater than 20 foot-lamberts and not lower than 5 foot-lamberts.*

Required Light Output of Projector.—When the size of the screen and its reflection coefficient at the maximum viewing angle to be used are known, and when the desired picture brightness is known, it is easy to calculate the number of *lumens* (units of light flux) required from the projector. The formula is:

$$\text{No. of lumens} = \frac{\underset{\text{(in foot-lamberts)}}{\text{Desired brightness}} \times \underset{\text{(in sq.-feet)}}{\text{area of screen}}}{\text{Screen reflection coefficient} \atop \text{(expressed as a decimal, } \textit{not } \%\text{)}}$$

Three cases have been worked out by the Committee. The results are given in Table I. The values given in the column headed *Matte-Surface Screen, Minimum* are sufficient to provide the minimum brightness of 5 foot-lamberts for all spectators. As a general rule twice this amount of light, as shown in the "Recommended" column, should be used with the matte-surface type of screen. The column headed *Beaded Screen, Recommended* assumes that this screen will be used with a maximum viewing angle of 20 degrees. Under this condition the spectators along the centerline of the room will see a picture corresponding to a brightness of 19 foot-lamberts, while those seated at the sides will see a picture corresponding to a brightness of 5 foot-lamberts. Thus the numbers of lumens shown in this column should not be increased, since the recommended maximum value of screen brightness will be exceeded for those sitting along the centerline of the room. Whenever it is possible the values shown in the table for the beaded screen should be adhered to.

TABLE I

Recommended Screen Brightness

Screen Size	Matte-Surface Screen		Beaded Screen
	Recommended Lumens	Minimum Lumens	Recommended Lumens
30″ × 40″	106	53	46
3′ × 4′	152	76	67
3′ 9″ × 5′	238	119	104
4′ 6″ × 6′	344	172	150
5′ 3″ × 7′	468	234	204
6′ × 8′	612	306	267
6′ 9″ × 9′	774	387	338
7′ 6″ × 10′	956	478	417
9′ × 12′	1376	688	600
10′ 6″ × 14″	1872	936	816
12′ × 16′			1070

It is expected that in the near future projector manufacturers will make available tables showing the output in lumens of each model of projector with each of the lamp and lens combinations provided. From such tables it will be a simple matter to select projectors that will give the right screen brightness in a given location, or to determine the limiting screen sizes for a given projector.

When screens larger than 8 or 9 feet wide are needed, as in large auditorium projection, it will be found that projectors using incandescent lamps are incapable of furnishing the amount of light required by the table. If pictures are to be projected on more than a few occasions in such auditoriums, 16-mm arc projectors should be installed. Such projectors are capable of furnishing approximately 1100 lumens, and thus give satisfactory pictures up to a width of about 14 feet on matte-surface screens, which are required by the shape of the usual large school auditorium. Obviously such projectors would not be used in classrooms, since the amount of light they furnish would be excessive under practically all classroom conditions. A lecture room seating 150 to 300 students may be a borderline case, in which an arc-lamp type of machine would be as desirable as the more usual incandescent type for a relatively permanent installation.

Room Darkening.—Good tonal quality in the projected picture is impossible if the room in which it is being viewed is not adequately darkened. On the other hand, this does not mean that the room must be absolutely dark. Studies have indicated that a general room light of the order of $^1/_{10}$ foot-candle is not harmful.[7,8] This is a level of illumination under which it is difficult but not impossible to read ordinary newspaper type.

Aside from making provisions for excluding light from the room until the general level of illumination is at least as low as is indicated above, it is particularly necessary to make sure that no narrow beams of light, especially sunlight, enter the room to produce bright spots on walls near the screen, or to strike other objects in the room from which dazzling reflections will be thrown. For the comfort of the spectators the screen should be the brightest object in the room.

Classroom Acoustics and Sound Reproduction.—The volume of sound needed for satisfactory reproduction of speech or music in a classroom depends on several factors besides the size of the room. The most important of these is the amount of sound-absorbing material present.

A room in which the walls, ceiling, and floor are all of hard materials, such as plaster or wood, requires comparatively little sound energy from the loud speaker in order to produce a loud effect, but sound heard under this condition does not have the clearness or the pleasing quality that is obtained in a room where there are curtains or other materials that absorb sound. In many classrooms the only sound-absorbing material is the clothing of the pupils and the teacher. This is the reason why in such classrooms speech is fairly easily understood when the class is present, but has a disagreeable loud, blurred, ringing, or echoing quality when the room is nearly empty. Hard surfaces, such as plaster or wood, reflect sound even more efficiently than the best mirror reflects light. Unless the sound-waves meet some soft or porous substance, they are reflected and re-reflected many times. Thus the sound of a speaking voice builds up into a roar, or reverberation, which takes a noticeable time to die away after the last word has been spoken. The same effect naturally occurs when speech is reproduced by an electrical system, as by a radio receiver or a sound motion picture projector. The presence of sound-absorbing material in the room causes the sound to die away more rapidly, so that the blurred effect is absent or greatly reduced.

Classrooms that are to be used for sound motion-picture projection should be provided with some sound-absorbing materials either in the form of heavy curtains or drapes covering preferably at least $^1/_3$ of the wall space, or, better, in the form of acoustic blocks covering the greater part of the ceiling. It is not necessary or desirable to provide enough sound-absorbing material to produce a "dead" effect in the room; it is necessary to provide only enough sound absorption to make it easy for two people to converse in an ordinary tone of voice when they are at opposite ends of the otherwise empty room without experiencing any difficulty in understanding each other due to the blurring caused by excessive reverberation. Those who have funds available for special acoustic treatment of classrooms can obtain expert advice from companies specializing in this type of treatment, though in general they should try to err on the side of having too little sound-absorbing material applied, rather than too much. It is only in a room of auditorium proportions that it is important to have exactly the right amount of sound-absorbing material.

When only a little sound-absorbing material is present in a room, the higher-pitched components of the speech are absorbed more than the low-pitched components. This has the effect of making the speech sound low-pitched, or "boomy," as well as blurred. Intelligibility under such conditions is improved by electrically attenuating, or weakening, the lower-pitched components of the speech. At the same time the "balance" of the speech is improved, so that it sounds more natural. One of the functions of the tone control on the projector is to provide a means of removing some of the low-pitched components of speech when it is necessary to use the projector in an excessively reverberant room.

Reproduction of music in a reverberant room is sometimes quite pleasing, though this is not true of music that is very rapid in character or of music in which solo instruments are prominent. On the other hand, reproduction of music in a room that is too "dead" gives an effect of inadequacy, of "thinness," lack of "fullness," or "roundness." It is for this reason that care should be taken not to make the room too dead.

The amount of sound energy required for adequate loudness of reproduction in a room depends upon the volume of the room, but different degrees of acoustical liveness make greater differences in the amount of sound energy required than the differences in size that are ordinarily encountered in classrooms. Because these acoustical variations from room to room exist, and are difficult to measure, it is not practical to give a table of required sound outputs for classrooms of various sizes. Fortunately the sound output can be conveniently adjusted by the volume control on the projector, so that all that is necessary is to make sure that the projector selected has adequate maximum power for good music reproduction in the room or rooms where it is to be used. In a general way it may be said that a power output of from 5 to 10 electrical watts will be sufficient for almost any classroom. For auditoriums, at least 15 electrical watts will be needed, and more should be available.

Measurement of sound power by electrical watts is not an entirely satisfactory procedure, because loud speakers may differ considerably in the efficiency with which they convert electrical energy into sound energy. Unfortunately the conversion efficiency of a loud speaker is exceedingly difficult to measure. For this reason all that can be done in practice is to make certain that the projector selected, in combination with its particular loud speaker, is capable of producing adequate loudness before it overloads, that is, before it reaches the point at which further increase of loudness causes the sound to be just noticeably distorted.

Selection of Projector.—When the general questions of screen size and type, projector light output and sound energy output have been settled, the question still remains as to what particular make of projector should be purchased. The engineering specifications which make up Part III of this report, when properly applied, will furnish a basis for deciding whether a particular projector is or is not suitable for educational service within the limits corresponding to its light output and sound output. However, these specifications are unavoidably expressed in terms of quantities which can be measured only by a fully equipped testing laboratory, having personnel experienced in the making of this particular class of tests. In the absence of a certificate from a trustworthy source to the effect that a particular projector meets these specifications, the user must generally rely on the result of competitive demonstration of different makes of projectors. Several observations with respect to such competitive demonstrations are in order.

A competitive demonstration of two or more projectors or a test of them by the prospective purchaser (the latter being preferable) should be conducted under the exact conditions that will exist when the chosen machine is placed in service. All machines must be tested on the same screen and with the same film.

The test-film is the most important item. It should have both sharp picture and good sound quality, or, preferably, two separate films should be selected for the tests of picture and sound, since these tests are not made simultaneously.

The projectors under test should be connected to the same power line, so that they will be operated on the same line voltage, but they should not be operated at the same time unless it has been ascertained that the power line is capable of carrying the multiple load without damage. If this precaution is neglected, fuses will probably be blown.

A choice between competing projectors should be made on the basis of fundamental performance, and not on the basis of special features, unless it is clearly apparent that these features are contributing to the excellence of the fundamental performance. The main points to be observed are sharpness and steadiness of picture, intelligibility and naturalness of speech reproduction, naturalness and steadiness of pitch in music reproduction, and smooth, quiet operation. Excellence in these respects necessarily implies general good workmanship and high quality of construction.

The prospective purchaser should first examine both projectors to see that their condensing and projection lenses are clean and that the lamps are new and are rated for the line voltage actually existing. Then he should switch on each machine in turn without film, and center the light on the screen. After a clean rectangular field of light has been obtained by focusing the projection lens, the screen should appear evenly illuminated and free from striations, or patches of color. If it appears that one projector delivers more light than the other, the observer should make sure that any rheostat that may be on either machine for controlling the lamp current is adjusted to the correct value before drawing any conclusion. Too much importance should not be attached to slight differences of light output, since different lamps, even of the same type and from the same lot, may differ enough in light output to produce a noticeable difference on the screen in this test.

Next, thread the film selected for checking picture sharpness and steadiness, first on one machine, then on the other, and project it, adjusting the focus as critically as possible, and noting any differences in sharpness between the center and sides of the screen. If it is necessary to be very critical in order to detect a difference in steadiness of picture between the machines, set the framing device so that the frame line is visible on the screen. Walk directly up to the screen and hold a ruler against it, so that the amount of frame-line "jump" can be observed directly on the ruler. As measured with an ordinary commercial film in good condition, this "jump" should not be more than $^1/_2$ of 1 per cent of the width of the picture. Make this test in the same part of the film for both machines.

Both machines should be operated at the speeds for which they are designed, and the picture scrutinized for visible flicker. A slightly greater amount of flicker will not indicate that one of the machines is inferior, provided it is also observed to give greater screen brightness than the comparison machine. In this connection it is helpful to bear in mind that flicker increases as the screen brightness increases, and also as the speed of the projector (number of frames per second) decreases. It is unlikely that flicker will be noticed at sound speed (24 frames per second) but it is likely to appear at silent speed (16 frames per second), especially if the screen brightness is near the upper limit.

Tests of sound-reproducing quality, to be conclusive, must be conducted under the acoustical conditions under which the machine will actually be used. For example, no final conclusions should be drawn from a test in an empty classroom or auditorium. Arrangements should be made to have an audience of normal size present and in their seats.

By way of test, the same sound-film should be run first on one machine and then on the other. During the running of the film the prospective purchaser should experiment with the tone controls and attempt to decide what adjustments give most satisfactory reproduction of speech and of music. On account of the variable element introduced by the tone controls, it will be necessary to run the sound test-film several times, first on one projector and then on the other, in order to decide whether or not there is a clear superiority of one over the other.

The sound-film selected for testing should contain both good speech and good music. Projector salesmen can usually provide demonstration reels which can be assumed to be of good quality. The important point is to run the same films on all machines being compared, at the same time, and under the same conditions. *Demonstrations at different times, or in different places, and with different films, are not conclusive, and are of little value.*

During the sound tests it is well to note how far the volume of music may be increased on each machine before noticeable distortion sets in. It is usually, but not invariably, true that the system that permits the higher volume without distortion will give cleaner reproduction at normal volume. This point can be checked by attentive listening.

Unless the observer is experienced in judging the quality of reproduced sound, it will be found best to run the same reel of test-film several times, rather than to project a wide variety of material. The latter, of course, is also desirable when time permits. Repeated listening to the same reel of film makes it easier to fasten attention on such points as the relative steadiness of film motion in the sound-reproducing mechanisms of the machines under test, as made audible by unsteady pitch of the reproduced sound or by the absence of such unsteadiness. For critical comparisons on this point, test-films containing musical selections of a slow character are required.

It is necessary to be certain that the test-film itself is substantially free from unsteadiness of pitch. One way of checking this point is to notice whether or not changes of pitch are heard in the same places when the film is reproduced on different projectors. If a change of pitch is always heard on the same note, it is probably in the film. In this case another film should be tried.

For detecting slow variations of film speed, commonly known as "wows," records of the piano are most suitable. A violin or 'cello record is perhaps as good a test as any for freedom from more rapid speed variations, which manifest themselves as a sort of roughness or, in extreme cases, a gurgling quality of the tone rather than as perceptible changes of pitch.

In general, the inexperienced listener should be careful not to form a hasty judgment as to which of two machines is superior in the matter of speed constancy. Some of the effects of unsteady film motion are subtle, and require experience for their correct interpretation.

Two intimately connected points of performance are the tonal, or frequency, range of the projector sound system and the amount of background noise it produces. (We are referring here to the noise that issues from the loud speaker, not to the noise produced directly in the room by the running of the mechanism.)

A good 16-mm sound projector is capable of reproducing with nearly uniform intensity all sound frequencies from 100 vibrations (or "cycles") per second to at least 5000 per second. The presence of this range can be checked by the playing of a frequency test-film, or it can be checked by noting how certain components of the sound are reproduced. A projector which has adequate high-frequency response will reproduce in a natural manner the high-pitched hissing sound of the letter *s* in speech. When high-frequency response is inadequate, the sound of the *s* is much more like that of the *th* in *thin*. One of the best tests is to listen attentively to the reproduction of words which *begin* with *s*.

If there is good high-frequency response there should be adequate low-frequency response, in order, in a sense, to "balance" the tonal quality. Since this balance of the sound is affected by room acoustics, as has been explained, it must be adjusted, in many cases, by the use of the tone control. Orchestral music is best for judging balance.

The observer should be aware, in this connection, that tonal balance between high and low frequencies has been demonstrated to be very largely a matter of personal taste; a matter which in many instances is conditioned by the type of radio receiver to which the listener is accustomed. It is highly desirable, therefore, that comparisons of tonal balance should be judged by a number of observers, each of whom has an opportunity to experiment with the tone-control facilities of the projectors under test, so as to determine what range of tone qualities can be produced. It is perhaps wiser in most cases to concentrate attention on the factor of intelligibility rather than to depend too much on judgment of tone balance.

While making changes of tone quality by means of the tone control, it will be noticed that the background noise changes greatly with the relative emphasis placed on the higher and lower frequencies. The projector which reproduces a wide-frequency range, other things being equal, will always produce more background noise than a projector having a narrow-frequency range. Reproduction of high frequencies is almost unavoidably accompanied by reproduction of hissing sounds from the film, from the photocell, and from other parts of the amplifying system. Reproduction of low frequencies necessarily increases the audibility of hum and other low-pitched background noises. In the reproduction of any type of recorded sound, a decision must be made as to whether it is preferable to reproduce an extended frequency range with the accompanying noise or to get rid of the noise at the expense of frequency range. While there is here a certain amount of room for the exercise of individual taste, it is the consensus of engineers that a range at least from 100 to 5000 cycles per second is necessary for good reproduction of speech and music. It is preferable to tolerate the slight amount of noise that accompanies this frequency range rather than to make the sacrifice of frequency range that is needed to get rid of the noise entirely. At the same time it is true that by superior design and construction of the amplifying equipment associated with a projector, it is possible to reduce background noise to an appreciable extent without sacrifice of the tonal range. The interrelation between these two aspects of reproduction has been emphasized here, however, in order to place the non-technical observer on his guard against drawing conclusions solely on the basis of either the tonal range or the amount of background noise that is noticed.

Consumer Demands and Projector Engineering.—Many equipment users do not realize the extent to which their demands for qualities such as small size, light weight, and portability influence the design and performance of sound motion picture projectors. Almost any widely expressed consumer demand can be met by the engineer, but as a rule this can be done only by some sacrifice of other desirable qualities, usually of performance.

In particular, the demand for small size and light weight has led to the adoption by the projector industry of certain practices in the design of the sound-reproducing amplifier and loud speaker that are deplored by most of the quality-conscious engineers in the industry.* Thus, while 16-mm sound projectors have been improved in many respects during the past few years, they could be made to perform still better, and, in fact, much better, if they were not required to meet this demand for light weight and extreme portability.

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* A loud speaker, to be efficient and free from distortion, requires a moderately large and massive field-magnet to produce a strong magnetic field around the "voice-coil" through which the signal currents from the amplifier are passed. Reducing the weight of the loud speaker necessarily means reducing the size of this magnet and therefore reducing the strength of the magnetic field. If the same amount of sound is to be produced as before, the amplifier must deliver more electrical power to the loud speaker having the weak field. Within the limits of size and weight that are customarily imposed today, this can be done only by the employment of types of vacuum-tubes that produce more distortion than the types in common use in radio sets and other sound-reproducing devices a few years ago when loud speakers with massive field magnets were the rule. Thus, because of the need for high amplifier power to offset loud speaker inefficiency, the amplifier supplies a slightly distorted signal to a loud speaker, which, because of its low efficiency, introduces still more distortion of its own.

The better sound projectors available today are deserving of far better loud speakers than are usually supplied. However, at the present time the cost of a suitable loud speaker of really high quality* is almost as great as the cost of the projector itself. This condition exists largely because few outside the theatrical motion picture field have known that this class of loud speaker equipment existed, and therefore the demand for it has not yet become great enough to permit placing it in quantity production. If loud speakers of really high quality were demanded for all sound motion picture installations of a relatively permanent character, a market would be created for such units in quantity, and it would become possible to sell them at a much lower price. Loud speakers of the present very light-weight type could still be used for services that require portability.

Two other features included in many current projector systems because of consumer demand deserve mention because of their adverse effect upon basic performance. The first of these is the clutch mechanism which permits stopping the film for the projection of single frames as still pictures. *The Committee is unanimous in recommending that this provision for still picture projection be omitted from 16-mm motion picture equipment for use in schools.* Records of film distributors show that the subjection of individual frames of film to excessive heat by this practice is one of the leading causes of film damage. While it is possible to protect the film against excessive heat by the usual "safety" shutter, introduced into the light-beam when the clutch is operated, this can only be done by cutting down the amount of light transmitted to a point so low that the picture on the screen is too dim to be seen properly. On the other hand, if enough light is allowed to pass to give an acceptable screen image, the film is sure to be damaged whenever the still picture is kept on the screen for any considerable length of time. When it is considered that the image obtained by projecting a single frame of motion picture film is none too sharp at best, it may be seen that this practice of providing for still projection of individual frames of film is of doubtful value, while as a cause of film damage it is demonstrably harmful.

A second feature commonly demanded is a microphone input, to permit the amplifier and loud speaker of the projector to be used for

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* The reference here is to loud speakers of the dual type, in which a horn is used for the higher frequencies and a large paper cone unit for the low frequencies.

public address work. A system designed only for sound-film reproduction could provide a noticeably reduced level of the hissing type of background noise commonly heard when the projector is reproducing sound at normal volume. The remedy for this situation consists in either abandoning the demand for the microphone input or increasing the price paid for the system.

Low selling price is quite properly an important consideration in the production of sound motion picture equipment for educational use, since the lower the cost of the equipment the more extensive can be its use. In order to obtain maximum value for the amount of money expended for such projection equipment, users would do well to demand only basic functions in the equipment furnished them, since these could then be provided in a more satisfactory form than under present conditions. As matters stand at present, the engineer must generally design not only in relation to cost but also in relation to the demand for auxiliary and more or less unrelated functions in the same piece of equipment. At best it is not easy to manufacture good 16-mm sound motion picture equipment, nor can this be done at too low cost, since the accuracy required in vital parts of the mechanism is of the order of $2^1/_2$ times as great as is required for comparable results in 35-mm equipment.

Film Quality and Its Effect on Projector Performance.—It is not always recognized that the quality of the film being projected has as important an effect upon the final screen result as the quality of the projection equipment. It is important, especially when judging projector performance, to be able to recognize the difficulties attributable to films rather than to apparatus.

An unsteady picture on the screen may be caused by imperfect printing of the film, by damaged sprocket-holes, or by unsteady mounting of the camera that took the picture. Jumping of the picture when a splice passes through the gate of the projector generally indicates that the splice was improperly made, either with the film edges not properly aligned or with the sprocket-holes not accurately matched where the film ends were cemented. Whenever a projector produces an unsteady picture, the user should make certain that the difficulty is not in the film being projected before condemning the machine.

It occasionally happens that the image on the film is not in sharp focus. This may be caused either by lack of sharp focus in the original photography or by improper printing.

It sometimes happens that films are received with which it is impossible to obtain a sharp focus all over the screen at once. It is possible to focus the center of the picture sharply, or the sides, but not both at the same time. On examination, such films will be found to be buckled. Buckled film should be returned to its source; it is usually impossible for the user to correct the condition.

A moderately common difficulty in sound-tracks is mislocation of the track. If the track is more than a few thousandths of an inch too near the film edge or too far from it, it is probable that part of its width will not be scanned by the reproducing light-beam in the projector. This can result in quite objectionable distortion of the sound. Sound-tracks that are mislocated are also frequently noisy, since images of improper parts of the negative film (for example, the edges of sprocket-holes) are likely to be printed in the sound-track area where the track itself ought to be.

Other causes of excessive noise in sound-tracks are low density of the track itself, that is, lack of sufficient blackness in the black parts; scratches, dirt on the negative, and dirt on the print itself. Sound-tracks that reproduce well will generally be found to be quite dark, clean-looking, and free from the printed impressions of dust specks and scratches on the negative. With a little experience it is usually possible to tell merely by looking at a sound-track whether or not it may be expected to reproduce with low background noise.

Some films, even though manifesting none of the difficulties described above, give unsatisfactory reproduction on all projectors. The difficulty usually is an absence of high frequencies in the sound, manifested by lack of crispness and intelligibility and an absence of the *s* sound. This condition may have been caused by the selection of an unsuitable voice for the recording, by improper use of the microphone in recording, or by printing on equipment lacking good optical definition.

Another difficulty sometimes encountered is a harsh quality in the sound similar to that obtained with a radio receiver when it is not tuned accurately to the broadcasting station, or when the volume has been increased until the amplifier system overloads. This may be produced in sound-films by the attempt to record sound at too high a volume level. In variable-density sound-tracks it may be caused by improper printing or development.

A condition that is likely to continue to afflict the 16-mm sound industry for some time to come is the lack of uniformity of sound quality on otherwise good films produced by different methods. For example, films made by optical reduction from negatives originally produced for 35-mm theatrical purposes generally have less high-frequency response than films produced specifically for reduction to the 16-mm size. Films produced directly in the 16-mm size can be given almost any desired type of sound quality, but this very fact makes it possible for producers whose tastes differ to vary the sound quality in ways that are sometimes undesirable. In addition to these sources of variation it will sometimes be found that different prints of the same subject differ perceptibly in sound quality. This may happen, for example, by the use of different printing machines in the same film laboratory, the different machines not being in equally good adjustment.

Sound Quality Obtainable from 16-Mm Film.—The rather discouraging picture just outlined may well lead to the question "Just what is it possible to accomplish with 16-mm sound-film?" A definite and encouraging answer can be given. With films that are well made in all respects and with the best currently available projection equipment, a quality of sound can be obtained that is substantially on a par with that commonly heard in good neighborhood motion picture houses. Background noise need not be objectionably high. Music reproduction can be equal to that of an excellent radio receiver. Speech reproduction can be completely intelligible and natural.

Failure to achieve this standard of performance in 16-mm sound-film projection is a result of removable difficulties either in film or equipment. Both these can be remedied by proper selection of projection equipment, by expert servicing of the equipment when necessary, and by careful selection of films.

REFERENCES

[1] Report of the Projection Practice Committee, *J. Soc. Mot. Pict. Eng.*, **XXX** (June, 1938), p. 638.

[2] HARDY, A. C., AND CONANT, F. H.: "Perspective Considerations in Taking and Projecting Motion Pictutes," *Trans. Soc. Mot. Pict. Eng.*, **XII**, 33 (1928), p. 117.

[3] TUTTLE, C. M.: "Distortion in the Projection and Viewing of Motion Pictures," *J. Soc. Mot. Pict. Eng.*, **XXI** (Sept., 1933), p. 204.

[4] The Problem of the Projection Screen Brightness Committee, *J. Soc. Mot. Pict. Eng.*, **XXVI** (May, 1936), p. 489.

LOWRY, E. M.: "Screen Brightness and the Visual Functions," *J. Soc. Mot. Pict. Eng.*, **XXVI** (May, 1936), p. 490.

O'BRIEN, B., AND TUTTLE, C. M.: "An Experimental Investigation of Projection Screen Brightness," *J. Soc. Mot. Pict. Eng.*, **XXVI** (May, 1936), p. 505.

COOK, A. A.: "A Review of Projector and Screen Characteristics, and Their Effects upon Screen Brightness," *J. Soc. Mot. Pict. Eng.*, **XXVI** (May, 1936), p. 522.

WOLF, S. K.: "An Analysis of Theater and Screen Illumination Data," *J. Soc. Mot. Pict. Eng.*, **XXVI** (May, 1936), p. 532.

TUTTLE, C. M.: "Density Measurements of Release Prints," *J. Soc. Mot. Pict. Eng.*, **XXVI** (May, 1936), p. 548.

TEELE, R. P.: "Photometry and Brightness Measurements," *J. Soc. Mot. Pict. Eng.*, **XXVI** (May, 1936), p. 554.

LITTLE, W. F., AND WILLIAMS, A. T.: "Résumé of Methods of Determining Screen Brightness and Reflectance," *J. Soc. Mot. Pict. Eng.*, **XXVI** (May, 1936), p. 570.

LUCKIESH, M., AND MOSS, F. K.: "The Motion Picture Screen as a Lighting Problem," *J. Soc. Mot. Pict. Eng.*, **XXVI** (May, 1936), p. 578.

[5] HARRIS, S.: "Photometric Nomenclature and Conversions," *J. Soc. Mot. Pict. Eng.*, **XXXV** (Dec., 1940), p. 557.

[6] TEELE, R. P.: "Photometry and Brightness Measurements," *J. Soc. Mot. Pict. Eng.*, **XXVI** (May, 1936), p. 567.

[7] Report of the Theater Lighting Committee, *J. Soc. Mot. Pict. Eng.*, **XVI** (Feb., 1931), p. 239.

[8] WOLF, S. K.: "An Analysis of Theater and Screen Illumination Data," *J. Soc. Mot. Pict. Eng.*, **XXVI** (May, 1936), p. 534.

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PART II

THE OPTICAL PROPERTIES OF COMMERCIALLY AVAILABLE SCREENS FOR 16-MM PROJECTION

The brightness of the image in projection is determined by the amount of light reaching the screen from the projector and by the reflecting properties of the screen surface. Screens that reflect the light in a highly directional manner can provide, under proper conditions, pictures more than five times as bright as would be obtained with non-directional screens in combination with the same projector.

Directional screens, however, have disadvantages which sharply restrict their fields of proper use. They are highly efficient within limited viewing angles, but relatively inefficient at large viewing angles. More important is the fact that they produce serious inequalities of brightness between different parts of the screen for all but a few favorably located spectators.

Because of these effects, an accurate knowledge of the properties of different types of screens is essential for the intelligent selection of projection equipment.

In order to be able to base its recommendations upon a precise knowledge of the characteristics of the screens that are commercially available at the time of this report, the Committee obtained samples of screen materials from six manufacturers. After the exclusion of screens perforated for sound transmission, which are not used in 16-mm projection, this collection of samples included seven beaded screens, six matte screens, and two aluminum-surfaced screens.

The procedure followed in determining the characteristics of these fifteen samples was to project a beam of light perpendicularly on each sample and measure the brightness of the center of the illuminated spot at different angles from the axis.

The differences found between individual beaded screens were relatively unimportant. The same was true of the matte-surfaced screens examined. Therefore the results have been averaged for each of these types. The two averages are plotted in Fig. 3.

Fig. 4 shows the characteristics of the two aluminum-surfaced screens, which are obviously dissimilar. The screen that gave curve

A has a relatively smooth surface, while the one that gave curve *B* is rough in texture.

Some readers may be puzzled by the fact that values higher than 100 per cent appear in the curves of Fig. 3 and Fig. 4. This will be readily understood if it is remembered that the results of such screen reflection measurements are customarily expressed in terms of an ideal, or theoretical, reflecting surface which, by definition, reflects 100 per cent of the incident light, and distributes this reflected light in such a way that the surface appears equally bright at all angles of view. Thus, a surface that has highly directional reflecting properties may appear many times as bright as this theoretical standard within a certain range of viewing angles. But, since no surface can reflect more than a total of 100 per cent of the light that falls on it, a directional reflector must necessarily be less bright than the standard when viewed at angles outside this range.

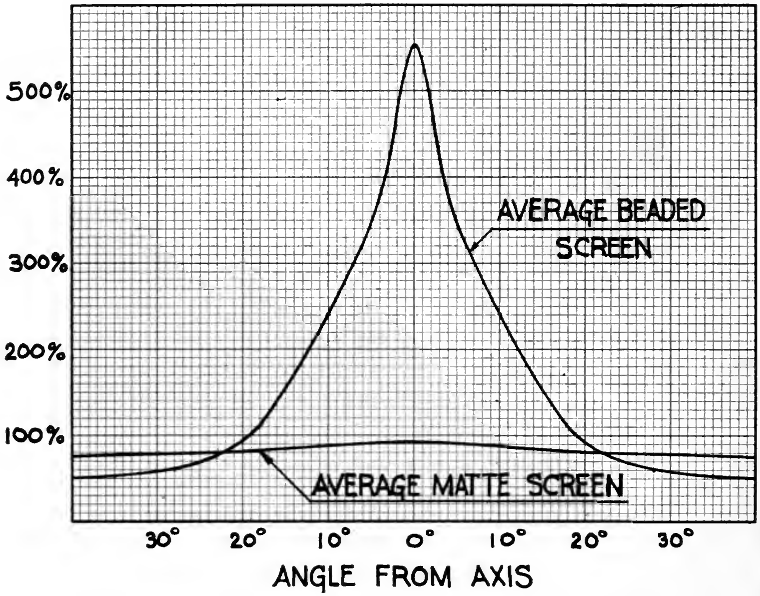

FIG. 3. Apparent coefficient of reflection of matte and beaded screens at various angles to axis.

A working standard that closely approximates the ideal is available in the form of a freshly scraped surface of a block of pure magnesium carbonate. This practical working standard was used in making the measurements for the Committee. Therefore, the curves of Fig. 3 and Fig. 4 may also be interpreted in this way, that a value of, for example, 135 per cent at a given angle means that, when viewed from this angle, the brightness of the screen in question was $^{135}/_{100}$ of the brightness of the magnesium carbonate reference surface under the same illumination.

There is an important difference, not appearing in these curves, between the beaded type of screen and the two other types. The beaded screen surface reflects the light most strongly in the exact direction from which it came, even when the incident light-beam is not perpendicular to the screen surface. The matte-surfaced and metallic screens do not share this property. They reflect the light most strongly along the path that would be followed by the single reflected beam if the screen surface were replaced by a polished mirror. This action is scarcely noticeable in the case of the matte screens, since these are almost entirely non directional, but it is readily noticed in the case of the aluminum-surfaced screens. It will be shown later that this semi-specular type of reflection causes con-

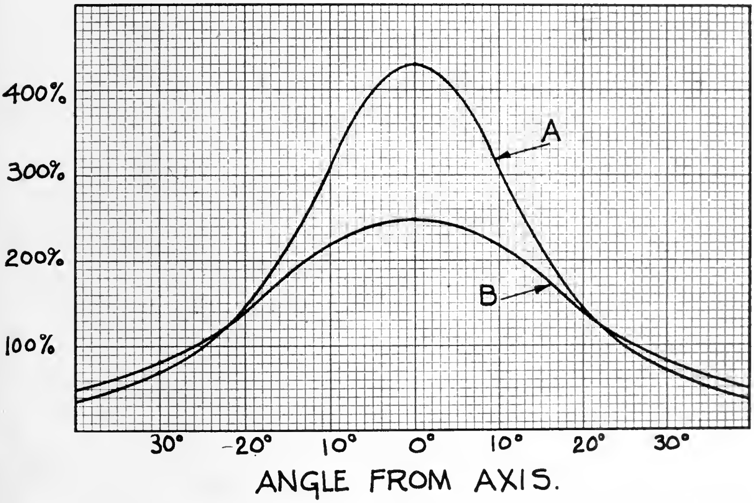

FIG. 4. Apparent coefficient of reflection of two semi-specular (metallic) screen surfaces at various angles to axis.

siderably greater differences of brightness between different parts of the metallic screens than are found with the beaded type.

In view of the Committee's recommendation that the average screen brightness (for any one spectator) be held between the limits of 5 and 20 ft.-lamberts, it is obvious that a directional type of screen should not be used for viewing angles greater than the one at which the apparent coefficient of reflection is $^1/_4$ of the value along the axis. Fig. 3 shows that, for the average beaded screen, this angle is 16 degrees. However, it will be noted that the peak is very sharp. Since in practice the projector must be located far enough above the heads of the spectators to avoid the casting of shadows on the screen, and since all parts of the screen send this sharp maximum of reflected light directly back to the projector, it appears reasonable to assume that no spectators receive this maximum of reflected light. The Committee has made this assumption, and has calculated its table of recommended light flux from the projector (Table I of Part I of this report) from the values of the apparent coefficient of reflection for 5 degrees and 20 degrees in the case of the beaded screen.

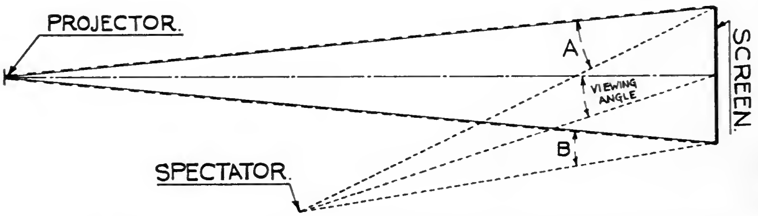

FIG. 5. Method of measuring angles to determine screen brightness ratios for beaded screen.

Fig. 4 shows that, on the basis of the 4 to 1 ratio between the maximum and the minimum brightness, the screen corresponding to the curve marked *A* is suitable for use up to a viewing angle of 25 degrees, while the screen corresponding to the curve marked *B* more than satisfies the requirement at a viewing angle of 30 degrees. These screens are nevertheless unsatisfactory for use with groups of more than a few spectators, because they produce large differences of brightness between different parts of the picture.

When a spectator is located near the front of the seating area and at one side, he views the two sides of the screen at widely different angles. Therefore, if the screen has a highly directional reflection characteristic, the brightness of the near side of the screen for this spectator is considerably greater than the brightness of the far side. A good estimate of the magnitude of this effect can be obtained by the proper use of the data in the curves of Fig. 3 and Fig. 4.

Fig. 5 is a diagram of the condition as it applies to the beaded screen. With this type of screen, as has been stated, the strongest beam of reflected light is sent back in the direction from which it came, even when the incident light beam is at an acute angle to the screen surface. Therefore the line of sight for maximum brightness at each side of the screen is as shown by the coarse dotted line, coinciding with the solid line which indicates the path of the incident light.

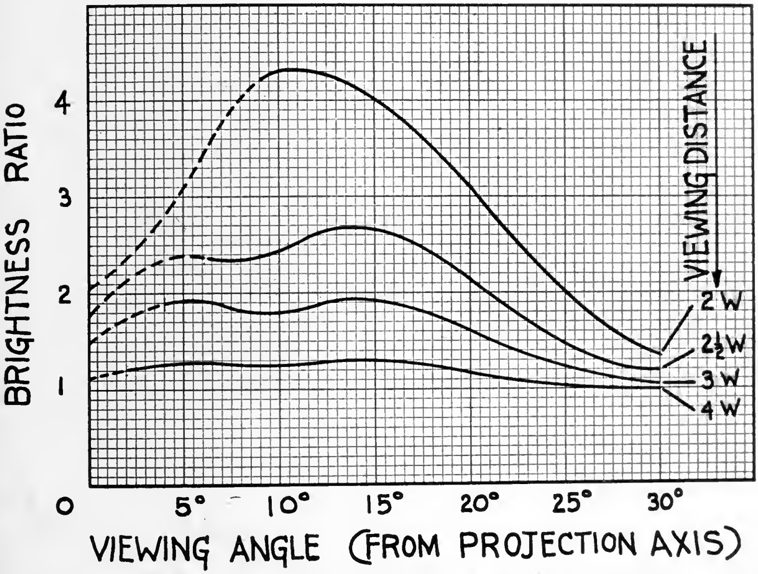

Fig. 6. Brightness ratio of brightest part of screen to darkest part of screen at various viewing angles. Beaded screen. (Screen, projector, and spectators' eyes on same level.)

The spectator's actual lines of sight to the two sides of the screen are shown by the two fine dotted lines. By reading from the top curve of Fig. 3 the brightnesses corresponding to angles *A* and *B* of Fig. 5 we obtain a fairly accurate measure of the difference of brightness of the two sides of the screen for this spectator's position.

For example, consider the spectator who sits in a row $2^1/_2$ times the screen width in front of the screen, and a distance at the side such that he has a viewing angle of 15 degrees. (The "viewing angle," as used in this discussion, is the angle between the projection axis and the spectator's line of sight to the center of the screen.)

For this spectator we find, either by calculation or by drawing a diagram and measuring the angles with a protractor, that angle *A* is $19^1/_2$ degrees, while angle *B* is $9^1/_2$ degrees. The corresponding brightness values, from Fig. 3, are 95 per cent and 250 per cent. Therefore, this spectator sees the near side of the screen as slightly more than $2^1/_2$ times as bright as the far side of the screen.

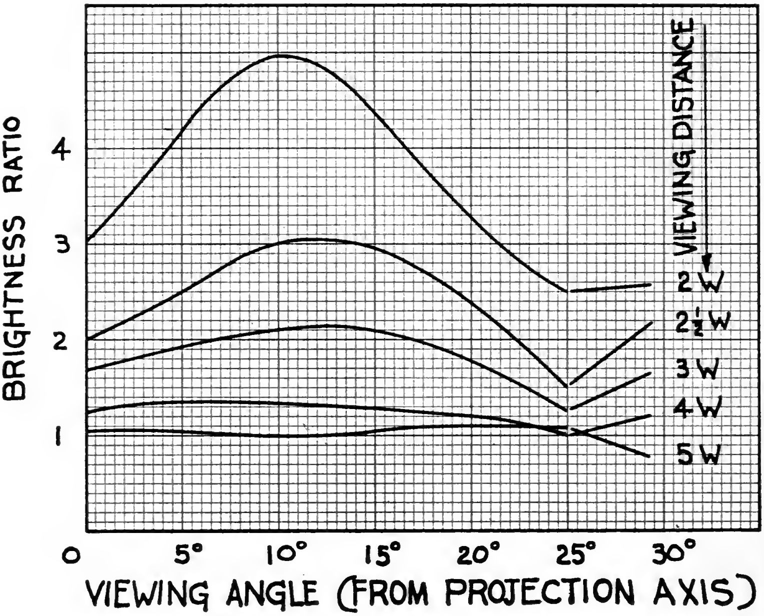

FIG. 7. Brightness ratio of brightest part of screen to darkest part of screen, at various viewing angles. Beaded screen. (Screen and projector high enough for light-beam to clear spectators' heads.)

By applying this method to a large number of locations in the seating area, we obtain the curves of Fig. 6, which show how the brightness ratio of the brightest part of the screen to the darkest part of the screen varies with the position of the spectator.

The method by which the curves of Fig. 6 were obtained tacitly assumes that the projection lens, the center of the screen, and the spectator's eyes are all on the same level. With this arrangement no spectators can be seated in the triangular space between the screen and the lens of the projector, since anywhere in this space their heads would cast shadows on the screen. This fact is indicated in Fig. 6 by drawing parts of the curves as dotted lines, since these parts correspond to parts of the seating area that are not usable.

A more practicable way of arranging matters, at least for groups of the size common in classroom work, is to place the screen so that its bottom edge is a few inches higher than the average level of the spectators' eyes, and to place the projector also just high enough to avoid interference by the spectators' heads. With this arrangement the darkest part of the screen is always the upper far corner. The brightest part varies in position; if the spectator is at 0 degrees, it is at the center of the bottom edge of the screen; as he moves to one side it moves along the bottom edge of the screen until it reaches the near bottom corner. The problem is three-dimensional, and the mathematical calculations required to solve it are laborious. The mathematics need not be discussed here; the results, however, have been obtained for a typical case, and are given in Fig. 7.*

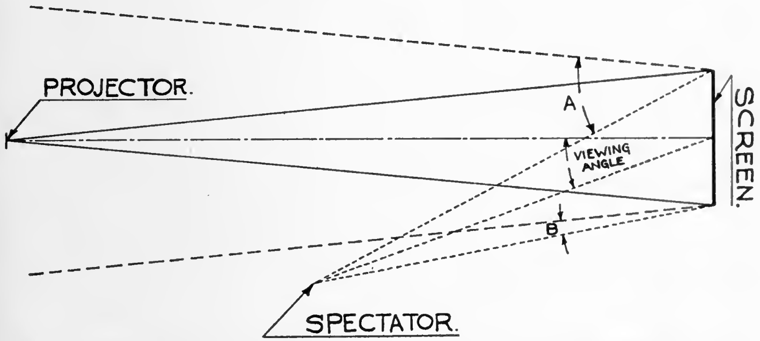

FIG. 8. Method of measuring angles to determine screen brightness ratios for semi-specular (metal-surfaced) screen.

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* The actual arrangement on which Fig. 7 is based is as follows: Screen size, $37^1/_2 \times 52$ inches. Height of projection lens, $55^1/_2$ inches. Bottom of screen, 52 inches high. Height of observer's eyes, 48 inches. The analysis will hold with little error for any arrangement in which the lens and the bottom of the screen are on about the same level, and the light-beam just clears the tops of the spectators' heads.

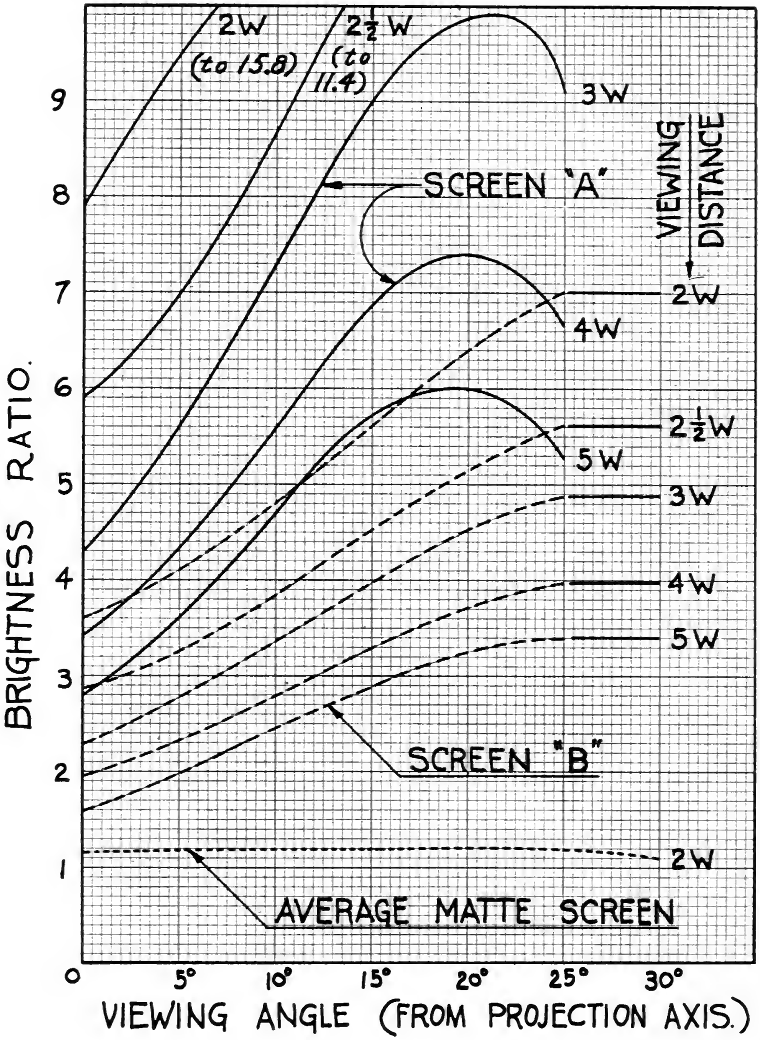

FIG. 9. Brightness ratio of brightest part of screen to darkest part of screen for various viewing angles, for average matte screen, and for the semi-specular screens of Fig. 4.

Those members of the Committee who worked on the screen problem reached the conclusion, by practical tests, that a brightness ratio of 3 to 1 between the brightest part of the screen and the darkest part of the screen was as great as should be tolerated. On this basis it may be seen from Fig. 7 that, in the case of the beaded screen, most of the locations in the front of the seating area, distant from the screen between 2 and $2^1/_2$ times its width, are not satisfactory. It is for this reason that this area has been marked as undesirable in Fig. 2 of Part I of this report.

It has been stated that, while beaded screens send the strongest reflected light back along the incident beam, metallic screens send it in the direction determined by the usual law of specular reflection. Accordingly, the diagram of Fig. 5 must be modified as shown in Fig. 8 to make it applicable to the case of the metallic screen. It will be noticed that angle A, at the far side of the screen, is increased, while angle B, at the near side, is decreased. Because of these changes in the angles, the brightness ratios are much higher for the metallic than for the beaded screens, even though both of the curves of Fig. 4 are less steep than the upper curve of Fig. 3.

The actual brightness ratios for the two aluminum-surfaced screens of Fig. 4 are shown in Fig. 9. The values given are for the three-dimensional arrangement, corresponding to Fig. 7. These curves show that with either of these metallic screens there is only one part of the room from which a picture of satisfactory brightness-uniformity can be seen, and that is the space close to the projector. The situation can be improved somewhat by tilting the top of the screen slightly toward the projector, but the improvement is not great enough to warrant the use of either of these screens for a large group of spectators. Screens of the metallic type are needed for stereoscopic projection with polarized light, but otherwise their use should be avoided.

The high degree of brightness-uniformity obtained with the matte type of screen is shown by the curves at the bottom of Fig. 9. In no case is the brightness ratio greater than 1.2. This amount of non-uniformity is hardly perceptible to the most critical eye. The matte type of screen also provides nearly equal picture brightnesses for all spectators. In the average case the brightness at a viewing angle of 30 degrees is 85 per cent of the brightness on the axis.

Thus from the standpoint of the performance factors that contribute to proper appreciation of the picture by all spectators, the matte type of screen is far superior to the directional types. It should be chosen in all cases where a projector of adequate illuminating power can be obtained.

BIBLIOGRAPHY

JONES, L. A., AND FILLIUS, M. F.: "Reflection Characteristics of Projection Screens," *Trans. Soc. Mot. Pict. Eng.*, No. 11 (1930), p. 59.

JONES, L. A., AND TUTTLE, C.: "Reflection Characteristics of Projection Screens," *Trans. Soc. Mot. Pict. Eng.*, No. 28 (Feb., 1927), p. 183.

LITTLE, W. F.: "Tests of Motion Picture Screens," *J. Soc. Mot. Pict. Eng.*, **XVI** (Jan., 1931), p. 31.

Report of the Projection Screens Committee, *J. Soc. Mot. Pict. Eng.*, **XVII** (Sept., 1931), p. 441.

LYMAN, D. F.: "Relation between Illumination and Screen Size for Non-Theatrical Projection," *J. Soc. Mot. Pict. Eng.*, **XXV** (Sept., 1935), p. 231.

(*Continued on next page*)

PART III

PERFORMANCE SPECIFICATIONS FOR 16-MM PROJECTION EQUIPMENT FOR EDUCATIONAL SERVICE

The following specifications attempt to give clear definitions of good performance with respect to each of the functions of a projector or screen. Specification in terms of mechanical or electrical design or principles of operation has been avoided, since it is believed immaterial to the user how a result is obtained as long as the result is satisfactory.

In many instances it has been necessary to specify the method of measurement as well as the result required, in order that the specifications might have precision. In connection with the specifications of sound-reproducing performance it has been necessary to define a number of test-films. Arrangements have been made by the Committee for the production of these test-films, which are to be made generally available. Further announcement on this subject will appear in an early issue of the JOURNAL.

Since there are many ways in which given aspects of performance may be defined, notes have been added to certain of the specifications in order to make clear the thought processes that led the Committee to adopt the particular form of specification given.

The specifications are not complete in all details. Further investigations are being conducted with respect to several of the topics in order that definite measurement technics may be supplied where they are now lacking, and limits in some cases may be more precisely determined. The Committee recognizes these shortcomings in this report, but nevertheless believes that the specifications in their present form will be useful enough to justify publication at the present time rather than waiting until all uncertain points have been clarified.

No attempt has been made to put these specifications in a form such that they could be applied by the average user of equipment, however intelligent or well informed he may be. The Committee believes that the specifications must be definite if they are to be useful. It has been possible to achieve definiteness only by the specification of measurement procedures that in most cases can be carried out only by a well equipped measurement laboratory.

The Committee hopes soon to be able to supplement its present report by the presentation of papers by some of its members discussing specific measurement problems in greater detail than is possible in a report of the present character.

(*A*) ***Picture Projection***

(*1*) *Steadiness of Picture.*—The *Picture-Steadiness Test-Film* shall be a film carrying a readily measurable test-pattern placed upon it by a mechanism which positively locates each frame vertically by a pilot-pin entering a perforation, and horizontally by pressing the edge that is to be guided in the projector against a solid guide. The test-pattern shall have been placed on the test-film directly, and not by any intermediate printing process from another film. The pattern may consist of two or more circular holes $^1/_{16}$ inch in diameter punched through each frame of the film. If the test-pattern is produced by punching, the film used shall have been exposed and developed previously to a density between 0.8 and 1.2. The test-film shall not be shrunk more than 0.5 per cent.

Picture unsteadiness shall be measured by projecting the test-film at standard speed (16 frames per second in the case of a silent projector; 24 frames per second in the case of a sound projector). Scales shall be placed vertically and horizontally on that part of the screen on which the projected image of the test-pattern appears, and the amount of unsteadiness shall be noted by observing the movement of the test-pattern on these scales.

Vertical unsteadiness having a period shorter than one second shall not exceed 0.3 per cent of the picture width.

Horizontal unsteadiness of any period shall not exceed 0.3 per cent of the picture width.

(*2*) *Freedom from Travel-Ghost.*—The *Travel-Ghost Test-Film* shall carry a pattern of small transparent areas on a dark background. At least three of these transparent areas shall be located $^1/_{10}$ of the frame height from the top of the frame, and an equal number $^1/_{10}$ of the frame height from the bottom of the frame.

This test-film shall be projected at 16 frames per second on a screen of such size that a brightness of 40 foot-lamberts is obtained with the shutter running but with no film in the projector gate. This screen shall be viewed from a distance equal to twice its width.

Under the above test conditions, no travel-ghost shall be visible.

(3) *Freedom from Tendency to Damage Film.*—The film used for this test shall be freshly processed, having been uniformly fogged and developed to a density between 0.5 and 0.8. It shall be used in the form of a loop containing one splice. This loop shall be threaded through all parts of the projector mechanism that touch the film in normal operation. The lamp shall be turned on continuously during the test. The room in which the test is conducted shall be closed and otherwise well protected against avoidable dust.

Under these conditions, after 200 passages through the mechanism, the film shall exhibit no perforation damage and no scratches on either surface in either picture area or sound-track area.

(4) *Take-Up Efficiency.*—With reels having dimensions suitable for the projector and with the correct take-up adjustments for these reels, the take-up shall provide a tension on the film of not more than 10 ounces at the beginning of a reel and not less than $1^1/_2$ ounces when the reel is full.

(5) *Mechanical Durability.*—The projector shall be guaranteed by the manufacturer against failure due to defective material or workmanship for a period of one year.

This guarantee shall not, however, be required to extend to parts that are normally subject to wear and replacement, such as lamps and motor brushes.

(6) *Quietness in Operation.**

(7) *Provision for Framing.*—The projector shall have conveniently accessible means for framing the picture through a range extending 0.015 inch above and 0.015 inch below the normal position, measured at the film.

(8) *Light Output.*—The manufacturer shall state, in lumens, the limits of light output of each model of projector with each lamp and lens combination furnished.

For this purpose the light output shall be measured with the shutter running, but with no film in the gate.

Measurements shall be made in the plane of a screen located a distance from the projector such that the projected image of the picture aperture is 40 inches wide by (approximately) 30 inches high.

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* The Committee recognizes that quiet operation is an important feature of good performance, but considers that the information at present available is not sufficient to permit the writing of a satisfactory specification of allowable noise level.

The illuminated area of the screen shall be divided into 12 equal squares. At the center of each of these squares the illumination shall be measured, either by a visual method or by means of a photoelectric light-meter corrected by suitable color-filters to conform within a good approximatiom to the visibility curve of the eye.

Suitable precautions shall be taken to insure that the optical train of the projector is in normal operating condition, and that the lamps used are representative ones, and are operated at their design voltages.

The arithmetical average of the 12 illumination measurements, in foot-candles, shall be multiplied by 8.33 (the area of the screen in square-feet) to obtain the stated result in lumens.

The statement of light output shall include a complete specification of each type of lamp used, by wattage and voltage ratings, type, and design life.

(*9*) *Color of Light on the Screen.*—The color-temperature of the light delivered to the screen when the source is operated at its rated voltage shall be in the range from 3000° to 4700°K.

(*10*) *Uniformity of Screen Illumination.*—The illumination shall be measured on a screen not less than 40 inches wide. Measurements shall be made at the center and at four points in the corners, located $^1/_{20}$ of the screen width from the top or bottom edge, and the same distance from the side edges of the screen.

The average illumination at the four corner points shall be not less than 55 per cent of the illumination at the center. At no corner shall the illumination be less than 40 per cent of the illumination at the center of the screen.

The illumination on the screen shall be free from noticeable bands or patches differing in color or brightness from the adjacent parts of the screen.

(*11*) *Accuracy of Light-Source Location.*—Unless the manufacturer has provided means of adjusting the position of the light-source, the maximum deviation of the light-source from its design position, due to the combined tolerances of the factors that affect light-source position, shall not be sufficient to cause the uniformity of screen illumination to fail to satisfy requirement No. 10, above.

(*12*) *Freedom from Flicker.*—The test for flicker shall be made by allowing the light from the projector, with no film in the gate, to fall upon a screen of size and surface such as to give a screen brightness of 3 foot-lamberts. Under this condition the projector shall roduce no visible flicker when running at its normal speed. If the rojector is designed to operate at more than one speed, the test shall e made at a speed of 16 frames per second.

(*13*) *Accessibility of Optical Parts for Cleaning.*—All external surfaces of the condensing lenses, and the front surface of the mirror ised behind the lamp, shall be accessible for cleaning without the use f tools. If removable for cleaning, these parts shall be so mounted s to be positively returnable to their proper positions.

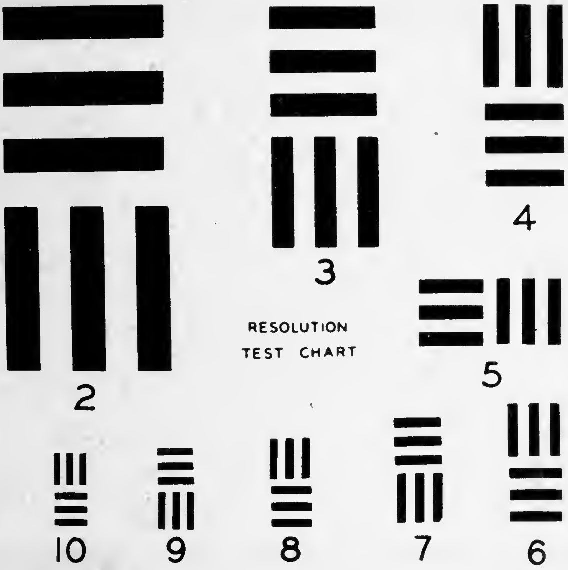

FIG. 10. Resolution test-chart.

(*14*) *Location of Film in Image Plane of Lens.*—As the film passes the picture gate of the projector, it shall be so held that its plane is perpendicular to the lens axis within limits such that there are no differences in sharpness of focus among the four corners of the picture, visible to an observer twice the screen width distant from the screen.

(*15*) *Image Quality of Projection Lens.*—The projection lens shall be tested by mounting it on a special test projector arranged to hold, in proper relation to the lens axis, a glass-plate test-object made as follows:

Copies of the test-chart shown in Fig. 10 are arranged as shown in Fig. 11, and photographed with a reduction such that the black outline shown in Fig. 11 has a height of 7.21 mm (0.284 inch) and a width of 9.65 mm (0.380 inch), with a radius of 0.5 mm in the corners. The ratio of reduction of the test-charts is such that the nine sets of lines in the reduced images are spaced at 20, 30, 40, 50, 60, 70, 80, 90, and 100 lines per millimeter. The sensitive coating of the glass-plate, and the lens used in making the reduction, have resolving power high enough that all the lines of the test-pattern are clearly resolved.

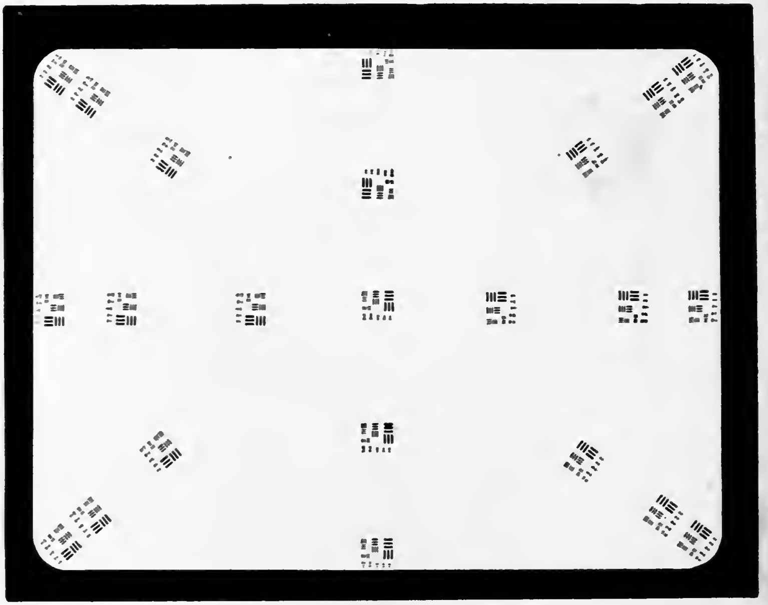

FIG. 11. Arrangement of test-chart images in picture frame area.

The test projector shall be placed at a distance from the screen such that the projected image of the black border of the test-object measures 30 × 40 inches. Care shall be taken to insure that the screen is perpendicular to the projection axis. The lens under test shall then be focused so that the central image is as sharp as possible.

The observer, standing close to the screen, shall note the finest lines that are definitely resolved in both the tangential and radial directions, and record the resolution figures for

(*a*) Center of the screen
(*b*) Average of mid-sides (top and bottom)
(*c*) Average of mid-ends (left and right)
(*d*) Average of the four corners

The following minimum resolving powers shall be obtained:

	Lines per Millimeter
(*a*) Center	80
(*b*) Mid-sides (top and bottom)	60
(*c*) Mid-ends (right and left)	40
(*d*) Corners	30

In addition to meeting the above requirement of resolving power, he projection lens shall be free from the following defects to a degree uch that they are not easily noticeable when the image is viewed rom a distance equal to twice the width of the screen:

(*a*) *Haze.*—Some lenses possess a large amount of spherical aberration, which as the effect of covering the image with a misty haze of light, without seriously psetting the resolution. This causes unpleasant projected images. A good pro-ection lens gives a clean, crisp image.

(*b*) *Chromatic Aberration.*—This is not a common defect. It may be detected y the presence of a colored haze visible in the finer details over the whole of the eld.

(*c*) *Lateral Color.*—This defect is manifested by the presence of one-sided color inges appearing only in the outer parts of the field and vanishing completely in he center.

(*d*) *Distortion.*—In the presence of this aberration straight lines in the outer art of the field appear as curved lines. The straight boundaries of the picture ate itself make good test objects for the detection of distortion. A lens should ot be rejected on the ground of distortion unless the defect is bad enough to be istracting to an average observer.

(*16*) *Provision for Focusing.*—The projection lens shall be so nounted as to be readily brought to an exact focus. The mounting ither shall provide means by which the lens may be locked in its osition of focus or shall hold the lens solidly enough to prevent disurbance of the focus by the vibration of the projector.

(*17*) *Mounting of Interchangeable Lenses.*—When a projector is lesigned to accommodate lenses of several focal lengths, the construcion shall be such as to insure that each lens is centered on the optical xis and maintained with its axis perpendicular to the film plane vithin close enough limits to avoid any inequalities of focus among he four corners of the picture, visible to an observer twice the screen vidth distant from the screen.

(*18*) *Temperature Rise of Film.*—The film, during its passage through the projector, shall not be raised to a temperature high enough to cause permanent distortion of the base.

The test for possible excessive temperature rise of the film shall consist of projecting a 30-inch loop of film having a density of 2.00 or higher, for 100 continuous passages through the gate. The test-film shall then be wound into a roll of processed film in normal condition and allowed to remain so wound for a period of 24 hours before being examined for distortion of the base.

(*19*) *Temperature Rise of Projector Housing.*—During continuous operation of the projector at the lowest speed for which it is designed, at a room temperature of 80°F, the temperature of no external part of the projector except the top cover of the lamp-house shall rise above 155°F.

(*20*) *Adequacy of Ventilation for Incandescent Lamps.*—The ventilation of the lamp house shall be sufficient to prevent bulging of the lamp envelope or other damage to the lamp during continuous operation at any available speed at any time during the life of the lamp, provided that the lamp is operated at its rated voltage and the ambient temperature is not higher than 80°F.

When provision is made for reverse operation of the projector mechanism, the lamp-house ventilation during continuous reverse operation shall be sufficient to prevent damage to the lamp.

The electrical circuits of the lamp and of the motor or motors which drive the ventilating fan and projector mechanism shall be so interlocked that the lamp can not be turned on at a time when the ventilating fan is not running at a speed sufficient for proper cooling of the lamp, provided that in cases where projectors are designed for operation on either alternating or direct current, the user has properly adjusted such switches or rheostat controls as may have been provided by the manufacturer in order to obtain normal film speed on both types of current.

(*21*) *Rewind.*—Power rewind, if provided, shall be capable of rewinding 400 feet of film under a tension of not less than 3 ounces in not more than 2 minutes.

(*22*) *Lubrication.*—The projector mechanism shall either be equipped with "oilless" bearings of an efficient type or provided with easily accessible and plainly marked oiling means so constructed that the application of oil as specified by the manufacturer will insure adequate lubrication of all bearings in the machine.

(*23*) *Range of Line Voltage for Satisfactory Operation.*—The manuacturer shall specify on the name-plate of the projector the range of ine voltages on which it is designed to operate.

(*24*) *Directional Reflection Characteristic of Screen.*—The disribution of the reflected light from a screen used for 16-mm proection shall be so related to the arrangement of the spectators that he brightness of the screen as seen from the maximum existing viewng angle is not less than 25 per cent of the brightness of the screen as een from a position near the axis of projection.

(*25*) *Efficiency of Screen Reflection.*—The reflection coefficient of he screen within the angle over which requirement No. 18 is satisied shall not be less than 70 per cent.

(*B*) *Sound Reproduction*

(*1*) *Steadiness of Film Motion.*—The *Uniform-Motion Test-Film* hall carry a 3000-cycle tone, recorded at a level not lower than 6 lecibels below full modulation, with a frequency deviation of not nore than 0.2 per cent. This film shall be either an original negative r a direct positive, not a print.

As measured by the RCA flutter indicator, speed variations ntroduced by the projector when reproducing this test-film shall ot exceed 0.6 per cent.

(*2*) *Accuracy of Length and Location of Scanning Beam.*—The *Scanning-Beam Length and Location Test-Film* shall be an original egative sound-track. It shall be in two sections. The first section hall consist of a uniformly exposed band regularly interrupted to proluce a 300-cycle tone and having its inner edge 0.017 inch from the dge of the film, together with a second band regularly interrupted o produce a 700-cycle tone and having its inner edge 0.099 inch from he edge of the film. The second section shall consist of a band nterrupted to produce a 500-cycle tone and having its inner edge .026 inch from the edge of the film, together with a band interupted to produce a 1200-cycle tone and having its inner edge 0.090 nch from the edge of the film.

The term "inner edge" in the above specification means the edge earest the position of the centerline of the standard sound-track.

The inner edges of the exposed bands shall be free from any bluring in excess of 0.0005 inch, and shall be located within 0.001 inch of he positions specified.

The scanning light-beam in the projector shall be of such length and so located that it reproduces neither the 300-cycle tone nor the 700-cycle tone, but does reproduce both the 500-cycle tone and the 1200-cycle tone.

(3) *Accuracy of Azimuth Adjustment of Scanning Beam.**—The *Azimuth Test-Film* shall consist of three sections of 5000-cycle variable-density track, modulated 100 per cent.

The first section shall have an azimuth error of 1.0 degree, ±0.1 degree.

The second section shall have correct azimuth adjustment within 0.1 degree.

The third section shall have an azimuth error of 1.0 degree, ±0.1 degree, in the direction opposite to that of the error in the first section.

The test shall be made by reproducing this test-film and reading the output levels of the three sections by means of a volume indicator or output meter connected across the voice-coil of the loud speaker or a resistance load used to simulate the loud speaker. The output from the middle section shall be greater than the output from either the first or the third section.

(4) *Frequency Response.*—The *Frequency Test-Film* shall consist of at least 15 feet of 400-cycle track for level adjustment, followed by at least 10 feet of each of the following frequencies:

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* The Committee has attempted so far as possible to write these specifications in terms of overall performance rather than performance of individual parts. It is for this reason that scanning-beam width, for example, has not been specified, since it is covered by the specification of overall frequency response (Requirement No. 4). It may appear strange, therefore, that scanning-beam azimuth adjustment is treated separately, since the aspects of performance that it affects, that is, overall frequency response and distortion, are covered by overall specifications.

It is necessary to measure scanning-beam azimuth error separately, however, because the distortion it introduces lies mainly in the frequency range from 1000 to 3000 cycles. Direct distortion measurements in this frequency range are much more difficult than the azimuth adjustment test.

The test laid down in the specification insures that the azimuth adjustment of the projector will be correct within 0.5 degree. This limits the harmonic distortion produced to a maximum of 5 per cent total at 2000 cycles when a 1.0 mil scanning-beam is used, as in most 16-mm projectors.

Cycles	Cycles
50	2000
100	3000
200	4000
300	5000
500	6000
1000	7000

The modulation in all sections of the film shall be such that the level of modulation imparted to a scanning light-beam of negligible width (0.0002 inch or narrower) does not differ by more than 2 decibels from the level of modulation imparted by the 400-cycle section.

When reproducing this frequency test-film, it shall be possible, by at least one adjustment of the tone-control provided on the projector, to obtain a response curve having a variation of not more than 10 decibels between 100 cycles and 4000 cycles, and of not more than 14 decibels between 100 cycles and 5000 cycles. In making this test the output voltages shall be measured across a non-inductive resistance load equal to the impedance of the loud speaker at 400 cycles.

This test shall be made with a power-line voltage of 117 volts at the amplifier terminals.

(5) *Power Output Rating.*—The power output of the projector and amplifier system shall be measured by the use of a *Wave-Form Test-Film* consisting of a 400-cycle symmetrically modulated variable-area sound-track having a total amplitude of modulation of 0.048 inch ± 0.002 inch, and having a total harmonic content of not more than 1 per cent, of which not more than 0.5 per cent is made up of odd-order harmonics.

Using this film as the source of signal, the output shall be measured across a non-inductive resistance load equal to the impedance of the loud speaker at 400 cycles. The harmonic content shall be measured either by means of a selective wave-analyzer such as the General Radio Type *736-A* or by means of band-pass filters isolating the outputs at 800 cycles and at 1200 cycles for individual measurement.

The measurement shall be made with a power-line voltage of 117 at the amplifier terminals.

At this power-line voltage, no vacuum-tube or other component part of the amplifier shall be subjected to a higher voltage or operated at a higher rate of power dissipation than the manufacturer's maximum ratings for the part in question. Special vacuum-tube circuits requiring special manufacturer's ratings shall be so indicated.

Using unselected vacuum-tubes which, however, perform within the manufacturer's ratings for their types, the projector and amplifier shall deliver the rated power output with a total harmonic content of not more than 5 per cent, of which not more than 4 per cent shall be made up of odd-order harmonics.

(6) *System Noise.*—A *Standard Output Test-Film* shall be provided, consisting of two sections of 400-cycle variable-area track. The first section shall have a total amplitude of modulation of 0.48 inch ± 0.002 inch. The second section shall be recorded with an input level 18 decibels lower than is required to produce the first section. The print of these two tracks shall have an image density of 1.6 or higher, and a fog density between 0.03 and 0.05.

An auxiliary short length of film uniformly exposed and developed to a density of 0.6 (transmission of 25 per cent) is required.

The test shall be made by first reproducing the higher output section of the Standard Output Film and adjusting the volume control of the projector until the rated maximum output of the amplifier is being delivered across the load resistor specified for the test under requirement No. 5. The volume control shall be left at this setting and the film removed from the machine. A short length of the 0.6-density film shall be placed in the path of the light-beam from the reproducing optical system. Then, with the projector mechanism running at standard speed, the output noise level shall be measured with a standard volume indicator meter across the load resistor.

This test shall be made with the tone-control adjusted for the most nearly uniform frequency response that is available in the range from 100 to 5000 cycles.

The test shall be made at a power-line voltage of 117 volts.

Under the above conditions of test, the noise level shall be at least 30 decibels below the rated maximum power output level of the system.

(7) *Adequacy of Available Amplification.*—Sufficient amplification shall be available to develop the rated maximum output power of the system when reproducing the lower level section of the Standard Output Test-Film specified above.

The test shall be made at a power-line voltage of 117 volts.

(8) *Loud Speaker Power-Handling Capacity.*—The loud speaker

supplied with a sound projector shall be capable of handling the full rated power output of the associated amplifier without rattling and without generating objectionable distortion.*

(*9*) *Loud Speaker Frequency Response.*—The frequency response of the loud speaker shall effectively cover the range from 100 to 5000 cycles per second.**

(*10*) *Accuracy of Exciter-Lamp Filament Location.*—The maximum departure of the filament of the exciter lamp from its design location, permitted by the combined effect of the lamp manufacturer's tolerances and the projector manufacturer's tolerances, shall not be sufficient to cause a reduction of more than two decibels in the level of reproduced sound, or to cause the production of harmonics in excess of the limit specified under requirement No. 5, above.

(*11*) *Safety of Electrical System.*—The projector shall have been approved for safety by the Underwriters' Laboratory.

(*12*) *Mechanical Noise.*†

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* This specification expresses the general intent of the Committee, but is obviously incomplete without specification of the method of test. Investigation has shown that at the present time there is not sufficiently widespread agreement among specialists in acoustical measurements to permit the writing of a generally acceptable complete specification covering the power-handling capacity of the loud speaker.

** The above note also applies to the measurement of loud speaker frequency response.

† The Committee recognizes that mechanical noise from the projector mechanism must be kept below certain limits if sound reproduction is to be satisfactory but considers that the information at present available is not sufficient for the writing of a specification.

(*Continued on next page*)

Supplement to the Report of the Committee on Non-Theatrical Equipment

RESOLUTION TESTS ON 16-MM PROJECTION LENSES

R. KINGSLAKE

Since some means for the quantitative expression of the performance of a projection lens is very desirable, especially when attempting to set up standards of projector quality, it is suggested that the visual resolving power of the lens, expressed in lines per millimeter at the film plane, be used as a criterion. The lines should be equally spaced, with the spaces equal in width to the lines, so that a test-chart labeled "100 lines per mm," shall consist of straight black lines $^1/_{200}$ mm wide separated by $^1/_{200}$-mm spaces. At least three lines and two spaces should be included in the test-chart.

It is suggested further that the performance of a projection lens should be specified by stating the resolving power at (*a*) the center of the field, (*b*) the average of the mid-points of the top and bottom of the gate, (*c*) the average of the mid-points of the left and right sides of the gate, and (*d*) the average of the four corners of the gate. The gate dimensions should be in accordance with the SMPE standard, namely, 7.21 × 9.65 mm with a 0.5-mm corner radius.

To facilitate this test, a glass photographic test-plate has been constructed of the required size, and at each of the specified points is situated a panel carrying resolution test-charts spaced 20, 30, 40, up to 100 lines per mm, the lines lying both radial and tangential to the field (Fig. 10). A few additional panels may be added to complete the whole target (Fig. 11). The requirement for resolution is that both the radial and tangential lines at any spacing shall be clearly visible as lines and not as a diffuse patch.

A suitable target was made to a greatly enlarged scale by sticking paper prints from a negative transparency on a wooden board. This was then reduced photographically to the desired size on Eastman Spectroscopic High-Resolution plates (Type *548*), using a highly corrected Microfile lens. This emulsion has a very high resolving power, and it was found possible to make plates on which the 100-line charts are clearly recorded. A photomicrograph of a corner of one of the test-charts is shown in Fig. 12. The writer is indebted to

Mr. B. Elle of the Eastman Kodak Company for his kindness and skill in making these test-plates.

THE TEST PROJECTOR

A simple projector was then constructed to make the tests (Fig. 13). It consists of a standard Kodascope lamp house with 300-w lamp, ventilating fan, condenser, and heat-absorbing glass. The lamp was operated at perhaps 65 per cent of its rated voltage, and as a result of all these precautions, the test-plates remained cool enough not to fracture during the test. Adapters were constructed to hold various standard makes of projection lens, the rear of each adapter being machined square to the axis of the lens. The glass test-plate was then held against the rear face of the adapter, film side toward the lens, by means of spring clips. A circular hole just larger than the diagonal of the projector aperture was bored in the rear of each adapter to assist in the accurate centering of the test-plate relative to the projection lens axis.

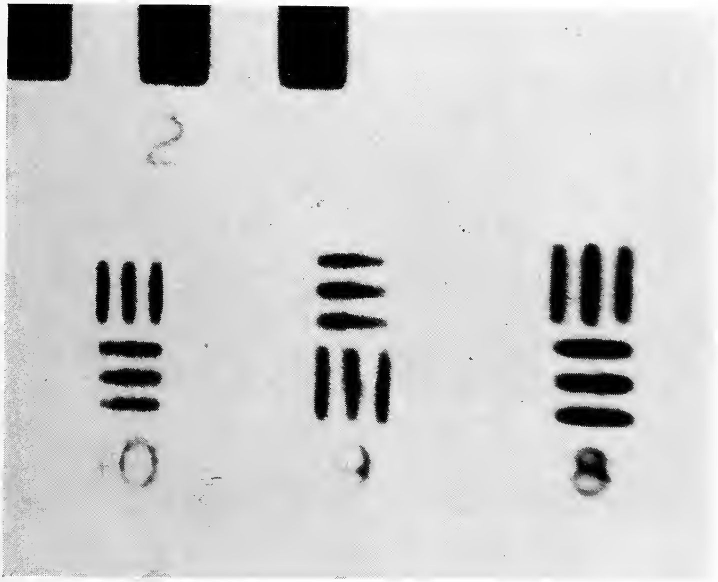

FIG. 12. A photomicrograph of the 100, 90, and 80-line sections of the test plate (×450).

Most projection lenses have a decidedly curved field. For this reason it is necessary to adopt a standard focusing procedure to be used in making a test. It was decided to focus the lens so that the resolution observable at the center of the field is as good as possible. This provides a definite and repeatable criterion of focus, based upon the assumption that most users of cine projectors are more interested in the center of the picture than in any other part.

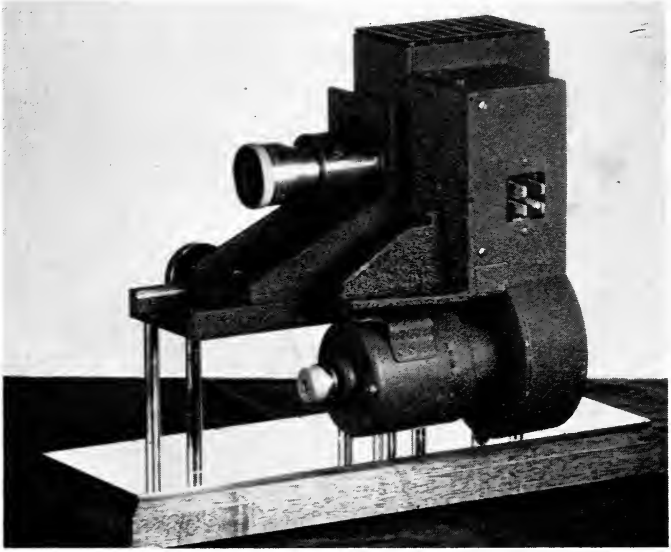

FIG. 13. The test projector.

The size of the projected image is not important, but it may conveniently be about 21 × 28 or 30 × 40 inches. The projected image should be studied close-up when determining the resolving power. A telescope to view the screen is practically a necessity when focusing the projector. Care must be taken to ensure that the light in the center of the field is falling perpendicularly on the screen.

THEORY

Assuming that the eye can resolve two lines subtending an angle of 1 in 2000 (1.7 minutes of arc), then an observer sitting at a distance of two picture-widths from the screen could just resolve details in the screen-image spaced at $^1/_{1000}$ of the picture width. Carried back into the film plane, the actual width of the gate being about 10 mm, this least resolvable distance becomes just $^1/_{100}$ mm. We may thus draw up a table of optimum eye resolutions for different viewing distances:

Viewing Distance (in Multiples of Picture Width)	Theoretical Number of Lines per Millimeter Resolvable by the Eye (Measured at the Film-Gate)
2	100
2.5	80
3	67
4	50
5	40
6	33

It is therefore useless to require better resolution in our projection lens than these figures. In practice, the finest resolution is needed only in the central parts of the screen, where the most significant parts of the picture will generally be found. Actual projected images can not usually be resolved to the extent indicated in this table, because the spherical aberration of the projection lens tends to blur the images slightly.

OTHER PROPERTIES OF THE IMAGE

Although good resolution is the principal requirement of an image-forming system, there are other properties that should be watched. However, if they are not easily noticeable when the image is viewed from a distance of two screen-widths, they are not likely to be serious.

(*a*) *Haze.*—Some lenses possess a large amount of spherical aberration, which has the effect of covering the image with a misty haze of light, without seriously upsetting the resolution. This causes unpleasant projected images, and lenses showing the defect should be avoided. A good projection lens gives a clean, crisp image.

(*b*) *Chromatic Aberration.*—This is not a common defect, and it may be detected by the presence of a colored haze visible in the finer details over the whole of the field.

(*c*) *Lateral Color.*—This defect is manifested by the presence of one-sided color fringes, appearing only in the outer parts of the field and vanishing completely in the center.

(*d*) *Distortion.*—In the presence of this aberration, straight lines in the outer part of the field appear as curved lines on the screen. The straight boundaries of the gate itself make good test objects for the presence of distortion. A lens should not be rejected on the ground of distortion unless it is bad enough to be distracting to an average observer.

OBSERVATIONS

A number of representative 16-mm projection lenses were tested by this method, and the results are recorded below. The positions (*a*), (*b*), (*c*), and (*d*) refer to the center, top, side, and corner of the frame as outlined above.

Manufacturer	E. F.	*f*/No.	Resolution				Remarks
	(Inch)		(*a*)	(*b*) (Lines per mm)	(*c*)	(*d*)	
(*a*)	1	2.5	80	50	20	<20	Normal lens type
	$1^1/_8$	2.5	70	70	60	50	Same lens with field flattener
	$1^1/_2$	2.5	80	70	60	50	
	2	2.5	70	70	60	50	
	2	1.6	100	60	20	<20	Normal lens type
	2	1.6	90	80	60	40	Same lens with field flattener
	3	2.0	100	70	50	20	
	3	1.4	90	80	70	40	
	4	2.5	80	60	50	40	
	4	1.6	60	50	40	30	
(*b*)	2	2	70	60	40	20	
	2	2	100	50	20	<20	
	$1^1/_2$	2	>100	30	<20	<20	
	1	2	100	30	<20	<20	
	3	2.5	80	70	50	30	
(*c*)	2	2	90	50	30	20	
	2	2	100	60	30	<20	
	2	1.6	60	40	30	<20	
(*d*)	1	2.46	100	40	<20	<20	
	$1^1/_2$	1.8	90	60	40	20	
	2	2.0	100	50	<20	<20	
	2	1.6	100	70	40	<20	
	3	2.3	90	60	50	40	
	$3^1/_2$	2.7	100	80	60	40	
	4	2.8	80	80	70	70	
(*e*)	2	1.65	90	40	30	20	
(*f*)	2	1.4	70	70	60	20	

CONCLUSIONS

The most common type of projection lens is the *f*/1.6 or *f*/2.0 lens, 2-inch focus, having excellent central definition, and a strongly curved field. These commonly show resolution figures of approximately:

(*a*)	(*b*)	(*c*)	(*d*)
100	60	30	<20

Upon refocusing, these figures can readily be changed to something like this:

50	70	30	20

If a 2-inch *f*/1.6 lens is equipped with a field flattener, the resolution in the center is slightly diminished, but that at the corners is much increased:

90	80	60	40

A similar case is found for a 1-inch *f*/2.5, which became transformed by the addition of a field flattener as follows:

(without)	80	50	20	<20
(with)	70	70	60	50

However, an *f*/1.6 lens in the 3-inch or 4-inch size is often quite satisfactory.

As a result of these studies, it is concluded that, assuming the lens is focused as accurately as possible for the center of the field, acceptable resolution figures would be as follows:

Center	80 lines per mm
Top and bottom	60
Left and right sides	40
Corners	30

REPORT OF THE STANDARDS COMMITTEE*

At the Hollywood Meeting of the Society last fall a report was given of the activities of the Standards Committee for the year 1940 to that date. Since that time the Standards mentioned as having been reviewed during the past two years by the Committee, the corresponding group in the Research Council, and other interested persons, have been approved by the American Standards Association and appeared as American Motion Picture Standards and Recommended Practices in the March, 1941, issue of the JOURNAL. The proposed SMPE Recommended Practices mentioned in that same report for 35-mm and 16-mm raw stock cores, motion picture screen brightness, lantern slides, and cutting and perforating specifications for 35-mm positive and negative raw stock have been approved by the Society and have likewise appeared in the March, 1941, JOURNAL.

The procedure for adopting SMPE Recommended Practices and for proposing, in the name of the Society, Standards or Recommended Practices to the ASA Sectional Committee on Motion Pictures has been revised by the Board of Governors and has resulted in a simpler method of adoption of SMPE Recommended Practices. This consists essentially of discussion and approval by the full Standards Committee and further approval by the Board of Governors and publication in the JOURNAL with, of course, provision for suggestions or changes by any member of the Society or any other interested party. The above-mentioned Recommended Practices were handled in this manner.

The work in progress includes proposed SMPE Recommended Practices for edge numbering 16-mm film, and designations of winding directions for 16-mm film, which have recently received initial approval and are being voted upon by the full Committee at the present time.

Other subjects such as 16-mm emulsion position for printers, specifications for 16-mm and 8-mm reels, 16-mm sound-track and scanning area, sound-track blooping patches, standard volume indi-

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received April 22, 1941.

cator, glossary, sound-track nomenclature, sound transmission of screens, projection lenses, and 35-mm projection sprockets are either under consideration by the Committee or have been referred to other Committees of the Society or to the Research Council of the Academy of Motion Picture Arts and Sciences for further information or suggestions. The Committee suggested a group of papers or symposium on sprockets to aid in clarifying the situation on this subject.

The Standards Committee wishes gratefully to acknowledge the coöperation of the Society Officers, the other Committees in the Society, various individual members, and the Research Council of the Academy of Motion Picture Arts and Sciences.

STANDARDS

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H. Bamford
M. C. Batsel
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R. E. Shelby
J. L. Spence
H. E. White

REPORT OF THE THEATER ENGINEERING COMMITTEE*

In the Report of this Committee, presented at the Hollywood Convention last October, and published in the December, 1940, issue of the JOURNAL, the growth of the Society's activities in the various phases of theater engineering was described. It was pointed out also that many phases of theater design, particularly from the projection viewpoint, had been considered by the Committee and had resulted in a number of recommended practices and procedures in general acceptance by the industry. Nevertheless, there were other phases that had not yet received adequate consideration—these phases referring more particularly to the theater structure rather than to the process of projection.

Accordingly, by action of the Board of Governors, on July 13, 1939, what was formerly known as the Projection Practice Committee was dissolved, and a new Committee was established, known as the Theater Engineering Committee. This new Committee originally functioned primarily through two sub-committees, namely, the Sub-Committee on Projection Practice and the Sub-Committee on Theater Design.

For a long time, the original Projection Practice Committee had been studying the question of picture brightness and its measurement. Some years ago, another Committee of the Society, known as the Screen Brightness Committee, had done considerable work on this subject and had published a noteworthy report and accompanying symposium on various features of screen brightness in the May and August, 1936, issues of the JOURNAL. With the publication of this material, the Screen Brightness Committee became relatively inactive since the information then at their command did not permit further constructive analysis.

In the interim, the study was continued to some extent by the then existing Projection Practice Committee, and during the past year it became increasingly evident that further active work could be done on the subject. Accordingly, it was decided to establish a third subcommittee of the Theater Engineering Committee, to be known as

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received May 1, 1941.

the Sub-Committee on Screen Brightness, which was to include in its scope, not only the actual specifications of screen brightness in theaters, but also the problem of devising appropriate means of measuring screen illumination and brightness, and of discovering or devising suitable meters for the purpose. Since this new sub-committee has been functioning only a short time, its work has not progressed to the point at which it can make definite recommendations to the industry. However, some progress has been made during the past few months, and the Theater Engineering Committee is pleased to include in this report the first report of the new Sub-Committee on Screen Brightness.

The personnel of the Theater Engineering Committee, sub-divided into its three sub-committees is given below. Each sub-committee also has its subordinate working committees.

THEATER ENGINEERING COMMITTEE

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Projection Practice Sub-Committee

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H. D. Behr
K. Brenkert
F. E. Cahill, Jr.
C. C. Dash
A. S. Dickinson
J. K. Elderkin
J. Frank, Jr.
R. R. French
E. R. Geib
M. Gessin
A. Goodman
H. Griffin
S. Harris
J. J. Hopkins
C. Horstman
L. B. Isaac
I. Jacobsen
P. J. Larsen
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J. R. Prater
F. H. Richardson
J. J. Sefing
R. O. Walker
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A. T. Williams

Theater Design Sub-Committee

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F. W. Alexa
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S. Harris
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E. R. Morin
K. C. Morrical
I. L. Nixon
C. C. Potwin
A. L. Raven
R. F. Ross
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J. J. Sefing

Screen Brightness Sub-Committee

F. E. Carlson, *Sub-Chairman*

F. T. Bowditch
F. J. Durst
W. F. Little
S. Harris
W. B. Rayton
C. Tuttle
H. E. White
A. T. Williams

PROJECTION PRACTICE SUB-COMMITTEE

Much of the work undertaken by the Sub-Committee on projection practice is at the present time incomplete, so that definite reports are not appropriate at this time. Work is continuing on the fourth revision of the Projection Room Plans, and it is hoped that a new report on this subject may be available in the near future.

Tools, Tolerances, and Safety Factors.—The Working Committee on Tools, Tolerances, and Safety Factors has held a number of meetings and has made a number of tests on projection equipment.

The purpose of the Committee is to conduct a study of the motion picture projector mechanism from the servicing and operating viewpoint, and to determine the degree of wear at various points that may be tolerated with safety, and to find or devise tools or gauges that may assist the projectionist in checking the degree of wear, and the corresponding departure of the mechanism from suitable operating conditions. Several meetings of the Working Committee have been held and a number of tests have been conducted on projection equipment to determine the relation between the pressure of the film shoe and the spacing between the shoe and the surface of the film-gate. This relation has been found to be linear, being approximately 0.0005 inch per gram of pressure. Slight variations in the positions of the gates apparently make little noticeable difference in the picture jump. However, it is the intention to check this matter more accurately and to determine the minimum pressure required for steady operation. In addition, further tests will be made to determine the relation between shoe pressure and wear on the film perforations, and the relation between the shoe pressure and the wearing of the sprocket-teeth.

This report should be regarded as preliminary, and it is hoped that a comprehensive report will be available at the next Convention.

Sub-Committee on the Power Survey.—In the last report of the Theater Engineering Committee was included a preliminary report of the Working Committee on the Power Survey, in which it was pointed out that numerous data had been accumulated through questionnaires distributed among 1600 theaters of the country. The purpose of these questionnaires was to secure a cross-section of data in relation to (*1*) the trend in current consumption for the various electrical units used in theaters throughout the country, (*2*) the total cost of electrical current, (*3*) energy consumption charges, and (*4*) the average proportions of power used for projection, air conditioning, lighting, *etc.* The previous report included a brief table of data pertaining to these factors. Insufficient time has been available to complete the tabulation, and it is hoped that a complete report will be available by the Fall of this year.

Carbon Arc Terminology.—It had been noted that some confusion existed in the motion picture industry with regard to the terms applied to various types of arc. In particular, specific definitions of the terms "high intensity" and "low intensity" were not available. The Projection Practice Committee, therefore, submits the following definitions of these terms:

The fundamental distinction between the high intensity and low intensity carbon arcs is based upon the origin and character of radiation. The chief contributing factors and associated characteristics are composition of the carbons, current density, and brilliancy.

Low Intensity

The *low intensity* carbon arc is one in which the principal light source is incandescent solid carbon at or near its temperature of volatilization. In the case of the direct current low intensity arc, as used for projection, this is the crater face of the positive carbon. The maximum brilliancy of this crater face is limited by the vaporizing temperature of carbon to a value of about 175 candles per square millimeter. This crater brilliancy varies but little with changes in current within the usual operating range, but the crater area increases considerably with increasing current. Current density in the positive carbon for the familiar commercial lamps ranges from approximately 50 to 200 amperes per square inch.

High Intensity

The *high intensity* carbon arc, as used for projection, is one in which, in addition to the light from the incandescent crater surface, there is a significant amount of light originating in the gaseous region immediately in front of the carbon in an atmosphere containing flame materials (materials which become highly luminescent when volatilized in the arc stream). In the case of the direct current high intensity arc this light comes from within and near the crater of the positive carbon. The maximum brilliancy of the crater obtained in various types of direct current high intensity carbon arcs used in common commercial lamps ranges from 350 to 1200 candles per square millimeter with current densities in the positive carbon ranging from about 400 to well over 1000 amperes per square inch. Increase of current increases the crater area only slightly, but produces marked increase in brilliancy.

Symposium on Projection Practice.—One of the aims of the Projection Practice Sub-Committee is to make available to the projectionists of the country technical data in such form as it may be easily applied in practice. With this thought in mind the Committee has formulated a brief symposium on projection practice for presentation at this Convention. Following the presentation of this Report of the Theater Engineering Committee, there will be four papers prepared by members of the Projection Practice Committee dealing with "Projection Room Equipment Requirements," "The Projection Room—Its Location and Its Contents," "Factors Affecting Sound Quality," "Factors to Be Considered in a Sound Screen."

REPORT OF THE THEATER DESIGN SUB-COMMITTEE

The Glossary compiled by this Sub-Committee is intended for use for all those interested in motion picture theater design. The Glossary will be submitted to the SMPE Standards Committee for possible inclusion in the General Glossary of Motion Picture Terms, which is under preparation by them, and will be called to the attention of other interested organizations or groups, including the American Institute of Architects and various architectural periodicals and trade papers.

One of the chief benefits which it is hoped will be derived from this work will be to help in the writing of a uniform Code, which will govern the functional design of motion picture theaters. The present non-uniformity and confusion which exist in the large number of Building Codes both as to legal requirements and terminology has been brought to the attention of this committee through the study of a large number of existing Building Codes throughout the United States.

It is realized that it would be an almost impossible task to bring about a major change in the existing codes, particularly as regards uniformity. However, it is felt that this Committee can start with an attempt at standardization of terminology and the fixing of uniform viewing and hearing requirements in auditoriums. This would enable such authorities as are contemplating changes in existing Codes or writing new Codes for motion picture theater construction to be guided by the important visual and auditorium requirements in the theater.

In addition to the Glossary, the Committee is first giving consideration to the lighting of theater auditoriums. It is recommended that the wall and ceiling surfaces within the spectators' field of vision, while viewing the picture, should appear to the spectator as a uniformly and uninterruptedly illuminated surface. Anything in the lighting that would tend to distract the viewer's attention from the screen picture should be avoided if possible. It is very important for best results in the projection of colored pictures that the color of the lighting and wall surfaces be neutral. No departure from uniformity should be made unless the changes of intensity are gradual.

The Committee is not prepared to specify actual values of illumination but does stress, for the time being, uniformity of illumination and the elimination of isolated islands of light in dark surroundings or dark voids in areas of light.

This recommendation very definitely affects the style of architectural ornamentation and the design of the auditorium interior. The surfaces employed must be of such texture and color over large areas as will make possible this uniform illumination. Ornamental projections or cavities which cast shadows, and painted decorations in various colors and intensities are objectionable. The fact must not be overlooked that the motion picture screen is a source of light and may cause undesirable and objectionable illumination of auditorium surfaces or ornaments if the latter are improperly designed.

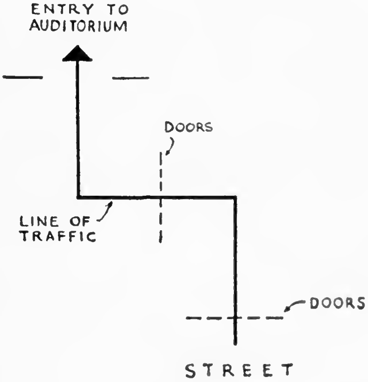

FIG. 1. Light-trap.

In connection with illumination, it is important that the arrangement of walls and doors of the outside lobby, the main lobby, the foyer, and so forth, be so arranged as to entrap the light coming from the street. If the line of traffic from the street to the auditorium is straight, this problem is difficult to solve unless extra sets of doors are used at intervals to block the light. A more efficient method of an intimate form can be successfully evolved by so arranging doors and walls that the line of traffic follows a zee shape (Fig. 1). This is helpful also in eliminating objectionable drafts and in reducing the infiltration of street noises.

Glossary of Terms Used in Theater Design

Aisle.—A passageway in a seating area.

Center aisle.—An aisle on the longitudinal axis of the theater.

Wall aisle.—An aisle along one of the side walls of a theater.

Intermediate aisle.—Any longitudinal aisle that is not a center aisle or wall aisle.

Cross-over.—A transverse aisle.

Balcony.—An area of seats, part, or all of which overhangs another seating area.

Orchestra Floor.—The lowest seating area of a theater.

Stadium.—An area of seats higher than and to the rear of the standee rail or partition, accessible directly from the standee space.

Stepped Platform Seating.—Stepped platforms, one above the other upon which seats are placed. The amount of rise from one platform to another being determined by the sight clearance factor.

Uniformly Pitched Auditorium Floor.—A floor having an equal rise or fall for each row of seats.

Variably Pitched Auditorium Floor.—A floor incline having a changing pitch for every row, or groups of rows of seats to obtain proper sight clearance.

Auditorium Bowl Floor.—A floor incline for curved rows of seating in which the change of pitch takes place by keeping all of the seats of each respective row on one level.

Concentric Arcuated Seating Rows.—Seats placed in curved rows, the radii of which increase for each row, placed farther from the auditorium front wall.

Down Pitch Auditorium Floor.—A floor which pitches in part or whole downward toward the auditorium front wall to provide sight line clearances.

Reverse Pitch Auditorium Floor.—A floor which pitches upward in part or whole toward the auditorium front wall to provide raised seating levels located near to a motion picture screen to bring these seating levels as close to the screen level as possible.

Combination Pitch Auditorium Floor.—A floor which pitches downward toward and then upward toward the front wall of the auditorium.

Auditorium Lighting.—Any auditorium lighting in use when the motion picture show is not in progress.

Projection Period Lighting.—Any lighting of the auditorium that may be necessary or desirable during the projection of the motion picture.

Transition Lighting.—The gradation of illumination from outdoors to the auditorium.

Light Trap.—An arrangement of wall and doors designed to exclude undesired light from the auditorium.

Re-reflected Screen Light.—Light reflected from the screen and re-reflected from any other surface in the auditorium.

Atmospheric Light Reflection.—Reflection of light by particles in the atmosphere of the auditorium.

Auditorium.—The space in a theater from any point of which the performance may be viewed.

Standee Partition (*or Rail*).—A partition (or rail) separating a last row of seats from a cross-over.

Standee Space.—A space in a theater in which patrons are permitted by law to stand and view the performance.

Lobby.—The space between the first and second sets of doors of a theater.

Foyer.—A gathering place between the auditorium and the lobby.

Outside Lobby.—A partially enclosed space in front of the first set of entrance doors. (Sometimes called "Vestibule.")

Soffit.—Generally used to refer to the ceiling under the balcony.

Right Side (of auditorium).—The right-hand side, looking toward the screen.

Left Side (of auditorium).—The left-hand side, looking toward the screen.

Mezzanine.—An intermediate level between seating levels.

Auditorium Front Wall.—False wall or structural wall at the front of the auditorium on the audience side of the screen.

Exit Court.—A space for egress open to the sky.

Exit Passage.—A space for egress entirely enclosed.

Auditorium Rear Wall.—The wall at the opposite end of the auditorium from the screen.

Auditorium Side Walls.—Walls other than the front or rear walls of the auditorium.

Proscenium Opening.—The opening in the auditorium front wall through which the screen is viewed.

Rear Screen Space.—The space on the side of the screen away from the audience.

Traffic Control.—Physical or suggestive. Any device (architectural lighting or decoration, signs, door controls, barriers, *etc.*) used to control the direction of the passage of people in the public spaces of the theater structure.

Vomitory.—A walled in passage used for circulation to seating areas usually cut through a raised inclined seating level.

Balcony or Stadium Fascia.—The surface facing the motion picture screen which forms part of the protective wall and rail in front of a balcony or stadium.

REPORT OF SUB-COMMITTEE ON SCREEN BRIGHTNESS

The recently appointed Sub-Committee on Screen Brightness has held its first meeting.

Reflection characteristics of the usual screen materials and their response under given conditions are for the most part appreciated only in a general way, or take on only academic significance. Most people, who have to do with the specification of screens and projectors and the other factors of theater design and operation which affect the basic fundamentals of motion picture exhibition, have lacked the means to acquaint themselves with the values of brightness actually experienced by the audience. An appropriate correlation of the physical factors with the physiological and psychological elements involved has therefore been difficult.

It is axiomatic that progress on a technical problem is limited until one can deal with it quantitatively and do so conveniently. The first objective of the Sub-Committee, therefore, is to develop measurement procedures and facilities of such low cost and convenience that, on the one hand, specialists will be encouraged to amplify the information they now have, and on the other, that knowledge and experience of these matters may be widely diffused among those who control the conditions under which pictures are viewed.

Brightness meters presently available have limitations as to cost or convenience in use by others than specialists. Accordingly, as its first step, the Sub-Committee has formulated provisional specifications for instruments which would facilitate attainment of its objective, and is placing these before instrument manufacturers to determine the feasibility of having them made available.

TELEVISION REPORT, ORDER, RULES, AND REGULATIONS

FEDERAL COMMUNICATIONS COMMISSION

WASHINGTON, D. C.

MAY 3, 1941

The following contains such extracts from the Report of the Federal Communications Commission as are deemed of interest to the members of the Society and other readers of the JOURNAL. *The complete report deals with the following main headings:*

- (*I*) *Definitions*
- (*II*) *Television Transmission Standards*
- (*III*) *Change or Modification of Transmission Standards*
- (*IV*) *Engineering Standards of Allocation*
- (*V*) *Objectionable Interference*
- (*VI*) *Transmitter Location*
- (*VII*) *Operating Power, Determination, and Maintenance*
- (*VIII*) *Equipment*
- (*IX*) *Monitors*
- *Appendix I: Charts for Determining Service Areas and Interference Range*
- *Appendix II: Requirements for Contour Maps in Establishing Service Areas*

REPORT ON MARCH 20, 1941, TELEVISION HEARING

DOCKET NO. 5806

By the Commission (Fly, Chairman, and Commissioners Walker, Payne, Thompson and Wakefield concurring—Commissioners Case and Craven not participating):

On March 20, 1941, a hearing was held for considering when television broadcasting "shall be placed upon a commercial basis" and for considering rules and regulations and standards for such stations.

Upon the hearings held in January and in April of 1940, the Commission found the industry divided upon the basic question whether television was ready for commercial broadcasting, and also found the industry divided as to transmission standards for television broadcast stations. Some believed that television had not reached the point where it could offer sufficient entertainment value to justify commercial operation and that standardization would result in the freezing of the science at the then level of efficiency. Others were determined to proceed at all costs with the launching of television on a large scale.

In its report of May 28, 1940, on the April hearing, the Commission declared:

> *As soon as the engineering opinion of the industry is prepared to approve any one of the competing systems of (television) broadcasting as the standard system the Commission will consider the authorization of full commercialization. That a single uniform system of television broadcasting is essential—so far as the basic standards are concerned—must also be amply clear. The public should not be inflicted with a hodge-podge of different television broadcasting and receiving sets*

Because the situation was one which threatened to hold up coördinated television development indefinitely and to delay public service on a widespread basis, the Commission offered its coöperation to the industry along lines in furtherance of the achievement of higher standards by research and development.

First, it provided for new experimental television stations in various sections of the country to engage in practical demonstration of prevailing competing systems. Later, it collaborated with the Radio Manufacturers Association (RMA) in creating the National Television System Committee (NTSC). The RMA felt that "Because of the inadequacy of the various suggested standards for television" all existing systems should be explored and developed, and new standards formulated. The NTSC was given this task.

The Commission now finds the industry entirely in agreement that television broadcasting is ready for standardization. The standards as finally proposed by the NTSC at the March 20, 1941, hearing, represent, with but few exceptions, the undivided engineering opinion of the industry. Some difference of opinion exists among broadcasters as to the date when commercial operation should begin. The National Broadcasting Company and the Columbia Broadcasting System, in effect, urged some delay in beginning commercial television. However, the Commission is of the opinion that the reasons advanced for the delay are not controlling. Other leading figures in the industry that earlier opposed commercialization, such as Philco, Zenith, and De Forest, now express the view that the present stage of scientific development warrants prompt standardization and commercialization.

The demonstrations conducted by different broadcasters and manufacturers for the benefit of the NTSC and the Commission revealed the merits and demerits of the systems upon which standards could be based. The eleven volumes constituting the proceedings of the Committee and its sub-committees stand as evidence of the great volume of work done. The Commission acknowledges its appreciation of the RMA and NTSC for their coöperation in performing this worth-while work.

The three-color television system demonstrated by the Columbia Broadcasting System during the past few months has lifted television broadcasting into a new realm in entertainment possibilities. Color television has been known for years but additional research and development were necessary to bring it out of the laboratory for field tests. The three-color system demonstrated insures a place for some scheme of color transmissions in the development of television broadcasting.

The NTSC proposals provide that color television be given a six-month field test before standardization and commercialization. The Commission finds this requirement necessary. However, immediate experimental color program transmissions are encouraged.

The standards proposed by the NTSC provide for most of the improvements held out as readily possible a year ago for monochrome transmissions (black and white pictures). These standards fix the line and frame frequencies at 525 and 30, respectively.* The 525 lines provide for greater detail in the pictures transmitted than the 441 lines advocated a year ago. They give substantially equal resolution and more fully exploit the possibilities of the frequency bands allocated for television. Different line and frame frequencies will likely be required for color transmissions. This, however, is a matter for future consideration after color transmissions have been adequately field tested.

A year ago one of the weakest phases of the proposed television standards was an unreliable synchronizing pulse which frequently caused the loss of the picture under interference conditions. A few weeks before the March 20, 1941, hearing, developments were brought forth for greatly intensifying the synchronizing signals transmitted. These developments have been incorporated in the new standards.

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* Certain experimental systems require variable line and frame frequencies. However, the fixed values proposed appear to be best for monochrome transmissions, because only 30-frame pictures have been fully developed and as long as the frequency band for television channels (aural and visual) is limited to 6 megacycles not more than 525 lines can be employed to advantage with 30 frames.

The demonstrations witnessed by the Commission impressively showed the tenacity with which this new form of synchronizing signals holds the picture in place under extremely adverse interference conditions.

The proposed standards require frequency modulation for sound accompanying the pictures. Television is therefore benefited by the recent development of frequency modulation.

The standards proposed by the NTSC reasonably satisfy the requirement for advancing television to a high level of efficiency within presently known developments. These standards are adopted by the Commission and made effective immediately.

The Commission feels that this state of the science affords some reasonable assurance against early obsolescence of equipment. At the same time, it must explicitly recognize the advancing and necessarily fluid state of the science. Accordingly, procedure has been provided for the consideration of new developments, including, but by no means limited to, color television.

Procedure is also provided for expediting completion of the television stations now authorized by the Commission. Existing licensees and permittees who can satisfy the Commission that their station construction will meet all the engineering requirements of the rules and regulations and standards for such stations may begin commercial operation on July 1, 1941.

The Commission finds that at least six months will be required for obtaining comparative test data on the alternative methods permitted for transmitting synchronizing signals. Such data are necessary for further limiting the signal synchronizing standards. The Commission is requesting the industry to provide the necessary test data as to both color transmissions and synchronizing signals within the six-month period following the beginning of commercial operation.

The regulations require that at least 15 hours' program service per week shall be rendered by each station.

The Commission adheres to the policy set forth in its report on the April, 1940, television hearing regarding multiple ownership or control of television broadcast stations. Under this policy no person is permitted to own or control more than three television broadcast stations.

This is to preserve the public benefits of competition in the use of the limited number of channels available for television broadcasting.

The order and appropriate regulations carrying out the principles of this report were adopted by a unanimous vote of the Commission *en banc* in its meeting of April 30, 1941.

II. TELEVISION TRANSMISSION STANDARDS

The Television Channel

(*1*) The width of the standard television broadcast channel shall be six megacycles per second.

(*2*) It shall be standard to locate the visual carrier 4.5 megacycles lower in frequency than the unmodulated aural carrier.

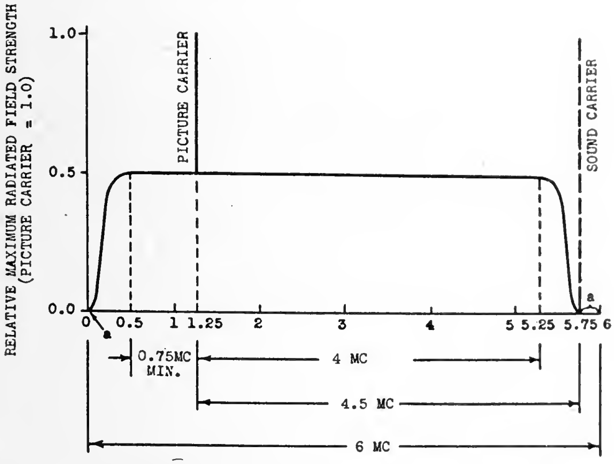

FIG. 1. Idealized picture transmission amplitude characteristic.
Relative field strength of picture side band not to exceed 0.0005. Drawing not to scale.

(*3*) It shall be standard to locate the unmodulated aural carrier 0.25 megacycle lower than the upper frequency limit of the channel.

(*4*) The standard visual transmission amplitude characteristic shall be that shown in Fig. 1.*

(*5*) The standard number of scanning lines per frame period shall be 525, interlaced two to one.**

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* In the use of any type of transmission permitted under Standards 9 and 15, the emissions (aural and visual) must be kept strictly within the 6 megacycle band authorized.

** The presently favored values for lines and for frame and field frequencies for experimentally field testing color transmissions are, respectively, 375, 60, and 120.

(*6*) The standard frame frequency shall be 30 per second and the standard field frequency shall be 60 per second.**

(*7*) The standard aspect ratio of the transmitted television picture shall be 4 units horizontally to 3 units vertically.

(*8*) It shall be standard, during the active scanning intervals, to scan the scene from left to right horizontally and from top to bottom vertically, at uniform velocities.

(*9*) It shall be standard in television transmission to modulate a carrier within a single television channel for both picture and synchronizing signals, the two signals comprising different modulation ranges in frequency or amplitude or both.*

(*10*) It shall be standard that a decrease in initial light intensity cause an increase in radiated power.

(*11*) It shall be standard that the black level be represented by a definite carrier level, independent of light and shade in the picture.

(*12*) It shall be standard to transmit the black level at 75 per cent (with a tolerance of plus or minus 2.5 per cent) of the peak carrier amplitude.

Aural Signal Modulation

(*13*) It shall be standard to use frequency modulation for the television transmission with a maximum frequency swing of 75 kilocycles.

(*14*) It shall be standard to preëmphasize the sound transmission in accordance with the impedance-frequency characteristic of a series inductance-resistance network having a time constant of 100 microseconds.

Synchronizing Signals

(*15*) It shall be standard in television transmission to radiate a synchronizing wave-form which will adequately operate a receiver which is responsive to the synchronizing wave-form shown in appended Fig. 2.

(*16*) It shall be standard that the time interval between the leading edges of successive horizontal pulses shall vary less than one-half of one per cent of the average interval.

(*17*) It shall be standard in television studio transmission that the rate of change of the frequency of recurrence of the leading edges of the horizontal syn-

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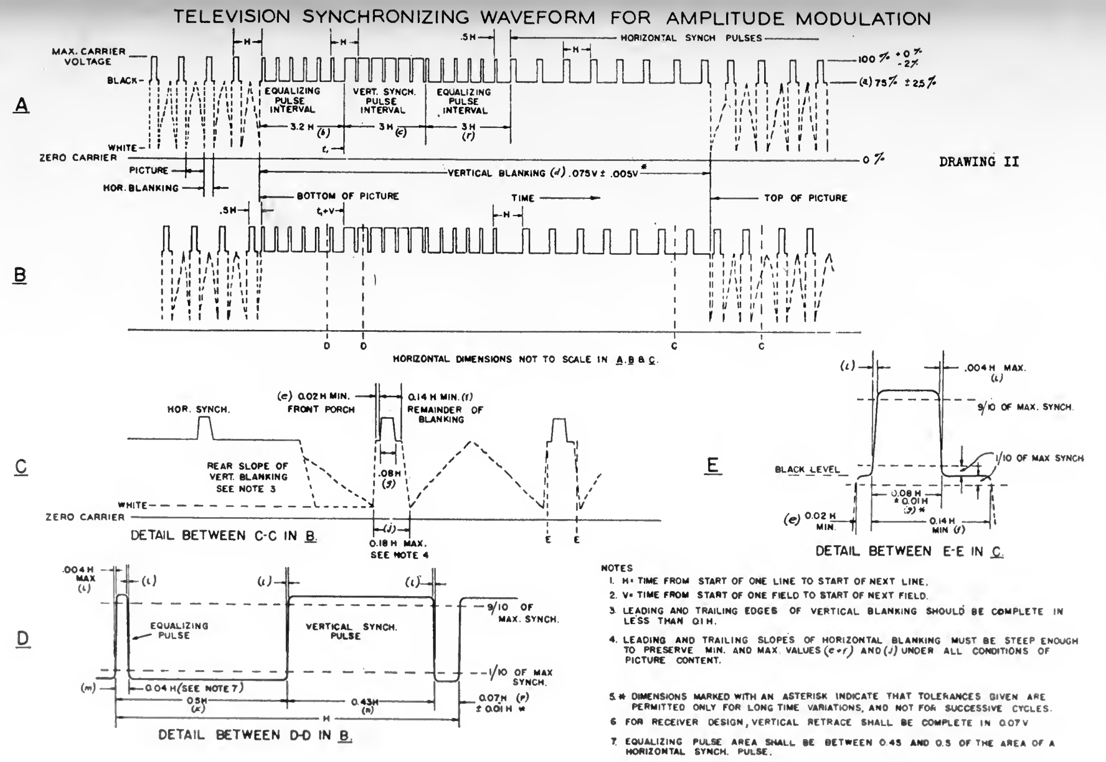
* Practical receivers of the "RA" type (those which attenuate the carrier 50 per cent before detection) designed for the synchronizing signals shown in Fig. 2 will also receive interchangeably any of the following:

(*a*) Amplitude modulated synchronizing and picture signals of the 500-kilocycle vertical synchronizing pulse type.
(*b*) Synchronizing signals of the alternate carrier type with amplitude modulated picture signals.
(*c*) Frequency modulated picture and synchronizing signals.

Each of the above signals will be permitted over a reasonable period for transmitting regularly scheduled programs as required by Sec. 4.261 (*a*) of the Rules and Regulations Governing Television Broadcast Stations.


TELEVISION SYNCHRONIZING WAVEFORM FOR AMPLITUDE MODULATION

DRAWING II

NOTES

1. H = TIME FROM START OF ONE LINE TO START OF NEXT LINE.
2. V = TIME FROM START OF ONE FIELD TO START OF NEXT FIELD.
3. LEADING AND TRAILING EDGES OF VERTICAL BLANKING SHOULD BE COMPLETE IN LESS THAN 0.1 H.
4. LEADING AND TRAILING SLOPES OF HORIZONTAL BLANKING MUST BE STEEP ENOUGH TO PRESERVE MIN. AND MAX. VALUES (e + f) AND (j) UNDER ALL CONDITIONS OF PICTURE CONTENT.
5. * DIMENSIONS MARKED WITH AN ASTERISK INDICATE THAT TOLERANCES GIVEN ARE PERMITTED ONLY FOR LONG TIME VARIATIONS, AND NOT FOR SUCCESSIVE CYCLES.
6. FOR RECEIVER DESIGN, VERTICAL RETRACE SHALL BE COMPLETE IN 0.07 V
7. EQUALIZING PULSE AREA SHALL BE BETWEEN 0.45 AND 0.5 OF THE AREA OF A HORIZONTAL SYNCH. PULSE.

FIG. 2. Synchronizing wave-form.

chronizing signals be not greater than 0.15 per cent per second, the frequency to be determined by an averaging process carried out over a period of not less than 20, nor more than 100 lines, such lines not to include any portion of the vertical blanking signal.

(*18*) It shall be standard to rate the visual transmitter in terms of its peak power when transmitting a standard television signal.

(*19*) It shall be standard in the modulation of the visual transmitter that the radio frequency signal amplitude be 15 per cent or less of the peak amplitude, for maximum white.

(*20*) It shall be standard to employ an unmodulated radiated carrier power of the aural transmission not less than 50 per cent nor more than 100 per cent of the peak radiated power of the picture transmission.

(*21*) It shall be standard in television broadcasting to radiate signals having horizontal polarization.

III. CHANGE OR MODIFICATION OF TRANSMISSION STANDARDS

The Commission will consider the question whether a proposed change or modification of transmission standards adopted for television would be in the public interest, convenience, and necessity, upon petition being filed by the person proposing such change or modification, setting forth the following:

(*a*) The exact character of the change or modification proposed;
(*b*) The effect of the proposed change or modification upon all other transmission standards that have been adopted by the Commission for television broadcast stations;
(*c*) The experimentation and field tests that have been made to show that the proposed change or modification accomplishes an improvement and is technically feasible;
(*d*) The effect of the proposed change or modification in the adopted standards upon operation and obsolescence of receivers;
(*e*) The change in equipment required in existing television broadcast stations for incorporating the proposed change or modification in the adopted standards, and
(*f*) The facts and reasons upon which the petitioner bases his conclusion that the proposed change or modification would be in the public interest, convenience, and necessity.

Should a change or modification in the transmission standards be adopted by the Commission, the effective date thereof will be determined in the light of the considerations mentioned in sub-paragraph (*d*) above.

Following is a list of Television Broadcast Stations, at present operating, under construction, experimental, and relay broadcast.

SCHEDULE A

(AT PRESENT OPERATING)

Licensee and Location	Call Letters	Frequency (Kc)	Power Visual	Power Aural
Columbia Broadcasting System, Inc., New York, N. Y.	*W2XAB*	60,000–66,000 (Channel No. 2)	$7\frac{1}{2}$ kw	$7\frac{1}{2}$ kw
Don Lee Broadcasting System, Los Angeles, Calif. T. Hollywood, Calif.	*W6XAO*	50,000–56,000 (Channel No. 1)	1 kw	150 kw
National Broadcasting Co., Inc., New York, N. Y.	*W2XBS*	50,000–56,000 (Channel No. 1)	12 kw	15 kw
Philco Radio and Television Corporation, Philadelphia, Pa.	*W3XE*	66,000–72,000 (Channel No. 3)	10 kw	10 kw
Zenith Radio Corporation, Chicago, Ill.	*W9XZV*	50,000–56,000 (Channel No. 1)	1 kw	1 kw

SCHEDULE B

(UNDER CONSTRUCTION)

Licensee and Location	Call Letters	Frequency (Kc)	Power Visual	Power Aural
Earle C. Anthony, Inc., Los Angeles, Calif.	*W6XEA*	96,000–102,000 (Channel No. 6)	1 kw	1 kw C. P.*
Balaban & Katz Corp., Chicago, Ill.	*W9XBK*	60,000–66,000 (Channel No. 2)	1 kw	1 kw C. P.
Bamberger Broadcasting Service, Inc., New York, N. Y.	*W2XBB*	96,000–102,000 (Channel No. 6)	1 kw	1 kw C. P.
Columbia Broadcasting System, Inc., Chicago, Ill.	*W9XCB*	78,000–84,000 (Channel No. 4)	1 kw	1 kw C. P.
Crosley Corporation, Cincinnati, Ohio	*W8XCT*	50,000–56,000 (Channel No. 1)	1 kw	1 kw C. P.
Don Lee Broadcasting System, San Francisco, Calif.	*W6XDL*	50,000–56,000 (Channel No. 1)	1 kw	1 kw C. P.
Allen B. DuMont Laboratories, Inc., Washington, D. C.	*W3XWT*	50,000–56,000 (Channel No. 1)	1 kw	1 kw C. P.
Allen B. DuMont Laboratories, Inc., New York, N. Y.	*W2XWV*	78,000–84,000 (Channel No. 4)	1 kw	1 kw C. P.

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* C. P. = Construction Permit.

Licensee and Location	Call Letters	Frequency (Kc)	Power	
			Visual	Aural
Hughes Productions Division of Hughes Tool Co., Los Angeles, Calif.	*W6XHH*	60,000–66,000 (Channel No. 2)	10 kw	10 kw C. P.
Hughes Productions Division of Hughes Tool Co., San Francisco, Calif.	*W6XHT*	60,000–66,000 (Channel No. 2)	10 kw	10 kw C. P.
The Journal Company (The Milwaukee Journal), Milwaukee, Wis.	*W9XMJ*	66,000–72,000 (Channel No. 3)	1 kw	1 kw C. P.
Metropolitan Television, Inc., New York, N. Y.	*W2XMT*	162,000–168,000 (Channel No. 8)	250 w	1 kw C. P.
National Broadcasting Company, Inc., Washington, D. C.	*W3XMB*	60,000–66,000 (Channel No. 2)	1 kw	1 kw C. P.
National Broadcasting Company, Inc., Philadelphia, Pa.	*W3XPP*	102,000–108,000 (Channel No. 7)	1 kw	1 kw C. P.
Television Productions, Inc. (Area of Los Angeles, Calif.)	*W6XYZ*	78,000–84,000 (Channel No. 4)	1 kw	1 kw C. P.
WCAU Braodcasting Co., Philadelphia, Pa.	*W3XAU*	84,000–90,000 (Channel No. 5)	1 kw	1 kw C. P.

SCHEDULE C

EXPERIMENTAL TELEVISION BROADCAST STATIONS

Licensee and Location	Call Letters	Frequency (Kc)	Power	
			Visual	Aural
Allen B. DuMont Laboratories, Inc., Passaic, N. J.	*W2XVT*	78,000–84,000 (Channel No. 4)	5 kw	5 kw C. P.
Balaban & Katz Corp. (Area of Chicago, Ill.)		384,000–396,000	10 w	C. P.
Columbia Broadcasting System, Inc., Los Angeles, Calif.	*W6XCB*	162,000–168,000 (Channel No. 8)	1 kw condl.	1 kw C. P.
Farnsworth Television & Radio Corp., Ft. Wayne, Ind.		66,000–72,000 (Channel No. 3)	1 kw	1 kw C. P.
General Electric Company, Scotland, N. Y.	*W2XB*	60,000–86,000	10 kw	3 kw
Kansas State College of Agriculture & Applied Science, Manhattan, Kans.	*W9XAK*	50,000–56,000 (Channel No. 1)	100 w	100 w C. P.
Leroy's Jewelers, Los Angeles, Calif.	*W6XLJ*	230,000–236,000 (Channel No. 13)	1 kw condl.	1 kw C. P.

Licensee and Location	Call Letters	Frequency (Kc)	Power Visual	Power Aural
Purdue University, West Lafayette, Ind.	*W9XG*	66,000–72,000	750 w	750 w C. P.
RCA Manufacturing Company, Inc., Portable (Camden, N. J.)	*W3XAD*	321,000–327,000	500 w	500 w
RCA Manufacturing Company, Inc., Camden, N. J.	*W3XEP*	84,000–90,000 (Channel No. 5)	30 kw	30 kw
State University of Iowa, Iowa City, Iowa	*W9XUI*	50,000–56,000 (Channel No. 1) 210,000–216,000 (Channel No. 12)	100 w	
EXPERIMENTAL TELEVISION RELAY BROADCAST				
Balaban & Katz Corp. (Area of Chicago, Ill.)	*W9XBT*	204,000–210,000 210,000–216,000 (Channel Nos. 11 & 12)	250 w	C. P.
Balaban & Katz Corp. (Area of Chicago, Ill.)		384,000–396,000	10 w	C. P.
Columbia Broadcasting System, New York, N. Y.	*W2XCB*	336,000–384,000	6.5 w	C. P.
Don Lee Broadcasting System (Area of Los Angeles, Calif.)	*W6XDU*	318,000–330,000	6.5 w	
Allen B. DuMont Laboratories, Inc. (Area of New York, N. Y.)	*WIOXKT*	258,000–264,000 264,000–270,000 (Channels Nos. 15 & 16)	50 w	
General Electric Company, New Scotland, N. Y.	*W2XI*	162,000–168,00 (Channel No. 8)	10 w	
General Electric Company, Schenectady, N. Y.	*W2XD*	156,000–162,000 162,000–168,000	40 w	C. P.
National Broadcasting Co., Inc., Portable (Camden, N. J., and New York, N. Y.)	*W2XBT*	162,000–168,000	400 w	
National Broadcasting Co., Inc., New York, N. Y. (Port.-Mobile)	*W2XBU*	282,000–294,000	15 w	
Philco Radio and Television Corporation, Philadelphia, Pa.	*W3XP*	230,000–236,000 236,000–242,000 (Channels Nos. 13 & 14)	125 w	C. P.
Television Productions, Inc. (Area of Los Angeles, Calif.)	*W6XLA*	230,000–236,000 236,000–242,000	250 w	

CHARACTERISTICS OF INTERMITTENT CARBON ARCS*

F. T. BOWDITCH, R. B. DULL, AND H. G. MACPHERSON**

Summary.—*Although the carbon arc is usually considered as a continuous source of light, the experiments reported in this paper show that it may be used for the generation of light surges as well. If these surges are made to occur at a rate so fast that the arc stream does not have time to deionize between them, then the electrical circuit may be completely broken at the conclusion of each surge and closed again to initiate the next one. For longer periods between surges, a very low maintaining current is employed. The timing and duration of the light pulses are controlled by electronic switching of half-cycle current surges from an alternating-current supply.*

For a given size of carbon, much higher brilliancy and candle-power can be obtained in intermittent than in continuous operation; a brilliancy of 1600 candles per sq-mm is reported for a 7-mm carbon of the "Suprex" type. The efficiency of the intermittent carbon arc is limited by the thermal lag in the electrodes, in that they continue to radiate energy for a considerable period after the current is reduced to zero at the end of each surge.

The carbon arc is usually considered as a continuous source of light, although it is used only intermittently in motion picture photography and projection, the particular intervals of light usage being determined by the camera or projector shutter. Since as much as one-half of the light generated is wasted in this way, worth-while economies would appear to be possible by the elimination of this waste through the intermittent generation of light as needed.

Interest in such an intermittent light-source was further stimulated by the theoretical demands of a radically new system of motion picture photography, known as the "I-R" or "Increased Range System," sponsored by Dr. Alfred N. Goldsmith and others. In a typical application of this system, very short light-pulses of only one-eighth the duration of a single frame are required, separated by dark periods three times as long. Such a light-cycle, supplied by a continuous source and shutter, would necessitate the waste of 75 per cent of the generated light.

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received May 7, 1941.

** National Carbon Company, Inc., Cleveland, Ohio.

In attacking the general problem of an intermittent carbon arc, the idea was first conceived of employing an alternating-current source of suitable frequency with switching circuits permitting the delivery of heavy current surges to the arc during selected positive half-cycle intervals. Thus, while the arc would be maintained between surges at a low value of alternating current, it would operate as a direct-current high-intensity arc during the half-cycles when a heavy surge current was permitted to flow. A simplified diagram of the electrical circuit employed for this purpose is shown by Fig. 1.

In this figure, the carbon arc is shown in series with two ballast resistors, R_1 and R_2, across an alternating-current source. One of these resistors, R_2, may be intermittently short-circuited as desired through the switch S shown at the right. The combined resistors limit the current to a minimum value necessary to maintain the arc between surges; the single resistor R_1 determines the magnitude of the surge current which will flow while the switch S is closed. If rapid flashing of only one-half cycle duration is desired, then a simple knife-switch of the type indicated can not, of course, be used. A mercury-vapor switch of the ignitron type, however, completely satisfies all requirements as to capacity and speed and has been successfully employed in a number of circuits.

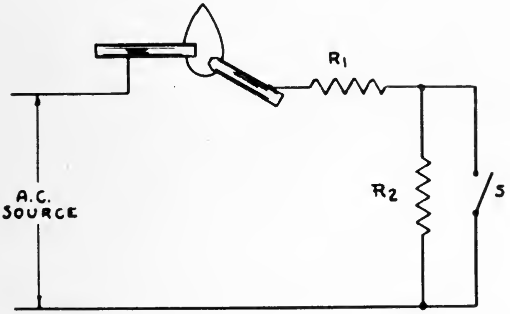

FIG. 1. Simplified circuit diagram of the intermittent carbon arc.

The complexity of the timing circuit which tells the ignitron when to short-circuit the ballast resistance is determined by the nature of the light-pulses required. For instance, if a surge is to be delivered every positive half-cycle, the ignitron and timing circuit can be dispensed with entirely and a simple half-wave rectifier used. However, if succeeding surges are to be separated by one or more idle cycles, then a more complex arrangement is required. A circuit found suited to this type of service is illustrated by Fig. 2.

In this circuit alternating voltage from the same source that supplies the arc is used to charge a condenser C through the transformer TR, the half-wave rectifier T_1, and the resistance R_3. This condenser is connected in the grid circuit of a mercury-vapor thyratron T_2 with polarity such that the condenser voltage opposes that of the negative bias battery B_1, reducing the negative grid potential of T_2 as the condenser charge increases until this thyratron is tripped. In tripping, current is permitted to flow into the ignitron firing electrode E, vaporizing the mercury and causing the ignitron T_4 to conduct, which short-circuits the ballast R_2. As the ignitron fires, the voltage across it drops to a value below the extinction point of thyratron T_2, so that this tube is extinguished. In the meantime, the voltage developed between the electrode E and the mercury pool during firing overcomes the bias voltage B_2, tripping the small argon-filled thyratron T_3 so that it may discharge the condenser C. Finally, at the end of one half-cycle, when the voltage across the ignitron falls to zero, it, too, is extinguished, so that all elements are returned to their initial condition ready to set off the next surge. The timing of this circuit may be adjusted in a number of different ways, since firing can not occur until the grid voltage of the thyratron T_2 reaches a specific minimum value. For instance, the secondary voltage of the transformer TR, the magnitude of the resistor R_3, and the magnitude of the condenser C may be independently adjusted to determine the number of half-cycle charging pulses needed to raise the condenser voltage to the critical tripping value. Also, this critical voltage

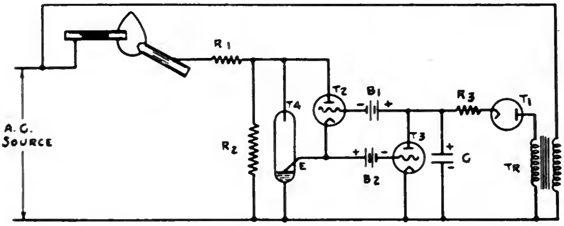

FIG. 2. Circuit diagram of the intermittent carbon arc with surge timing control at the beginning of any chosen half-cycle.

value may be adjusted by changing the voltage of the battery B_1 which must be overcome. By phase reversal through the transformer *TR*, the condenser is charged during half-cycles when the voltage is negative, so far as the main arc circuit is concerned; thus the condenser voltage remains steady during the positive half-cycles when firing might occur. In practice, circuit values are so adjusted that the voltage across condenser *C* is a little too low during the positive half-cycle just prior to the one when firing is desired, so that it will be appreciably above the required minimum when wanted.

The circuit just described insures that firing will occur very early in a predetermined half-cycle as desired. It will not, however, permit adjustment of the firing time throughout the duration of a half-cycle, and thus does not provide for a current surge lasting for only a predetermined fraction of a half-cycle. A circuit permitting such adjustment is shown by Fig. 3.

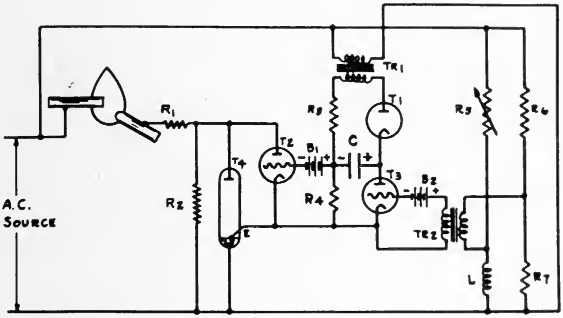

FIG. 3. Circuit diagram of the intermittent carbon arc with surge timing control at any time during any chosen half-cycle.

The left portion of this figure up to and including the thyratron T_2 is identical with that of the previous figure. Also that portion of the circuit including the transformer TR_1, the single-wave rectifier T_1, condenser *C*, and resistor R_3 constitute the essential timing circuit as before, but now operating to raise the plate voltage of thyratron T_3 to its tripping point, so that the resulting discharge through the resistor R_4 may trip T_2. The tripping of thyratron T_3, however, is also dependent upon the grid voltage pulse received each positive half-cycle through the transformer TR_2. This transformer has a constricted iron magnetic path giving a very peaked wave-form conducive to accurate timing of the voltage pulse, and the primary is supplied through the phase-shifting network composed of the four elements in Wheatstone bridge arrangement at the right. As with the previous circuit, the condenser C receives its charging pulses during negative half-cycles when the grid pulse applied to thyratron T_3 is of opposite polarity to that required for firing. On positive half-cycles, therefore, when firing might occur, the voltage across the condenser remains fixed, so that timing is solely controlled by the grid pulse. In operation, then, the thyratron T_3 receives a firing pulse once each positive half-cycle, in a phase relationship with respect to the source as determined by the setting of the phase-shifter circuit. If, during the preceding half-cycle, the voltage of the condenser C has risen to a sufficiently high value, the tube fires, tripping thyratron T_2 and ignitron T_4 along with it. The act of firing discharges the condenser, so that the circuit automatically clears itself, ready for the next sequence.

The time required for all these things to happen is, fortunately, only a matter of microseconds, from the firing of the first element in the chain of either one of the circuits described until the light-surge is emitted by the arc.

The choice of frequency of the alternating-current source is governed by the light-pulse timing required for a particular service. For instance, in motion picture projection at 24 frames per second, a 48-cycle source might be used, with current surges every positive half-cycle, giving a light-pulse of $^1/_{96}$-second duration as with the present 90-degree shutter. In the "I-R" system of motion picture photography previously described, a 96-cycle source with a half-cycle duration of $^1/_{192}$ second could be employed, with the timing circuit set to give surges during alternate positive half-cycles. Signalling applications might also be conceived in which any commercial frequency could be used, and the tripping of the ignitron controlled through the tapping of a telegraph key or other contacting device to give successive bursts of light, each consisting of a series of half-cycle surges.

The firing circuit shown in Fig. 3 is best adapted for experimental work, since it will do everything the simpler circuit can accomplish and, in addition, permits variation of the phase-angle at which the discharge through the arc starts. As previously mentioned, however, once the discharge has started it will continue until the end of the half-cycle, since there is no way of extinguishing the ignitron until the voltage across it falls to zero. Using the circuit of Fig. 3 and a

96-cycle source firing on alternate positive half-cycles, a series of measurements was made using the same ballast resistors in series with the arc, but starting the surge-current at different points after the start of the half-cycle. It was found that the peak candle-power during a surge is highest when the firing is started as soon as possible in the cycle, because of the greater crater area obtained. The peak intrinsic brilliancy, however, remains constant throughout a wide variation of starting phase-angle, from 30 to 75 degrees. When the arc is started at a large phase-angle, that is in the middle or toward the end of the half-cycle, it emits an intense throbbing noise at the flashing frequency, which gradually decreases to a minimum as the phase of starting is shifted toward the beginning of the cycle.

The circuits for the intermittent arc so far described call for the use of sustaining current between flashes, conducted through the ballast resistor R_2 of Figs. 1, 2, and 3. It was soon found, however, that when the flashes occur as often as every other cycle at 96 cycles per second, this sustaining current could be reduced to zero. That is, the resistor R_2 could be omitted entirely from the circuit, and flashes initiated from a complete open-circuit condition. The time between flashes is so short under these conditions that the arc does not have time to deionize completely, so that a conducting path remains for energy to fire the ignitron and then reëstablish the arc. It was also found possible to operate the arc with a small sustaining direct current, provided, of course, that the d-c sustaining source and the a-c surge source were otherwise electrically independent.

Two considerations proved to be important in determining which of these three arrangements was the best, *i. e.*, an alternating or a direct sustaining current, or none at all. In the first place, if it is desirable that the light between flashes should be kept as low as possible, then the arc should be operated without any sustaining current, since a minimum light between flashes is obtained in this way. However, this is possible only when the time between flashes is very short.

Another consideration of importance in this connection is that of the steadiness of the arc. One of the principal difficulties originally encountered was an unsteadiness in the light output associated with a wandering of the negative flame to various positions in front of and around the positive carbon, due to wandering of the cathode spot around the tip of the negative carbon. Apparently this spot did not remain anchored in one place when the current was reduced between flashes, since the current-density was then too low to load the negative carbon adequately. Using regular negatives, it was impossible to eliminate this unsteadiness so long as an alternating sustaining current or a zero sustaining current was used. The use of a direct sustaining current, however, held the cathode spot in one place, and eliminated this type of unsteadiness. It was found also that the use of a small-diameter copper-coated graphite negative was helpful in this respect, so that a reasonably steady arc could be achieved when no sustaining current was used. No means were found, however, for completely steadying the cathode spot when an alternating sustaining current was used.

Both positive and negative carbons for use with the intermittent arc must have sufficient current capacity to carry the rms or effective current without overheating. In cases where the surge current is passed through the arc at frequent intervals as in the "I-R System" application, it is desirable to use carbons of greater electrical conductivity than those of the same diameter conventionally used in d-c arcs. One of the best positive carbons for this purpose was a 7-mm "Suprex" with a copper coat of twice the usual thickness. When operated with no sustaining current, this carbon gave the steadiest performance without rotation, and in combination with a 5.5-mm copper-coated graphite negative at an angle of 20 to 30 degrees with the positive. At greater angles, a lip forms on the upper edge of the positive carbon, causing unsteadiness and a decrease in candle-power in a forward direction, while at an angle of less than 20 degrees, the negative flame is deflected first in one direction and then in another by the positive carbon, causing corresponding fluctuations in candle-power. The average consumption of the carbons with this trim, when surges with a peak current of 270 amperes were timed to occur every other positive half-cycle of a 96-cycle source, is 13 inches per hour for the positive carbon and 11 inches per hour for the negative carbon.

The appearance of the intermittent arc employing this trim is indicated by the photographs of Fig. 4. The first five photographs are side views of the arc, and give the appearance of the arc (*a*) just before the active half-cycle (−10 degrees); (*b*) at the start of the current surge (30 degrees); (*c*) at the peak surge current (90 degrees); (*d*) as the current is dying away (160 degrees); and (*e*) after the end of the conducting half-cycle (200 degrees). All pictures were made with the same exposure time, employing a specially constructed syn-

(*a*) Before surge starts. (−10°)

(*b*) As surge starts. (30°)

(*c*) At surge peak. (90°)

(*d*) Near cut-off. (160°)

(*e*) After cut-off. (200°)

(*f*) Before surge starts. (−20°)

(*g*) At surge peak. (90°)

(*h*) After cut-off. (210°)

FIG. 4. Photographs of the intermittent carbon arc at various phase-angles: 7-mm "Suprex" positive carbon; 270-ampere peak surge current (electrical degrees given beneath pictures refer to zero at beginning of surge half-cycle).

chronous shutter whose opening could be adjusted in phase along the time-cycle of events. The last three photographs show the front view of the positive crater: (*f*) before the start of the conducting half-cycle (−20 degrees); (*g*) at the peak current (90 degrees); and (*h*) after the end of the half-cycle (210 degrees). The photographic exposure is the same in all three of these pictures.

One of the most interesting characteristics of the intermittent arc is that it is possible to obtain much higher momentary values of intrinsic brilliancy and candle-power than can be obtained with the same carbons operating on direct current. The 7-mm "Suprex" carbon at 50 amperes' direct current produces 12,000 candle-power and a brilliancy of 600 candles per sq-mm. This same carbon, operated intermittently from a 60-cycle source and flashing the arc every fourth half-cycle, gives a peak candle-power of 70,000 to 75,000 and a peak brilliancy of 1350 candles per sq-mm at a peak current of 350 amperes. Flashing much less frequently, a maximum brilliancy of 1600 candles per sq-mm can be obtained from this carbon using a 675-ampere peak current.

The average light emitted during a light-pulse was measured by a photocell limiting the light reaching the active surface to a half-cycle by means of a sector opening in a synchronously driven disk placed in front of the cell. Measured in this way, the trim shown in Fig. 4 has an average candle-power of 26,000 during the surge half-cycle. During the first half-cycle of the inactive period between surges, the average candle-power is 3100, or 12 per cent of the candle-power during the current surge. The candle-power during the second and third half-cycles following the surge is 2400 and 2200, 9 per cent and 8 per cent, respectively, of the average surge candle-power. The brilliancy during the active half-cycle averages 660 candles per sq-mm, while the brilliancy during the succeeding three inactive half-cycles is 20, 12, and 10 per cent of this, respectively. When a sustaining current is used, the light between surges is still greater. The time-interval between current surges is evidently too short to allow the carbons to cool below incandescence; and since, with zero current between surges, re-ignition depends upon maintaining ionization during the inactive period, this is obviously an inherent characteristic of the intermittent arc on such a time-cycle of operation.

A test of the intermittent arc in an optical system was made, using a 14-inch Fresnel lens. The lens had a focal length of 14 inches and was placed $10^1/_2$ inches from the crater. At this distance the lens picks up a 70-degree cone of light from the positive carbon and projects a beam having an angular spread of 20 degrees. During the active half-cycle, a quantity of light equal to 88 lumen-seconds was projected in the beam per light-pulse. The light projected during the succeeding three inactive half-cycles was 14, 10, and 9 per cent of this, respectively.

These measurements of the light radiated during the inactive, or dark half-cycles, as well as the photographs of Fig. 4, indicate that the carbons do not cool to a very great extent between surges at the frequency employed in these experiments. Although this "thermal lag" is of use in permitting the reëstablishment of the arc after short periods with no sustaining current, it seriously reduces the efficiency of the intermittent arc in comparison with a d-c arc with a shutter when the duration of the light-pulses is of the same order of magnitude as the time between pulses. Comparisons made between the intermittent arc of Fig. 4 and an 11-mm high-intensity d-c arc with a shutter giving the same light-cycle produced the following result. Considering only the surge-light of the intermittent arc and the light passed by the shutter from the d-c arc, the intermittent arc was 1.6 times as efficient as the shuttered d-c arc in terms of candle-power-hours per watt-hour. Since current flowed only one-fourth of the time for the intermittent arc, a 4:1 instead of a 1.6:1 advantage over the continuous arc might have been anticipated, since three-fourths of the light generated in the latter case is wasted. That this did not prove to be the case is due to the thermal lag of the intermittent arc, which causes it to radiate energy between flashes.

The basis for expecting a 4:1 efficiency advantage for the intermittent arc over the shuttered d-c arc in this service depends upon obtaining the same instantaneous light for a given instantaneous current through the arc in both cases. This implies that the light is directly produced by the current. However, conditions in the arc which determine the production of light are essentially thermal in character, and the same atomic and molecular processes would take place, giving the same light, if the carbons and their associated gases were heated to the same temperature by any means whatsoever. Electrical means is ordinarily used for this heating, because it is most convenient. Light production, then, is a result of the temperature and its distribution, in an atmosphere provided by the controlled evaporation of core material from the positive carbon; there is no other connection between current and light.

In operation, heat is lost from the arc by radiation, convection, and conduction along the carbons at a rate depending upon the temperature of the various parts. These losses must be supplied by the current input in order to maintain the arc at a temperature suitable for light emission and for the evaporation of sufficient flame material. Calculations based upon radiation theory indicate that a black body at the temperature of the carbon electrodes during the active period of the intermittent arc will continue to lose radiant energy at substantially the same rate during the idle interval between flashes for the time-cycle just described. This is confirmed both by the photographs of Fig. 4, and by actual measurements of electrode temperature *vs.* time taken optically with a synchronous shutter. If the heat losses from the intermittent arc could be confined to the surge periods, then the anticipated efficiency advantage over a shuttered d-c source would be realized. However, the losses do continue during the intermediate periods, and at almost the same rate as during the surge periods. Consequently, in order to maintain the required temperature when wanted, additional energy must be supplied during the surge period to overcome these losses.

These remarks apply, of course, only to those applications where the time between light-surges is very short, as in both motion picture projection and the special photography application discussed. It is believed that they will apply to any situation in which the time between flashes is short enough to permit restriking without a maintaining current. As the time between flashes increases, however, the potential economy of the intermittent arc increases at a rapid rate, so that if and when such applications arise, the intermittent carbon arc may find commercial utility. In the meantime, it has provided a most interesting means for the advancement of fundamental arc theory.

DEVELOPMENT AND CURRENT USES OF THE ACOUSTIC ENVELOPE*

HAROLD BURRIS-MEYER**

***Summary.**—A technic is described by which acoustic conditions surrounding singers and instrumentalists during performance may be made to approximate those of a highly reverberant studio, irrespective of the normal acoustic characteristics of the theater, stage, or studio in which the performance takes place.*

The acoustic envelope is a curious and useful product of the sound research being conducted at Stevens Institute. Its applications have still to be thoroughly explored, but at the moment they seem to be much wider than originally contemplated. Working with the acoustic envelope has, moreover, led us into a most interesting series of studies based upon the observation that, to get a satisfactory performance of any sort in the theater, it is no less important that the performer hear what he needs to hear than it is to control the auditory component of the show for the audience.

Concert singers and instrumentalists perform, by choice, in small highly reverberant rooms since, in them, they are able to hear themselves easily. This phenomenon is familiar to all who have indulged in the popular pastime of "singing in the bath." With the same unanimity with which the artists prefer small, highly reverberant rooms, they deplore the acoustic conditions of most large concert halls and auditoriums.

The nature of the complaint is that the artist can not hear himself. The results of not being able to hear are the catalog of the artist's woes: tension, inability to relax, a feeling of being ill at ease, of low vocal efficiency, forcing the voice in an effort to project, using a higher key than is best for the song in an effort to get out more volume and fill up the house. Some singers carry all the pieces in their repertoire in a number of keys, and use the key that is nearest the res-

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received May 16, 1941.

** Stevens Institute of Technology, Hoboken, N. J.

onance frequency of the hall, despite the fact that few singers can sing the same piece equally well in more than one key.

It would be a boon to musicians performing in public or before the broadcast, recording, or motion picture microphone if they could be surrounded by acoustic conditions characteristic of the small studio, especially if this could be accomplished without affecting the acoustics of any area except that occupied by the artist.

Several years ago, Mr. Paul Robeson discovered that if he stood in front of the loud speaker of the public address system being used in a concert, he enjoyed some of the desirable acoustic conditions usually associated with the small studio. On the occasion of the stereophonic recording of the first forest scene from *The Emperor Jones*, we discussed the possibility of using this phenomenon to surround the performer by an acoustic envelope tailored to his demands. Experiments were conducted last August in the Maplewood (N. J.) Theater, which has many acoustic limitations. Simple equipment was then devised for Mr. Robeson and used in two out-of-town concerts and, for the first time in New York, at Carnegie Hall on October 6th, and thereafter throughout Mr. Robeson's concert tour.

When we tried to make the singer think he was in a small studio, it was first necessary to find out what it is about the acoustics of the small, reverberant room that is significant as far as the artist is concerned. We controlled individually the intensity of the sound as the artist heard it, and the frequency of the sound (*i. e.*, response curve); we varied the direction from which the sound came to the artist and the distance from which it came to him, which resulted in a time-interval at the artist's position between the original and the reproduced sound. We found that the artist would hear himself if he could perceive a difference in any characteristic of sound between the original sound as it left him and the reproduced sound as it came back. It is the difference which counts.

Once it was established that the artist's ability to hear himself depends upon a difference, it became a simple problem to find those differences most useful in making an acoustic envelope to surround the artist. Obviously, it must be possible to isolate the envelope surrounding the artist completely from the audience; that is, acoustic conditions in the audience part of the theater must not be affected. It must be impossible for the audience to be aware of the presence of any sound-control equipment; and the task must be accomplished with simple portable equipment.

Intensity differences are not useful. When the reproduced sound is less intense than the original, the artist can not hear it; when it is more intense, the artist is satisfied but the audience hears the reproduced sound.

Time differences are useful. If the artist hears the reproduced sound later than the original one, he is perfectly satisfied, even though the reproduced sound be of lower intensity than the original. This seems logical since such time difference is a characteristic of reverberation or room resonance.

Present practice indicates that the total distance from singer to microphone, and loud speaker to singer, need only exceed the distance travelled by the first reflected sound-wave, which is usually to the floor and back again.

Experiments involving frequency control at low intensity have shown that the presence or absence of low frequencies is not apparent except in the case of excessively loud reproduction. Overemphasized frequencies of 1500 cycles and up can be heard at low intensity. Low frequencies lack directional characteristics and, even with a highly directional speaker, will be heard in the audience if they have to travel more than a very short distance before reaching the artist. Moreover, they are not readily absorbed by wall surfaces or audience so, if they do get to the audience, the audience is aware of them. Also, when a footlight microphone is used, the system will pick up low-frequency sounds transmitted by the floor if the system responds to low frequencies. For these reasons, low frequencies are not used. High frequencies are directional enough to be kept away from the audience and are absorbed readily enough so that they are below background if they ever do get out. It is also interesting to note that in judging the quality of his own voice, the singer seems to feel a particular need for harmonics returned to him acoustically or electronically. We believe this to be so because highs are so readily absorbed. Replacing the highs for the singer then constitutes compensating for the acoustic limitations of the stage.

By eliminating unwanted characteristics, we are left with a system that (*1*) feeds sound back to the artist through 15 or more feet of air, and can limit the zone it affects so the audience can not hear it; and (*2*) has a response curve cut off below 500, and peaked above the highest fundamental note which can be sung, so that the significant harmonics are the only part of the sound that comes back.

The response curve is not particularly critical, although the one used in Fig. 1 is the result of quite thorough exploration of the frequency spectrum. It is cut off below 500 cycles, has a flat peak at 2000 cycles from which it drops off slowly, and is down 10 db at 6000 cycles. The attenuation at the upper end is a characteristic of the inexpensive equipment used and has no other significance. The singer seems to hear himself quite as well with this response as if the upper end of the spectrum were in. The technic is fully effective when the sound level, at the position of the artist, is not measurably affected by turning the system on or off, whether the measurement be made at flat response or weighted for loudness in conformity with the ear curve.

A single speaker can effectively cover a sharply defined stage area of approximately 200 square-feet, outside of which it is impossible to tell by ear whether the system is on or off. A single footlight microphone can respond effectively to music emanating from any point within that area. A level set well below the point of regeneration for the empty house is safe, and more than adequate for the full house.

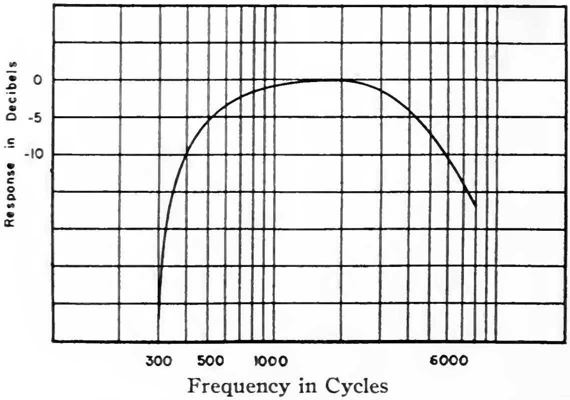

FIG. 1. Frequency characteristic of equipment used in the acoustic envelope.

Equipment in use at present consists of a crystal microphone, a 5-watt amplifier, and a moving-coil diaphragm loud speaker unit mounted on a small exponential horn. The overall response is as shown in Fig. 1. Further simplification of the apparatus is envisioned. The apparatus is generally disposed as shown in Fig. 2. The speaker is located at the side of the stage for convenience only. The system has been found to work satisfactorily with the speaker hung in the flies, mounted on a lighting tower, laid on the apron floor, hung under the fly gallery, or located onstage and pointed at a wing or back wall so that the sound is reflected to the artist.

In exploring the uses of the acoustic envelope, we first tried it on voices of all types in a number of theaters and concert halls, and found that the device was satisfactory except in the case of one radio performer whose technic is quite different from that of the concert artist. This performer was almost inaudible at a distance of 20 feet and could not tell whether the envelope was in operation or not.

Next we tried the envelope for a singer accompanied by full orchestra. In the first test, the singer, Paul Robeson, was satisfied, though the conductor, Eugene Ormandy, standing next to him, did not know there was any electronic device in operation. Radio pick-up was not affected and apparently can not be, so long as the microphone is outside the envelope area.

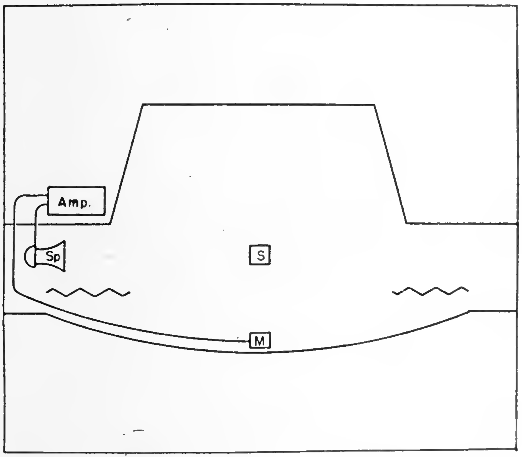

FIG. 2. Diagram showing instrument placement on concert stage for the acoustic envelope. *S* indicates position of singer.

In January the acoustic envelope was tried with a violinist at Town Hall, and later in the Stevens Theater. The artist's comment was that it made the violin sound better than that violin could sound, and that he felt the same added ease and freedom that singers experience.

Last Fall, when we undertook the problem of controlling backstage acoustics at the Metropolitan Opera House, we employed, among other devices, the acoustic envelope. Other phases of our work prevented a test covering the whole acting area, but, turned on individual artists during performance, the device performed so well that it has been written into the specifications for the permanent backstage sound-control system for the Metropolitan.

The only test made of the acoustic envelope in which performers were unaware of the fact that it would be used was in a joint concert of the Stevens and Barnard Glee clubs. The singers wondered why they sang so well.

Mr. Robeson suggested using the envelope as an aid to the actor in the spoken play, particularly in instances where the house was dead and the actor's role trying. Only one brief test of this use has been made at a rehearsal of *The Emperor Jones* in the Stevens Theater, but the results were sufficiently satisfactory to warrant further experiments which are contemplated.

Recording and broadcast studios generally have provision for the use of varying amounts of sound-absorbing or reflecting-wall surfaces, to control the brilliance of the music as the microphone gets it. Where the demands of the musician vary from what is wanted on the record or on the air, the acoustic envelope may prove helpful.

REFERENCE

This paper contains extensive quotations from "The Control of Acoustic Conditions on the Concert Stage," H. Burris-Meyer, *J. Acoust. Soc. Amer.*, **12** (Jan., 1941), p. 335, published through the American Institute of Physics. Figs. 1 and 2 are reproduced from the same source.

CURRENT LITERATURE OF INTEREST TO THE MOTION PICTURE ENGINEER

The editors present for convenient reference a list of articles dealing with subjects cognate to motion picture engineering published in a number of selected journals. Photostatic copies may be obtained from the Library of Congress, Washington, D. C., or from the New York Public Library, New York, N. Y. Micro copies of articles in magazines that are available may be obtained from the Bibliofilm Service, Department of Agriculture, Washington, D. C. at prevailing rates.

American Cinematographer

22 (May, 1941), No. 5

Breaking the Bottleneck of Fine-Grain Positive (pp. 210–211, 236)	W. Stull
Russia's Third Dimensional Movies (pp. 212–213)	S. Ivanov
Filming Infra-Red Night Effects in the Air (pp. 214, 236, 238)	E. G. Dyer
Hollywood's First Art Director (pp. 219, 238, 240)	J. Grant

Educational Screen

19 (May, 1941), No. 5

Motion Pictures—Not for Theaters (pp. 198–199), Pt. 27	A. E. Krows

Electronics

14 (May, 1941), No. 5

A Ruler for Record Patterns (p. 47)	D. R. King

International Projectionist

16 (March, 1941), No. 3

Some Common Projection Troubles Due to Power Line Deficiencies (pp. 7–8, 11)	L. Chadbourne
Effect of Abnormally High Filament Temperature on Tube Life (p. 12)	C. W. Scott
A.S.A. "Recommended Practice" for Motion Picture Projection (p. 14)	
RCA Theater Television: Program, Cast and Effect on Film Industry (pp. 15–16)	J. J. Finn
Coated Lenses in Photography: Their Effect upon the Screen Image (pp. 17–18)	C. G. Clarke

Journal of Physics

4 (1941), No. 3

A New Optical Mechanical System of Television (pp. 227–234)	O. B. Lurye

Kinematograph Weekly

291 (May 15, 1941), No. 1778

New Apparatus Demonstrated at B. K. S. Meeting (p. 26)

Kinotechnik

23 (March, 1941), No. 3

Die Messung der Bildwandleuchtdichte (Measurement of Screen Brightness) (pp. 33–37) H. ETZOLD

Untersuchung auslandischer Schmalfilmprojektoren in der Filmtechnischen Prufstelle der Reichsfilmkammer (Investigation of Foreign Substandard Film Projectors at the German Government Technical Film Testing Laboratory) (pp. 37–40)

Die Toneinrichtungen (Sound Equipment) (pp. 40–47)

Motion Picture Herald (Better Theaters Section)

143 (May 31, 1941), No. 9

Sealing Projection Room Ports Against Fire and Noise (pp. 36) J. J. SEFING

A Theater System for Television (pp. 41–42)

Philips Technical Review

5 (December, 1940), No. 12

The Blended-Light Lamp and Other Mercury Lamps with Improved Colour Rendering (pp. 341–347) E. L. J. MATTHEWS

FIFTIETH SEMI-ANNUAL CONVENTION

OF THE

SOCIETY OF MOTION PICTURE ENGINEERS

HOTEL PENNSYLVANIA, NEW YORK, N. Y.
OCTOBER 20TH–23RD, INCLUSIVE

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Hotel Reservations and Rates

Reservations.—Early in September, room-reservation cards will be mailed to members of the Society. These cards should be returned as promptly as possible in order to be assured of satisfactory accommodations. Reservations are subject to cancellation if it is later found impossible to attend the Convention.

Hotel Rates.—Special *per diem* rates have been guaranteed by the Hotel Pennsylvania to SMPE delegates and their guests. These rates, European plan, will be as follows:

Room for one person	\$3.50 to \$8.00
Room for two persons, double bed	\$5.00 to \$8.00
Room for two persons, twin beds	\$6.00 to \$10.00
Parlor suites: living room, bedroom, and bath for one or two persons	\$12.00, \$14.00, and \$15.00

Parking.—Parking accommodations will be available to those motoring to the Convention at the Hotel fireproof garage, at the rate of $1.25 for 24 hours, and $1.00 for 12 hours, including pick-up and delivery at the door of the Hotel.

Convention Registration.—The registration desk will be located on the 18th floor of the Hotel at the entrance of the *Salle Moderne* where the technical sessions will be held. All members and guests attending the Convention are expected to register and receive their badges and identification cards required for admission to all the sessions of the Convention, as well as to several *de luxe* motion picture theaters in the vicinity of the Hotel.

Technical Sessions

The technical sessions of the Convention will be held in the *Salle Moderne* on the 18th floor of the Hotel Pennsylvania. The Papers Committee plans to have a very attractive program of papers and presentations, the details of which will be published in a later issue of the JOURNAL.

Fiftieth Semi-Annual Banquet and Informal Get-Together Luncheon

The usual Informal Get-Together Luncheon of the Convention will be held in the Roof Garden of the Hotel on Monday, October 20th.

On Wednesday evening, October 22nd, will be held the Silver Anniversary Jubilee and Fiftieth Semi-Annual Banquet at the Hotel Pennsylvania. The annual presentations of the SMPE Progress Medal and the SMPE Journal Award will be made and officers-elect for 1942 will be introduced. The proceedings will conclude with entertainment and dancing.

Entertainment

Motion Pictures.—At the time of registering, passes will be issued to the delegates of the Convention admitting them to several *de luxe* motion picture theaters in the vicinity of the Hotel. The names of the theaters will be announced later.

Golf.—Golfing privileges at country clubs in the New York area may be arranged at the Convention headquarters. In the Lobby of the Hotel Pennsylvania will be a General Information Desk where information may be obtained regarding transportation to various points of interest.

Miscellaneous.—Many entertainment attractions are available in New York to the out-of-town visitor, information concerning which may be obtained at the General Information Desk in the Lobby of the Hotel. Other details of the entertainment program of the Convention will be announced in a later issue of the JOURNAL.

Ladies' Program

A specially attractive program for the ladies attending the Convention is being arranged by Mrs. O. F. Neu and Mrs. R. O. Strock, *Hostesses*, and the Ladies' Committee. A suite will be provided in the Hotel where the ladies will register and meet for the various events upon their program. Further details will be published in a succeeding issue of the JOURNAL.

PROGRAM

Monday, October 20th

9:00 a. m. *Hotel Roof;* Registration.

10:00 a. m. *Salle Moderne;* Technical session.

12:30 p. m. *Roof Garden;* Informal Get-Together Luncheon for members, their families, and guests. Brief addresses by prominent members of the industry.

2:00 p. m. *Salle Moderne;* Technical session.

8:00 p. m. *Salle Moderne;* Technical session.

Tuesday, October 21st

9:00 a. m. *Hotel Roof;* Registration.

9:30 a. m. *Salle Moderne;* Technical session.

2:00 p. m. *Salle Moderne;* Technical session.
Open evening.

Wednesday, October 22nd

9:00 a. m. *Hotel Roof;* Registration.

9:30 a. m. *Salle Moderne;* Technical session.
Open afternoon.

8:30 p. m. Fiftieth Semi-Annual Banquet and Dance.
Introduction of officers-elect for 1942.
Presentation of the SMPE Progress Medal.
Presentation of the SMPE Journal Award.
Entertainment and dancing.

Thursday, October 23rd

10:00 a. m. *Salle Moderne;* Technical session.

2:00 p. m. *Salle Moderne;* Technical and business session.
Adjournment

W. C. KUNZMANN,
Convention Vice-President

BACK NUMBERS OF THE TRANSACTIONS AND JOURNALS

Prior to January, 1930, the *Transactions* of the Society were published quarterly. A limited number of these *Transactions* are still available and will be sold at the prices listed below. Those who wish to avail themselves of the opportunity of acquiring these back numbers should do so quickly, as the supply will soon be exhausted, especially of the earlier numbers. It will be impossible to secure them later on as they will not be reprinted.

	No.	Price		No.	Price		No.	Price
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	20	1.25		26	1.25		34	2.50
1925	21	1.25		27	1.25		35	2.50
	22	1.25		28	1.25		36	2.50
	23	1.25	1927	29	1.25	1929	37	3.00
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Beginning with the January, 1930, issue, the Journal of the Society has been issued monthly, in two volumes per year, of six issues each. Back numbers of all issues are available at the price of $1.00 each, a complete yearly issue totalling $12.00. Single copies of the current issue may be obtained for $1.00 each. Orders for back numbers of *Transactions* and Journals should be placed through the General Office of the Society and should be accompanied by check or money-order.

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Test-Films.—See advertisement in this issue of the Journal.

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These films have been prepared under the supervision of the Projection Practice Committee of the Society of Motion Picture Engineers, and are designed to be used in theaters, review rooms, exchanges, laboratories, factories, and the like for testing the performance of projectors.

Only complete reels, as described below, are available (no short sections or single frequencies). The prices given include shipping charges to all points within the United States; shipping charges to other countries are additional.

35-Mm. Visual Film

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An optical reduction of the 35-mm. visual test-film, identical as to contents and approximately 225 feet long.

Price $25.00 each.

SOCIETY OF MOTION PICTURE ENGINEERS
HOTEL PENNSYLVANIA
NEW YORK, N. Y.

JOURNAL
OF THE SOCIETY OF
MOTION PICTURE ENGINEERS

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FANTASOUND*

WM. E. GARITY AND J. N. A. HAWKINS**

Summary.—*This paper discusses the multiple-speaker system known as "Fantasound," currently used with Walt Disney's "Fantasia."*

First are discussed some of the deficiencies of conventional sound-picture reproduction, and then a very complete history of the Fantasound development. In addition, are described in considerable detail the various important elements of the system.

The art of sound-picture reproduction is about 15 years old. While an engineer familiar with the complications of sound reproduction may be amazed at the tens of thousands of trouble-free performances given daily, the public takes our efforts for granted and sees nothing remarkable about it.

Therefore, we must take large steps forward, rather than small ones, if we are to inveigle the public away from softball games, bowling alleys, nightspots, or rapidly improving radio reproduction.

The public has to *hear* the difference and then be *thrilled* by it, if our efforts toward the improvement of sound-picture quality are to be reflected at the box-office. Improvements perceptible only through direct *A-B* comparisons have little box-office value.

While dialog is intelligible and music is satisfactory, no one can claim that we have even approached perfect simulation of concert hall or live entertainment. It might be emphasized that perfect simulation of live entertainment is not our objective. Motion picture entertainment can evolve far beyond the inherent limitations of live entertainment.

Before discussing the operation of the Fantasound equipment, some deficiencies of conventional sound-picture reproduction may be summarized:

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received April 25, 1941.

** Walt Disney Studios, Burbank, Calif.

(*a*) *Limited Volume Range.*—The limited volume range of conventional recordings is reasonably satisfactory for the reproduction of ordinary dialog and incidental music, under average theater conditions. However, symphonic music and dramatic effects are noticeably impaired by excessive ground-noise and amplitude distortion.

(*b*) *Point-Source of Sound.*—A point-source of sound has certain advantages for mon-aural dialog reproduction with action confined to the center of the screen, but music and effects suffer from a form of acoustic phase distortion that is absent when the sound comes from a broad source.

(*c*) *Fixed Localization of the Sound-Source at Screen Center.*—The limitations of single-channel dialog have forced the development of a camera and cutting technic built around action at the center of the screen, or more strictly, the center of the conventional high-frequency horn. A three-channel system, allowing localization away from screen center, removes this single-channel limitation, and this increases the flexibility of the sound medium.

(*d*) *Fixed Source of Sound.*—In live entertainment practically all sound-sources are fixed in space. Any movements that do occur, occur slowly. It has been found that by artificially causing the source of sound to move rapidly in space the result can be highly dramatic and desirable.

It is felt that Fantasound provides a desirable alternative to the four major deficiencies just described.

There have been other attempts to provide increased volume range and a broad sound-source. It appears that three separate program channels are an essential part of any solution to these sound problems. The matter of maximum usable loudness in the theater is closely related to the number of separate program channels used.

Three channels sound louder than one channel of three times the power-handling capacity. In addition, three channels allow more loudness to be used before the sound becomes offensive, because the multiple source and multiple standing-wave pattern prevents sharp peaks of loudness of long duration.

Three tracks and program channels have other advantages over a single-channel system. Cross-modulation between different sounds can be greatly minimized. Dialog, music, and effects could conceivably be placed upon separate tracks. It should be pointed out that single-frequency steady-state measurements of amplitude distortion do not necessarily give an indication of the amount of cross-modulation that may be present in a single channel. It has been found that low-frequency transients, caused by even-order overtones, can cause objectionable cross-modulation at levels somewhat below the nominal peak overload point of the amplifier.

For economic reasons, it is almost impossible to eliminate this source of cross-modulation from single-channel reproducing systems.

It is a simple matter to isolate conflicting program material on a three-channel system.

The use of three program channels allows phase differentiation to supplement amplitude differentiation in obtaining directional perspective. The phase differentiation also minimizes trouble with acoustic interference in the theater, which often accompanies attempts to use a multiplicity of horns on a single program channel.

THE DIFFERENTIAL JUNCTION NETWORK

The first step toward Fantasound occurred when we were asked to make a sound move back and forth across the screen. It was found that by fading between two speakers, located about 20 feet apart, we could simulate a moving sound-source, provided that the total level in the room remained constant. It became obvious at once that simple mechanical ganging of the volume controls feeding the two loud speaker circuits was not capable of producing the desired effect.

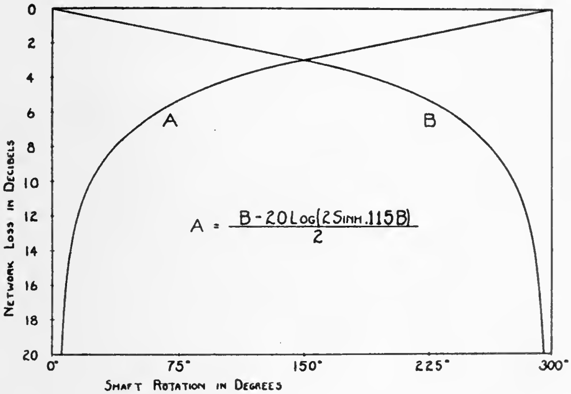


FIG. 1. Curves showing loss *vs.* shaft rotation of a typical two-circuit differential junction network. The cross-over point for the two losses is at -3 db.

A special two-gang volume-control was then designed with complementary attenuations in the two circuits such that the sum of the attenuations, *expressed as power ratios,* equalled a constant. The formula for the relationship between the two attenuations is:

$$A = \frac{B - 20 \log (2 \sinh 0.115B)}{2}$$

where A and B represent the two attenuations, expressed in decibels. Typical attenuation curves are shown in Fig. 1.

Many uses have been found for this type of network. It is extensively used in our Fantasound re-recording system to make constant output fades possible. A special 3-circuit differential junction network, nicknamed "The Panpot," is used to dub one original track onto one, any two, or all three of our Fantasound program tracks with smooth transitions and any desired level difference. Thus we simulate a moving sound-source by starting on either side-track and progressively moving the program material through the center-track to the other side-track. This move through three tracks, and thus three horns, is made smoothly by maintaining constant the *total* output of the three tracks and horns, regardless of the distribution among the three program circuits.

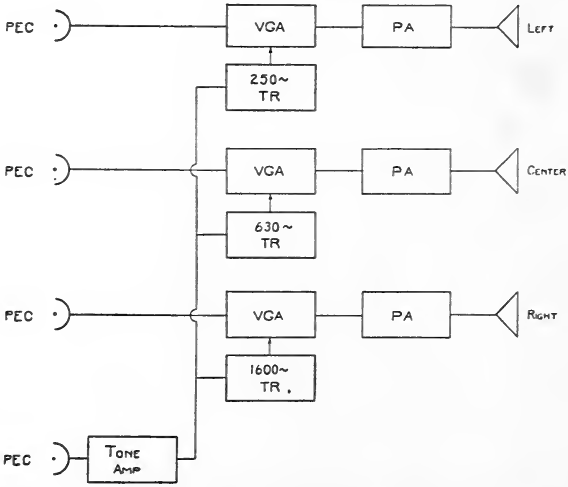


FIG. 2. Simplified block diagram of the Fantasound reproducing equipment.

The simple 2-circuit differential junction network has been used to make smooth, constant-level fades between two sound-sources. It also has been used to vary the ratio of close to reverberant microphone pick-up without affecting the output level. It was found to be a convenient means of controlling reverberation.

FANTASOUND REPRODUCING EQUIPMENT

A simplified block diagram of the reproducing equipment is shown in Fig. 2. On the left are shown the four photocells which scan three program tracks and a pilot control-track. Each program photocell feeds a variable-gain amplifier, then, through power amplifiers, the three-stage horns.

Associated with each variable-gain amplifier is a tone rectifier, which selects one of the three pilot tones on the control-track, rectifies it, and applies the resulting d-c control bias to the grids of the variable-gain stage. Thus the output from each loud speaker varies with the amplitude of its associated control tone.

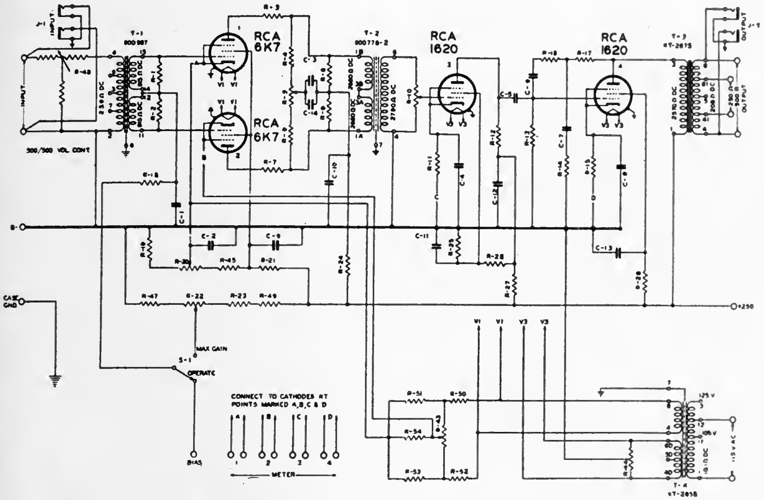


FIG. 3. Circuit diagram of the variable-gain amplifier.

TOGAD

The heart, or perhaps we should call it the brain, of the Fantasound reproducing equipment is the tone-operated gain-adjusting device, abbreviated, *Togad.*

The *Togad* equipment is composed of two units—the variable-gain amplifier and the tone rectifier. A sine-wave control-tone is applied to the input of the tone rectifier, where it is transformed into a d-c bias voltage. This d-c bias voltage is then applied to the variable-gain amplifier to vary its transmission. The equipment is arranged so that a 1-db change in tone level causes a 1-db change in program transmission through the variable-gain amplifier.

Variable-Gain Amplifier.—The variable-gain amplifier, abbreviated, *VGA*, is a single stage of transformer-coupled push-pull pentode voltage amplification (Fig. 3). Its transmission is a function of the d-c bias applied to its grid circuit. A variation of 50 db in the transmission through the *VGA* can be effected by changing the bias.

A two-stage, single-ended voltage amplifier follows the variable-gain stage and the three-stage unit has a maximum gain of 58 db and maximum power output of +6 db above 6 milliwatts.

The circuit features of the variable-gain stage include a balancing potentiometer in the plate circuit to balance out tone cross-talk; a loaded cathode resistor to provide high initial bias and low transmission in the absence of tone; and switches and bias potentiometers to test and adjust the bias-gain characteristic of the *6K7* variable-gain stage.

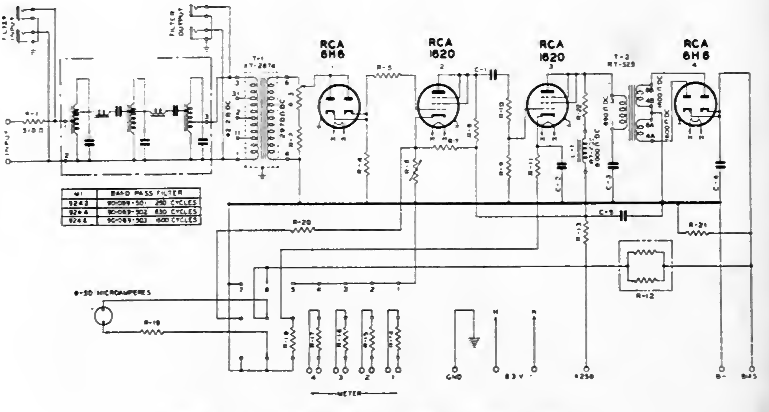


FIG. 4. Circuit diagram of the tone rectifier.

Normally, the maximum level applied to the *VGA* input terminals is about −45/0.006w, although up to about −30/0.006w the distortion is not excessive. Hum and tone cross-talk at this point are well below tube hiss.

The change in transmission, with bias, is the result of two effects occurring simultaneously. Raising the bias lowers the *mu* of the tubes, thus reducing the ability of the tubes to amplify. Raising the bias also raises the internal plate resistance, which increases the ratio of mismatch between the plate circuits of the tubes and the relatively low load resistance into which the tubes look. The combination of these two effects makes the transmission a complex inverse function of the bias.

It might be noted that screen and bias regulation have a marked effect upon the bias-transmission characteristic. The external control bias, obtained from the tone rectifier, is used to "buck out" a semi-fixed bias obtained from a cathode tap on the plate supply bleeder.

The Tone Rectifier.—The tone rectifier (Fig. 4) contains four important elements:

(*a*) A band-pass filter in the input circuit designed to select the proper control tone and reject noise and the unwanted tones.

(*b*) A compressing amplifier, using a *6H6* and a *1620* tube. The output of this amplier varies approximately as the logarithm of the logarithm of its input. The *6H6* half-wave rectifier cuts off the negative half-cycles of tone and the remaining positive half-cycles are applied to the grid of a *1620* triode functioning as a grid current compressor. Contact potential and gas current in both *6H6* and *1620* tubes are balanced out by the variable cathode-bias resistor in the *1620*. This particular log-log amplifier was devised by Kurt Singer.

(*c*) A *1620* triode amplifier, transformer coupled.

(*d*) A *6H6* full-wave rectifier, whose d-c bias output is fed to the variable-gain amplifier.

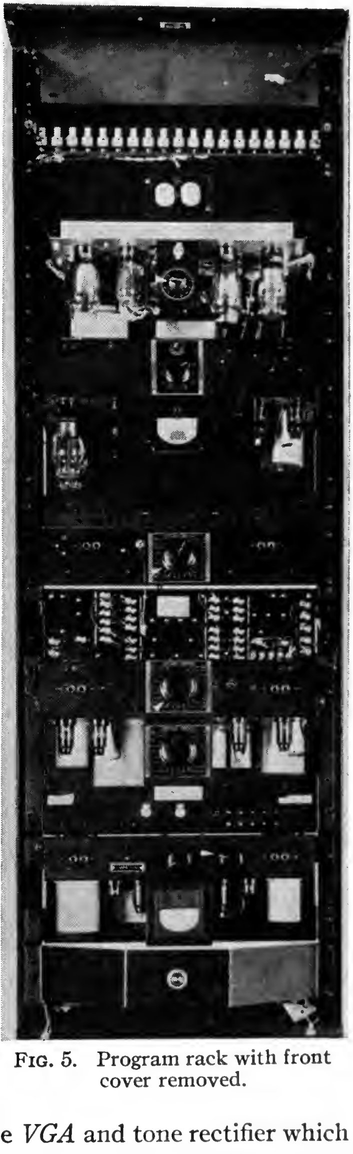


FIG. 5. Program rack with front cover removed.

There are many time-constants in the *VGA* and tone rectifier which contribute to the total "operate" and "restore" time-constants of the combination. However, all but the time-constants associated with the *6H6* rectifier ripple filter are so small, relatively, that they may be neglected. The *RC* products of both charge and discharge circuits are approximately equal and the "operate" and "restore" times are about 15 milliseconds.

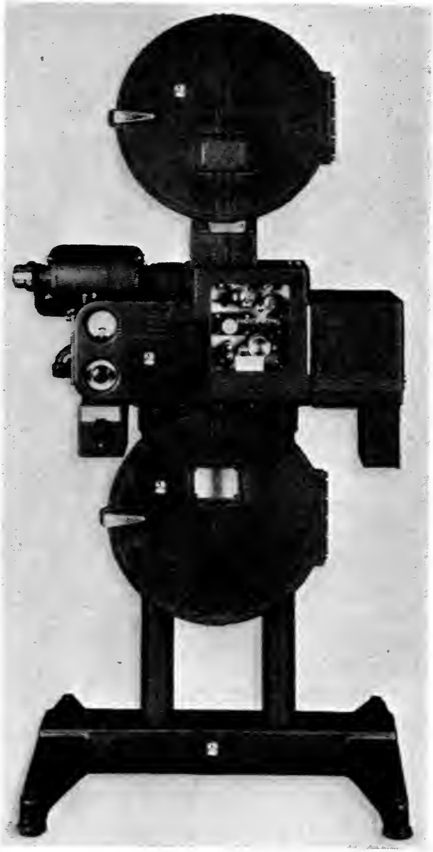


Fig. 6. Film-phonograph.

Fig. 5 shows most of the equipment used in one program channel. The topmost panel contains a pilot light. Below that is shown the tone rectifier unit. Next below is the variable-gain amplifier, which has two volume-control knobs in the center. Immediately below the *VGA* is an equalizer panel. Below that is a volume-control panel, and next below is a 20-watt power-amplifier. The lowest shelf contains a regulated plate supply.

In addition to the equipment shown in this rack, a program channel normally includes a single stage of preamplification ahead of the *VGA* and a 60-watt power-amplifier following the 20-watt amplifier. The front cover, normally used on this rack, is not shown in Fig. 5.

MULTIPLE-TRACK FILM-PHONOGRAPH

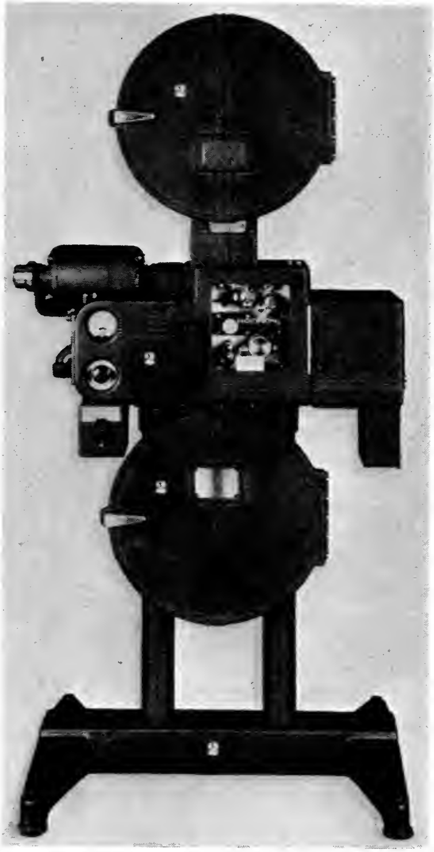
This film-phonograph, shown in Fig. 6, scans four 200-mil push-pull sound tracks simultaneously on one 35-mm print. It is driven in synchronism with a picture projector by means of a selsyn interlock system. The lamp and film compartments are shown in Fig. 7.

Film Drive.—The sound-tracks are scanned on a curved film-gate. Constancy of film movement is obtained by the use of a magnetically driven drum which draws the film down over the gate. Flutter measurements indicate that this is a highly satisfactory driving and scanning arrangement.

Optical System.—A single 10-volt, 5-ampere exciter lamp mounted in a double holder in the left compartment of the sound-head provides the illumination. All four sound-tracks are scanned simultaneously by a single optical system of the slitless type. The optical train consists of a light-collecting optical system which images the lamp filament as a long beam of light $1^1/_4$ mils high across the four sound-tracks. The illuminated image of the sound-tracks is then projected by a camera and cylindrical lens system onto four multiple beam-splitter lenses which, in turn, focus each half of the push-pull sound-tracks upon the respective cathodes of four push-pull phototubes (Fig. 8).

OPTICAL PRINTER

The Fantasound optical printer is designed to print four double-width sound-tracks side by side across the useful area of a 35-mm film, from negatives having a standard width sound-track in the standard location. The way in which this is accomplished may most easily be explained with reference to Fig. 9, which shows the printer threaded for operation in one direction. The negative passes around under the upper drum and is illuminated by an illuminating system enclosed in the lamp-house. Below the upper drum is the optical system which projects an image of the sound negative upon the positive raw-stock the *6H6* rectifier ripple filter are so small, relatively, that they may be neglected. The *RC* products of both charge and discharge circuits are approximately equal and the "operate" and "restore" times are about 15 milliseconds.



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Traversing Mechanism.—On the left of the upper mechanism (Fig. 9) is the traversing lever which controls the position of the image on the positive raw-stock. By raising this lever and moving it forward and backward, the entire upper mechanism and optical system are moved forward or backward across the film to be printed. The traversing mechanism provides four locking positions for the upper mechanism spaced 0.200 inch apart so that the resulting sound-tracks are spaced 0.200 inch apart on the print.

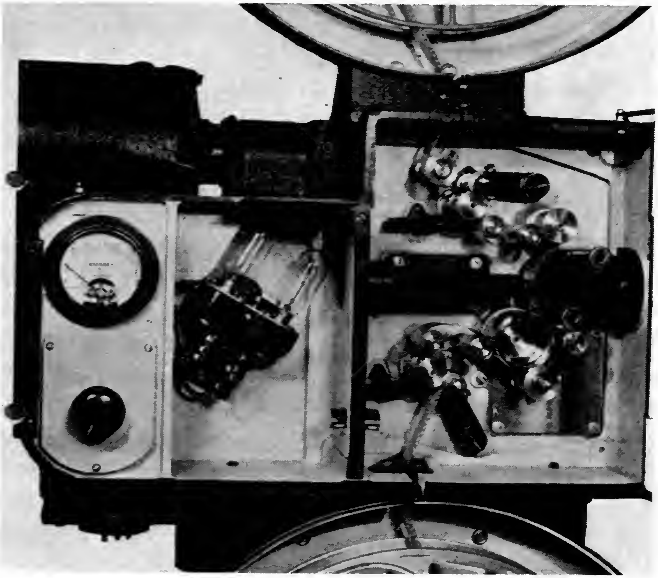

FIG. 7. Lamp and film compartments of film-phonograph.

Reversing Mechanism.—The printer is designed to print negatives either forward or backward; *i. e.*, either "heads" or "tails" out, at 90 feet per minute. It incorporates simplified threading in that regardless of the direction of printing, the threading is always done in one standard manner with tight film loops. Then by operating one lever, the correct film paths and loops are formed for either direction of film travel.

Fig. 10 shows the threading position. In this view, the arrow-shaped lever is shown in a vertical position. With the reversing lever in this position, the four loop-forming rollers, guide-rollers, and pressure-rollers assume the positions shown. The negative and raw-stock are threaded as shown, over the sprockets, loop-forming rollers, and drums. It will be noted that the film loops are fairly tight when the sprocket pad-rollers are closed. Also, on each side of each drum, the film lies between the flanges of a guide-roller.

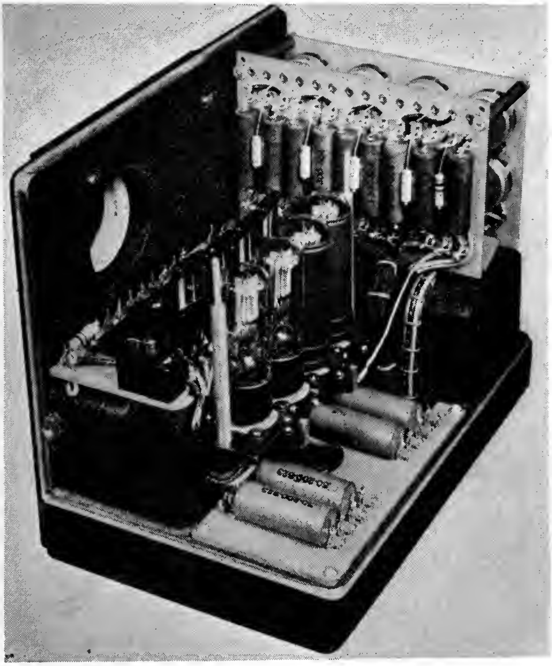

FIG. 8. Phototube compartment of film-phonograph.

Automatic Blooping.—Automatic blooping of splices is provided on the printer. Two blooping switches are shown in Fig. 9. These switches are designed to close when a double thickness of negative at a splice passes the switch rollers. When printing to the left, the right-hand blooper switch operates; whereas, when printing to the right, the left-hand switch operates. In either direction, when the portion of the printing stock on which the image of the splice will fall, passes the end of the blooper tube (Fig. 9), the light in the blooper tube lights and blacks out the image of the splice. A time-delay mechanism synchronizes the bloop and the splice. In series with the blooper lamp is the blooper indicator lamp, also shown on Fig. 9.

Direction Indicator.—On the lower right-hand sprocket is mounted a small lamp-house for exposing an arrow-shaped image on the guiding edge of the print. An arrow-shaped detent is ground on the outer edge of the sprocket and is so arranged that an arrow will appear on the print every 32 sprocket-holes, pointing toward the start, or in the direction of travel of the print when being reproduced.

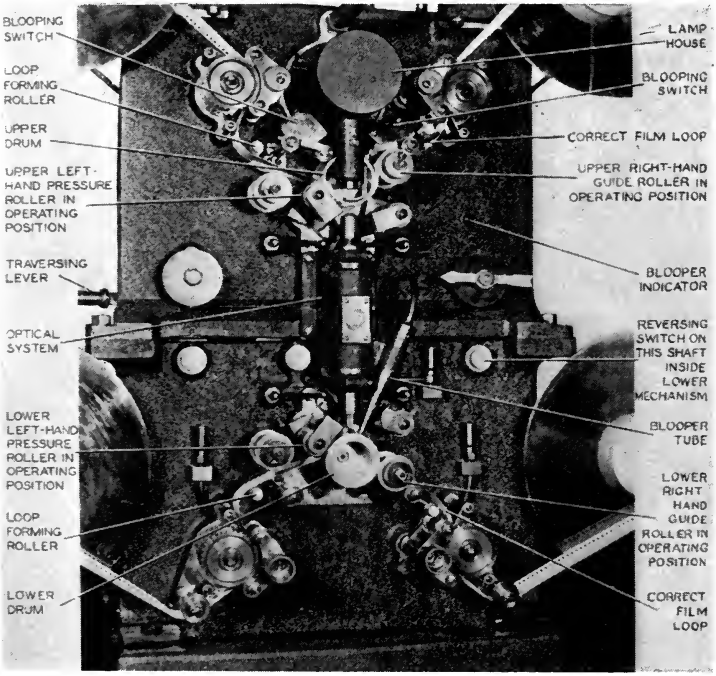

Fig. 9. Optical printer in operating position for printing to the left.

Lamp-House and Optical System.—The lamp used is the standard 10-volt, 7.5-ampere, curved-filament exposure lamp, and is housed in the light-proof lamp-house above the upper drum.

The functions of the various lenses will be explained, starting at the lamp end of the optical train. The first is a plain window which keeps dust out of the illuminating system. Next is a reversing prism which rotates the image of the filament 90 degrees in a horizontal plane.

The next item in the optical train is the ultraviolet filter, followed by a plano-cylindrical lens which focuses the image of the filament in one plane only upon the negative.

Below the negative is the optical system for projecting the image of the negative upon the printing stock. The top lens system is used to project an enlarged (5 to 1) image of the negative on a plane approximately in the center of the optical system. At the center of the optical system is a condenser lens followed by an aperture. This aperture limits the illumination in both planes and is 0.471 inch long by 0.050 inch wide. The lower lens system images this enlarged image at the center of the optical system upon the printing stock and has a reduction ratio of 5 to 1 in the direction of travel of the

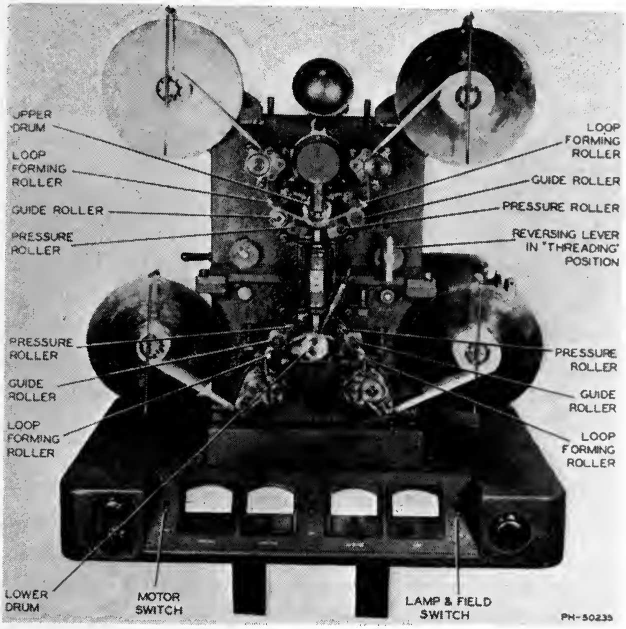

FIG. 10. Front view of MI-3817 optical printer showing threading position

film and a little less than 2.5 to 1 across the film. Thus the image of the negative on the printing stock has a ratio of 1 to 1 in the direction of motion of the film and a ratio of one to slightly over two across the film.

This printer has proved to be very free from flutter. The 9000-cycle loss from negative to print (corrected for 1000-cycle loss) averages less than one decibel.

HISTORY OF THE FANTASOUND DEVELOPMENT

Fantasound reproduction differs markedly in both results and equipment from standard theater reproduction. It may be of interest to follow the history of the development step by step.

A great many equipment combinations were explored on paper, probably several hundred. Of these, ten different systems have been built up and tried out, up to the time this paper was written. Even though *Fantasia* has been released, development has not stopped.

The *Mark I* system used three widely separated horns across the stage and horns in each rear corner of the house. Two tracks were used, one feeding the screen horn, or center-stage horn, while the other fed the remaining four horns selectively by means of a four-circuit differential junction network. By manipulating a manual control, the sound could be moved smoothly around the theater. Experiments with this system brought out the advantages of a broad sound-source.

The *Mark II* system was a simple expansion of the *Mark I* system, adding three horns; one on each side-wall about halfway back from the stage, and one in the ceiling at about the center of the house. These were in addition to the screen horn and four corner horns used in the *Mark I* system. This system used three tracks and a 6-circuit, manually controlled differential junction network. In addition to creating the effect of moving the sound *around* the theater, the controls allowed side to side movements in any plane between the screen and rear wall of the house. Simultaneous fore and aft control was also available.

Up to this time it was felt that the *Fantasia* roadshow equipment could be manually operated by a mixer who would go along with each show. He would provide manual volume range expansion as well as control the perspective effects. However, two objections to manual operation appeared. The five controls became rather complex for one man operation and the studio felt that it would be difficult to keep all shows alike, due to the large human element involved.

The use of a pilot tone-control arrangement was suggested to avoid these difficulties, and the *Mark III* system came into existence to study the advantages and difficulties of a pilot tone-control track.

This *Mark III* system was a single-channel *Togad* expander, controlled by either an oscillator or a tone track. Problems of cross-talk balance, tone-program amplitude characteristic, time-constants, distortion and noise compromise, and amount of range expansion desirable, *etc.*, were attacked.

The *Mark IV* system was identical with the 8-horn, 3-track *Mark II* system, except that *Togad* control replaced manual control. This system used 8 control-tones on the control track logarithmically spaced from 250 to 6300 cycles, using a preferred number series. This *Mark IV* system was installed in our Hyperion studios in the summer of 1939 and was used for sound and music department research until we moved to Burbank in 1940.

The equipment racks and sound-heads for this system required a floor space about 35 feet long by 4 feet wide. It used nearly 400 vacuum-tubes. All equipment appeared on jacks and almost any conceivable combination could be patched up in a few minutes.

The *Mark V* system, first installed at Burbank, was similar to the *Mark IV* system in that 8 horns, 3 program tracks, and an 8-tone control-track were used. However, by using 8 hybrid coils in the program circuits we obtained a still more flexible system. This system was in operation only one day. The equipment operated satisfactorily and no technical difficulties were encountered. The system failed only because the musical director, the music cutter, and the "enhancing mixer," could no longer remember from one rehearsal to the next, "What should come out where?"

From this extreme of complication, the pendulum swung to the *Mark VI* system, which used 3 stage horns, 3 program tracks, and a 3-tone control-track.

Our first serious dubbing of *Fantasia* was attempted on this system. Our original Fantasound dubbing set-up required 10 program mixers, each with 3 pots, designated "Left, Center, and Right" positional controls. In addition, 3 mixers with one pot each were used to handle the left, center, and right pilot tones. We soon found that the tremendous number of positional mixing cues made it nearly impossible for a mixer to handle 3 positional controls in such a way as to avoid undesirable discontinuties during moves. We then designed some differentially ganged 3-circuit pots, based on the differential junction network principle, which greatly simplified the mixing problem. This change allowed 6 mixers to satisfactorily control 24 program circuits.

The *Mark VII* system was the first of the RCA-manufactured systems. Functionally, this system closely resembled the *Mark VI* system. The only important difference lay in the use of a linear tone rectifier in place of the log-log rectifier used in our earlier systems. This changed the tone-program amplitude characteristic.

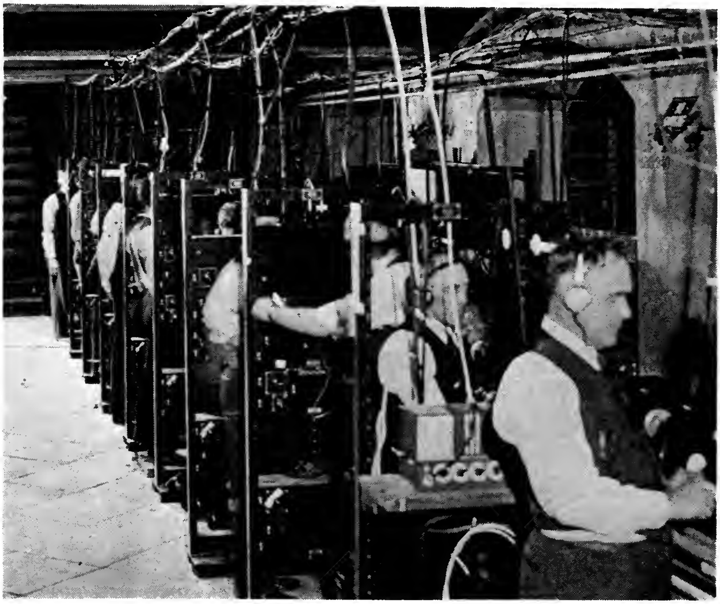

FIG. 11. View of eight recording channels at the Philadelphia Academy of Music.

The *Mark VIII* system consisted of the *Mark VII* equipment rearranged physically. An ingenious log-log tone rectifier, designed by RCA, replaced the linear tone rectifier used in the *Mark VII* set-up. The second dubbing of *Fantasia* was done through this system. After adding a stand-by channel, this equipment was installed in the *Broadway Theater* in New York for *Fantasia's* World Premiere.

The *Mark IX* equipment closely resembled the *Mark VIII* system.

The physical layout was again modified, a few minor changes were made, and two sets of rear-house horns were manually switched in to supplement or replace the left and right screen horns at several points in the picture. This system is operating in eight of the roadshows.

The *Mark X* system is identical with the *Mark IX* equipment, except that the switching and level changes in the rear horn circuits are done automatically instead of manually. The control arrangement uses a thyratron and mechanical relay system operated by means of notches on the edge of the film. This ingenious arrangement was developed by Messrs. Hisserich and Tickner of our engineering department. The *Mark X* system is installed at the *Carthay Circle* Theater in Los Angeles.

FIG. 12. View of some of the mixer positions at the Philadelphia Academy of Music.

SCORING AND DUBBING

Scoring.—All the numbers, except *The Sorcerer's Apprentice* and the vocal portions of *Ave Maria*, were scored at the Philadelphia Academy of Music. Eight push-pull variable-area recording channels were used (Fig. 11).

Separate channels recorded close pick-ups of violins, cellos and basses, violas, brass, woodwinds, and tympani. The seventh channel recorded a mixture of the first six channels and the eighth channel recorded a distant pick-up of the entire orchestra. The mixer handling the distant pick-up used horn monitoring, while the other mixers used headphone monitoring. Cathode-ray oscilloscopes were used as level indicators (Fig. 12).

The Sorcerer's Apprentice number was done in Hollywood on a somewhat similar multi-channel system. The *Ave Maria* vocal numbers were recorded on three channels: two close channels, separating male and female voices, with a distant overall channel for added reverberation.

FIG. 13. View of the 3-channel mixing position used in scoring the *Fantasia* vocal numbers at Burbank. (Messrs. Hawkins, Hisserich, and Marr.)

Fig. 13 shows the mixer arrangement used in recording the 3-channel vocal numbers. Three-channel horn monitoring was provided in our theater and the level-indicating oscilloscopes again proved valuable in avoiding overloads.

The necessity for checking the range compression on all channels during scoring and dubbing caused the development of a means whereby one man could visually monitor three oscilloscopes. By using color differentiation at the overload and underload points, eye fatigue was minimized. This was accomplished by masks on the face of the cathode-ray tube. An opaque mask eliminated everything below about 3 per cent modulation, including the complete negative, or downward, half-cycles. A translucent red mask covered the range from 3 to 100 per cent modulation on the positive half-cycles. Above 100 per cent modulation, the trace on the tube was not masked, and so was highly visible. Program material below 3 per cent modulation (100 per cent − 30 db) produced no visible indication. Material between 3 and 100 per cent modulation appeared as a white series of half-cycles, and modulation in excess of 100 per cent appeared as a brilliant green series of peaks. The recording, re-recording, and monitoring systems were poled so that the compression wave, referred to the original microphone, gave positive peaks on both oscilloscopes and galvanometers. This adaptation of the oscilloscope was devised by C. O. Slyfield. Over half a million feet of sound negative was exposed on our scoring channels on this picture.

FIG. 14. View of the program dubbing console in operation. (Tone console not shown.) (Left to right, at console, Messrs. Blinn, Steck, Marr, Perry, Moss, Hawkins, Slyfield, and Hisserich. At rear, Ed Plumb, *Musical Director;* Luisa Fiels, *Asst. Music Cutter,* and Stephen Csillag, *Music Cutter.*)

Dubbing.—Our re-recording process used 8 to 10 tracks, depending upon the sequence. Fig. 14 shows the re-recording console in operation. The output of the mixing panels fed three recorders, one for each horn channel, left, center, and right. Another channel recorded the tone track. These four re-recorded negatives were then printed on the composite quad print. The *Mark VIII* Fantasound reproducer was used for dubbing monitoring (Fig. 15). Including everything but release prints, about five million feet of film was used for this picture.

This history of Fantasound is far from complete. Another year and we shall know a great deal more about theater operating and maintenance problems on this type of equipment. To date, our operating and maintenance experience has been quite satisfactory.

FIG. 15. View of part of the dubbing monitoring equipment. (Messrs. Hawkins and Garity.)

We should like to acknowledge the suggestions and assistance of C. O. Slyfield, W. C. Lamb, Jr., C. A. Hisserich, H. M. Tremaine, P. J. Holmes, Melville Poche, H. J. Steck, and E. A. Freitas in the development of this system. We wish to express our appreciation to Walt Disney, whose vision and willingness to encourage technical development made this system possible.

VITASOUND*

NATHAN LEVINSON AND L. T. GOLDSMITH**

Summary.—*Two features that would add to the enjoyment and realism of sound in motion picture theaters are an increased volume range and a more widespread source of sound for music and effects reproduction. A method of accomplishing these aims is described which employs a control-track printed in the sprocket-hole area of the release print to operate a variable-gain amplifier and loud speaker control equipment.*

It has been long recognized in the motion picture industry that an increased dramatic use of sound in the theater would add to the enjoyment and realism of sound pictures. Two features that would contribute to this realism of music and sound effects are an increased volume range and a spreading of the source of sound.

W. A. Mueller[1] has pointed out that an increased volume range is neither necessary nor desirable for dialog reproduction, but that for music and sound effects an increase in the effective volume range of signal to auditorium or film noise of approximately 10 decibels is both practicable and desirable. As the volume range on the sound-track is limited by the available volume range of the film itself, an effective increased range can be secured by automatically raising and lowering the gain of the reproducing amplifiers in the theater.

The spreading of the source of sound can be accomplished by adding loud speaker systems outside the screen area. These added speakers, however, can reduce the illusion of the dialog coming from the screen if not properly placed and operated. The additional loud speakers may be automatically cut in the circuit for music and sound-effects and cut out of the circuit for dialog.

Additional reproducing equipment to accomplish these aims for the majority of feature films must be readily adaptable to the modern types of sound equipment found in the well equipped theaters. Also, the cost of the modification to the exhibitor must be a reason-

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received April 20, 1941.

** Warner Bros. Pictures, Inc., Burbank, Calif.

able one and the costs of operation, maintenance, and service must not be increased.

The Vitasound system was developed with the foregoing considerations in mind. A control-track printed in the sprocket-hole area of standard release prints is employed to operate a variable-gain amplifier to secure the increased effective volume range and to operate a loud speaker switching relay for extending the source of sound to loud speakers beyond the screen.

FIG. 1. Composite print with sprocket-hole control-track.

Fig. 1 shows three different sample widths of control-track as it appears on a standard composite release print. The two top frames have no operable control-track because the clear portion between the sprocket-holes is 110 mils wide, or as wide as the sprocket-holes themselves. The two central frames have a control-track 40 mils wide, which serves to cut in the side speakers automatically by means of the relay control. The two bottom frames have an almost completely closed or zero-width track which, in addition to operating the side speaker relay, is used also to increase the gain of the variable-gain amplifier by 10 db. Any intermediate width of control-track between 40 mils and zero may be printed to secure gain increases from zero to 10 db.

The control-track is scanned in the sound-head by a separate photocell at a point 14 frames ahead of the sound-scanning point. The point on the control-track corresponding to the sound on the sound-track is therefore printed 14 frames nearer the head end of the reel.

Fig. 2 shows the scanning bracket mounted in a sound-head around the hold-back sprocket. The scanning aperture is a 90 by 90-mil square opening cut in a shoe on the bracket which also supports a small 6–8-volt, 0.4-ampere lamp and a type *927* photocell. No optical system is necessary and the film is threaded over the sprocket in the normal manner.

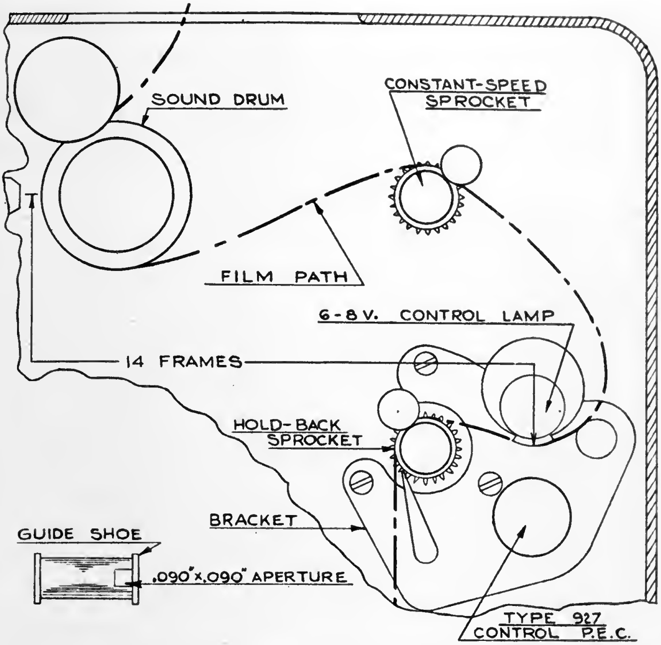

FIG. 2. Sound-head scanning bracket for sprocket-hole control track.

The control frequency is 96 cycles and varies in amplitude with the width of the clear portion of the film between the sprocket-holes. The output of the control-track photocell of each projection machine

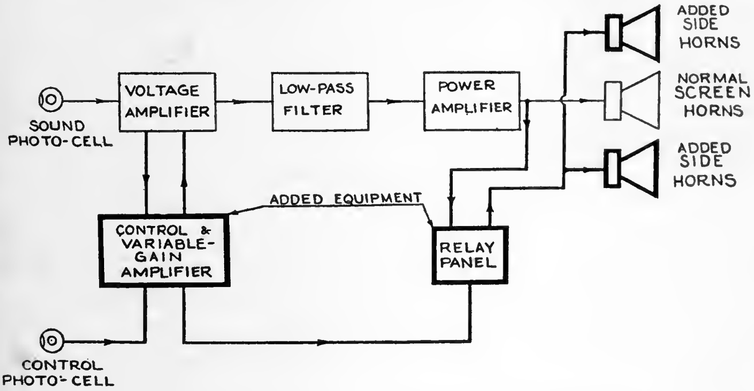

FIG. 3. Block diagram of control-track apparatus.

is connected by a low-capacity cable to a combination control-tone amplifier and variable-gain amplifier.

Fig. 3 is a block diagram of a typical sound-reproducing system modified for control-track operation. The heavy lines indicate the equipment added for Vitasound. The variable-gain amplifier has a normal zero insertion gain and is electrically connected in a 500-ohm link circuit between stages of the voltage amplifier. A speaker relay panel also operates from the control amplifier and closes the side horn circuit at the output of the power amplifier. The power amplifier must have sufficient power capacity for a 10-db increased output when maximum control is utilized.

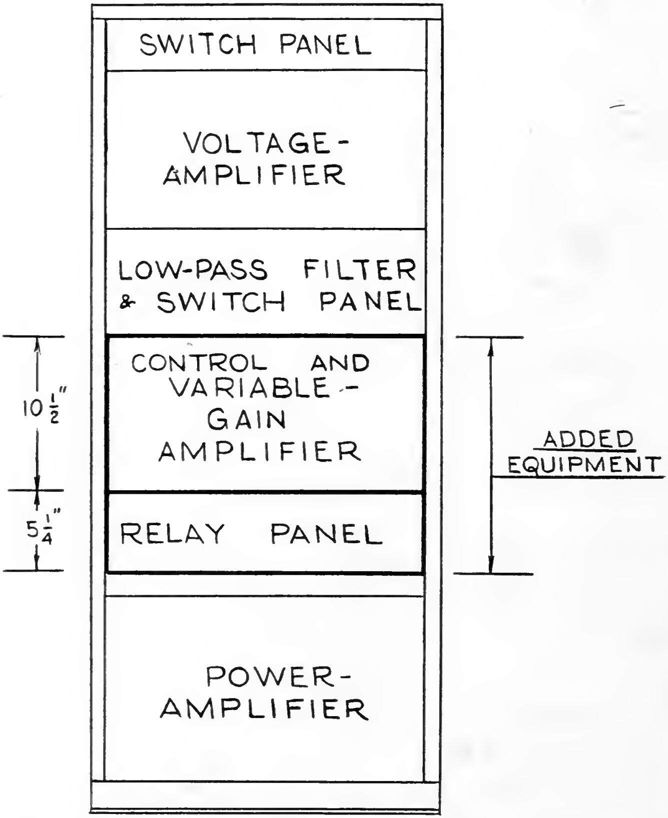

FIG. 4. Rack mounting for typical sound-reproducing system.

The side horns are each equal to one-half of the screen horn system in power-handling capacity and are of the same type so that the same amplifier equalization serves for both horn systems. The additional horns may be located at or near the sides of the proscenium arch in a line with the center horns.

Fig. 4 shows how the relay panel and combined control-tone and variable-gain amplifier are added to the existing rack of a typical sound system, in this case an RCA *PG-92*. In the case of cabinet-mounted amplifier systems, the same control-track equipment can be furnished mounted in wall cabinets. Both units of the control-track equipment have self-contained power supplies which are so regulated as to be independent of line-voltage variations from 90 to 130 volts. The variable-gain amplifier has two screwdriver adjustments; one for the point of gain increase, and one for the degree of maximum gain. A "normal-control" key serves to by-pass the amplifier if no control is desired. The relay panel has one screwdriver control for sensitivity. This adjustment is necessary only at the time of installation in order that the relay may operate to cut in the side horns at a control-track width of 40 mils or less.

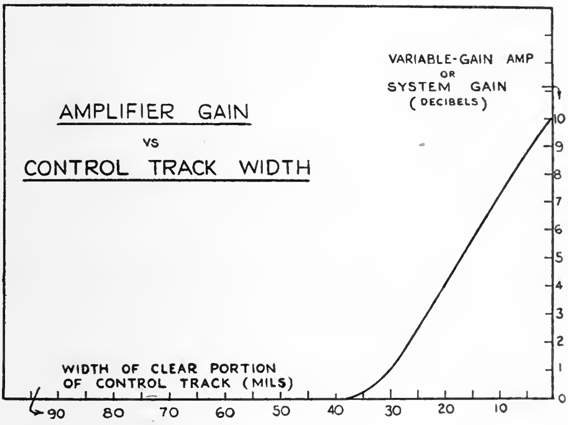

FIG. 5. Amplifier gain *vs.* control-track width.

Fig. 5 shows how the system gain is increased almost linearly over a 10-db range with a 40 to zero-mil change in width of the control-track. At present, the scanned width from 90 to 40 mils is not used. The operating time of the control equipment is of the order of 60 milliseconds, which is fast enough to allow full control on effects and music sections of short duration.

In practice the control-track is prepared on the film in the following manner: A control-track print is made up by splicing together prints of various widths appropriate to the degree of control desired. These tracks are available in the re-recording department in steps of 1 db. This cut control-track print is used for the production of a separate control-track negative, or is printed onto the undeveloped sound-track negative in order that release prints can be made from a separate control negative or from a composite control-sound negative as desired. The release composite print is then made in the normal manner except that the sound-track printer is equipped to print both the sound-track and control-track in one operation. There is no change in technic or increase in operating cost in the release laboratory in the case of composite control-sound negatives. The greater cost involved in the separate control-track method is due to the one additional printing operation. The cut control-track print is returned to the sound department after the negative is made, where it is broken down and used again to make other cut control prints.

Release prints with control-tracks reproduce normally in theaters where the equipment has not been modified to take advantage of the control feature. Conversely, standard release prints without control-tracks reproduce normally on modified theater equipment provided the film is threaded over the control lamp to miss the control-track attachment or that the print is clear in the area between the sprocket-holes. In either case the control equipment is inoperative. Oil, dirt, and scratches incurred during normal print life have no appreciable effect upon the operation because of the relatively large scanning aperture employed. Track misalignment in printing, and projector weave up to 10 mils have no effect for the same reason.

The equipment has been in use experimentally in the Warner Bros. *Hollywood Theater* in Hollywood, and the *Strand Theater* in New York for several months and has proved to be effective, reliable, and trouble-free in operation.

REFERENCE

[1] MUELLER, W. A., "Audience Noise as a Limitation to the Permissible Volume Range of Dialog in Sound Motion Pictures," *J. Soc. Mot. Pict. Eng.*, **XXXXV** (July, 1940), p. 48.

DISCUSSION

Mr. Reiskind: The various methods being tried out by the industry all have merit and the problem facing us is that of picking the method that offers the best engineering and commercial compromise. It is essential that we remember that the scheme adopted must not be very expensive, must be relatively simple to operate and maintain, and must not require special prints which can be played only on the new equipment.

It seems to me that the single-sound-track scheme using the sprocket-hole control-track that I discussed in my paper and which was described in detail by Messrs. Levinson and Goldsmith, offers the best compromise. While the three-track system will provide greater flexibility in obtaining dramatic effects, it does not seem that this advantage will compensate for the great increase in equipment complexity. The three-sound-track system requires three reproducing channels, complete from photocell to loud speakers, each including a variable-gain amplifier. The system requires three control tones, and it is proposed to record these as a 5-mil track in the narrow space between the sound-track and the picture. The 5-mil track provides very low output, which will necessitate the use of additional amplification in the control system. The three band-pass filters required to separate the tones will further increase the cost of the system. Very extensive modification will be required in the sound-head to provide reproduction of the four tracks.

The possibility of employing high-speed compression and expansion will provide additional noise reduction which must first make up for the loss caused by the reduction in track width to one-third normal and then may provide increased volume range. However, it appears to me that such a compressed print could not be satisfactorily reproduced on standard equipment. In the past we have seen several instances of the impracticability of expecting the exchanges to handle two types of prints.

I should like again to stress the factor of cost. Regardless of the improvement obtained, expensive modification will be practicable for only the largest theaters. This is directly contrary to the basic idea of the industry which aims to provide essentially the same entertainment for all audiences whether they attend large or small theaters.

MULTIPLE-SPEAKER REPRODUCING SYSTEMS FOR MOTION PICTURES*

H. I. REISKIND**

***Summary.**—Several types of multiple speaker reproducing systems have been demonstrated and used during the past two years. For general theater use such a system must be simple and must employ a release print that is interchangeable with standard release prints.*

The use of a number of loud speaker systems spread across the front of the theater and operating in parallel will effect a material improvement in the reproduction of music and "sound effects." By providing supplementary speakers well to the sides of the screen, operated by a control track so that they are faded out during dialog, an improvement in music and effects reproduction is obtained without harming dialog.

The sprocket-hole area may be used for the control track, thus eliminating the necessity of changing existing film standards or obsoleting reproducer equipments.

During the past two years a great deal of interest has grown up in the industry with regard to the improvements in reproduction which may be obtained by the use of multiple-speaker systems for sound motion picture reproduction. Not only have there been demonstrations of such systems[1, 2, 3] but several pictures have been released for multiple-speaker reproduction. One of these, Walt Disney's *Fantasia*,[4] makes use of special road-show prints and reproducing equipment, while several Warner Bros. pictures have been released as standard type prints including a sprocket-hole control track and shown on standard reproducing equipment modified to provide multiple-speaker reproduction.

In general two methods are employed and all the systems make use of either one or some combination of the two. One, the stereophonic method, uses two or three channels to produce motion of the sound source and thus allows the sound to follow the picture within the confines of the screen and in some cases to produce "off-screen" effects. The other method makes no attempt to provide sound motion within the screen area. Instead, the sound source for music

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received May 1, 1941.

** RCA Manufacturing Co., Indianapolis, Ind.

and sound effects, which generally are not localized on the screen, is broadened beyond the screen area by the use of multipled groups of loud speakers.

A committee composed of members of the various Hollywood studios has been set up under the Academy of Motion Picture Arts and Sciences and is engaged in studying the various systems with the view of standardizing one of them for general industry use.

With this amount of activity in the field it was felt that a discussion of some of the aspects of multiple-speaker reproduction and of one of the proposed systems would be of interest to the members of the Society.

It is of course understood that everyone is interested in standardizing a system that will be practicable for the majority of motion picture theaters. In order that it be generally acceptable the system should satisfy these five requirements:

(*1*) It should make an improvement in the dramatic quality of the motion picture presentation that will justify the cost of the change.

(*2*) The cost of the additional equipment should be low enough to make it practicable for the smaller as well as the larger theaters.

(*3*) Present standards of film, picture, and sound-track dimensions should not be changed in any way that will require modification of existing equipment except to provide the improved reproducing characteristics.

(*4*) Existing theater equipment of modern types should not be rendered obsolete. The improved reproduction characteristics should be obtainable by additions to the installed equipment.

(*5*) The modified equipment must reproduce sound from the present standard release films without any deterioration in quality over that which would be obtained from existing standard equipment. Release prints prepared for the improved type of reproduction should be reproduced on standard equipment with quality as good as would be obtained from a standard print.

It is possible, even within the limits of these requirements, to make a noticeable improvement in reproduction by taking advantage of the differences between what constitutes the most favorable conditions for reproducing dialog and music. It has been recognized almost from the earliest days of motion picture recording, that dialog represents a recording and reproducing problem that is entirely different from that presented by music, choruses, or sound-effect scenes. We might distinguish between the two types by saying that the original speech is produced by approximately a point-source while the original source of music and the sounds of most spectacular effect-scenes is one of large area.

The motion picture technic used for dialog scenes is one that plays almost all the action in medium or close shots. In order to improve both illusion and intelligibility we are interested in obtaining a high degree of "presence"; that is, we should like to get the effect of the sound coming from just in front of the screen.

Because of the limited size of the screen the technic is one of always bringing the action in front of the viewer rather than having him look toward the action; and in general it can be said that there is comparatively little motion in the scene with respect to the viewer. It must be recognized also that even when there is motion on the screen the angle subtended by the screen at the eyes of most of the viewers is quite small, and consequently the viewers are seldom conscious of such motion. On the basis of SMPE Recommended Practice[5] the screen subtends an angle of about $16^1/_2$ degrees at the eye of an observer in the middle of the theater. Particularly in a theater with a balcony, the angle at the majority of seats is even smaller.

Music and sound effects present an entirely different problem. Not only are they generally produced over a large area but in most instances the source of the music is not pictured on the screen, and we are more interested in obtaining a spatial effect than in localizing the source of the sound. A very similar condition applies in the spectacular type of sound-effect scene, such as the earthquake of *San Francisco*, the avalanche of *Lost Horizon*, or the battle in *The Sea Hawk*. Here we are interested in obtaining the illusion of sound coming from an area much greater than that pictured on the screen and the effectiveness of the scene would be enhanced by having the sound come from the entire front of the theater or in certain cases even have the audience entirely surrounded by the sound source.

We are able to differentiate between the various types of scenes in the recording operation and provide the microphone placement and acoustic environment best suited to each scene. However, in reproduction it has been the practice to use the same loud speaker system at all times. Because of the importance of the dialog in telling the story, our speaker systems have evolved into a form that is particularly well adapted to give a high degree of intelligibility and presence. The single set of speakers located back of the screen tends to approach a point-source, and while this is exactly what is needed to give maximum clarity and presence for dialog, it tends to give music a "squeezed" effect; particularly in a large theater. The comparison is especially striking when it is made between an actual orchestra and music reproduced through a single speaker system in the same theater.

Methods have been developed for overcoming this "squeezed" effect by the use of multiple sound-tracks and reproducing channels. The possibilities of auditory perspective have been demonstrated by the Bell Telephone Laboratories, on several occasions.[1, 3]

Another method of attacking the problem is based upon the idea that exact imitation of the original may not be our goal in the reproduction of music. Many persons, including musicians, feel that the sound from a real orchestra may not be the ultimate in impressiveness. The belief has been expressed that a better effect might be obtained from an orchestra if the violins, for example, instead of being seated in a group, were intermingled with the other instruments. In some ways reverberation produces a little of this effect in that it brings the sound to the listener from many directions and thus reduces the effect of definite location. It is accepted that a large amount of reverberation is necessary to make music pleasing. However, intermingling the instruments is impracticable from the players' standpoint, since it is largely because of the grouping that each section of instruments is able to play together, both as to tempo and pitch. Such an arrangement, however, can be accomplished in a reproducing system by several groups of speakers in multiple spread across the front of the theater. The effectiveness of this method of reproducing music was demonstrated in 1937 in the RCA sound reproducing system installed for the production *The Eternal Road*, where individual sound-tracks, reproducing channels, and speaker systems were employed for the orchestra, choruses, and soloists.[4] The individual solo and chorus channels allowed speaker placements giving the desired illusion of location. The orchestra music, which had been recorded on a single sound-track, was reproduced through a number of loud speaker systems spread across the front of the theater. This use of multipled speaker systems provided a large sound-emitting area more nearly approximating the original source than did the single-speaker system. This system did not localize the position of each instrument, but added a "spread" or spatial effect and gave the impression that the music actually filled the auditorium rather than that it came from a definite source at the center of the stage.

The effectiveness of the multiple-speaker system for music and effects has also been demonstrated by the sound-reinforcing system installed in the Radio City Music Hall. This system consists of three individual amplifier channels feeding three banks of speakers. One bank is located to the right, one to the left, and one above the center of the stage, and the system is arranged so that the three channels may be used individually or in parallel. Comparative tests almost six years ago convinced both the Music and Sound departments of the Radio City Music Hall that their multiple-speaker method gave more effective and pleasing reinforcement and more nearly simulated the effect of a large orchestra playing in a large auditorium than the use of three separate discrete channels.

The "Fantasound" system of reproduction is an example of the possibilities of combining both stereophonic reproduction and the principle of extending the source. Both methods are used in this picture, depending upon the effect desired. The "Ave Maria" number, which many consider the most impressive part of the performance, is an example of the results that may be obtained with multiple-speaker reproduction. For this selection a large number of speakers were installed along the sides and back of the theater and multiplied to the corresponding set of side speakers on the stage. In this way the sound from each side sound-track was reproduced along the entire corresponding side of the house rather than from the stage alone.[4]

Another example of the effectiveness of surrounding the audience by the sound source is the reproducing equipment installed for the RCA large-screen television demonstration at the New Yorker Theater. Loud speakers in multiple, located on all the walls and on the ceiling, as well as on the stage, materially improved the sound illusion, and in one scene were used to make the audience feel that they were actually being subjected to a bombing attack.

The improvement in music and effect reproduction obtainable through the use of multipled groups of speakers, and the development by C. M. Burrill of a method of using the sprocket-hole area of the film to provide a control signal, led M. C. Batsel to propose that a commercially practicable multiple-speaker reproducing system be developed for motion picture theaters.

This could be done by equipping theaters with additional speakers located well to the sides of the screen and arranging the control equipment so that these supplementary speakers would operate in parallel with the screen speakers during all music and effect sequences, but be off during dialog. This arrangement would provide a spatial effect or "acoustic spread" for the music and effects reproduction and still maintain the intelligibility and "presence" of the dialog, since dialog will be reproduced exactly as at present.

In addition to "acoustic spread," consideration was given to the desirability of providing increased volume range. It was recently pointed out by W. A. Mueller,[7] that the permissible volume range of reproduced dialog is limited by theater and audience noise at one end, and at the other by the maximum loudness to which the audience can comfortably listen. This range is less than the volume range of existing film recording methods, and it was therefore not considered necessary to have any volume control for dialog scenes.

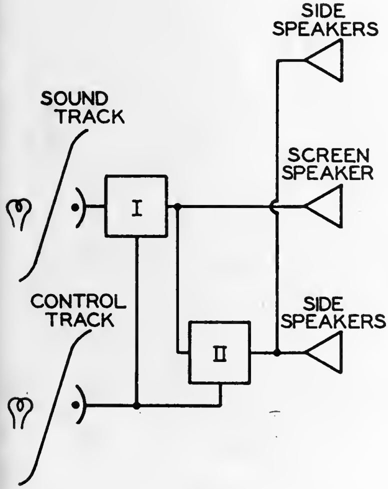


FIG. 1. Simplified block diagram of a multiple-speaker reproducing system.

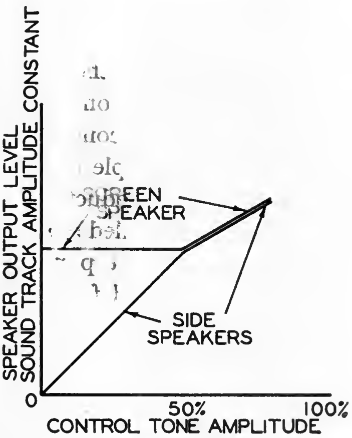
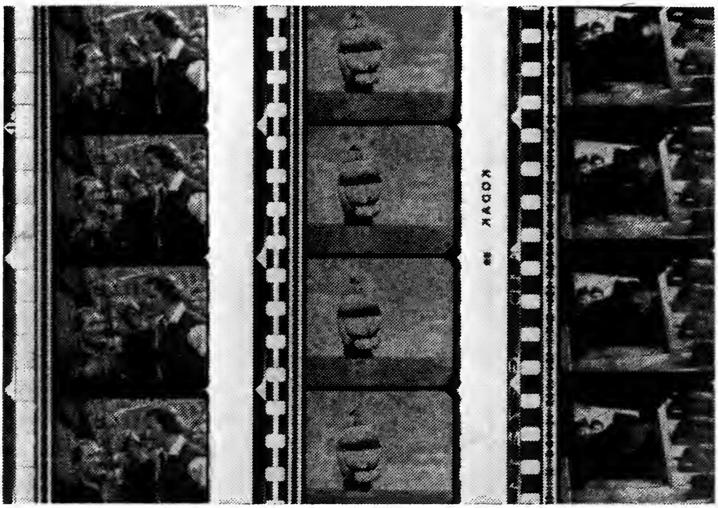


FIG. 2. Output characteristics of loud speaker groups in a multiple-speaker system.

Mr. Mueller pointed out also that with standard reproduction, audiences generally object to music reproduced at levels much higher than those used for dialog. However, tests made of music reproduction with acoustic spread indicated that higher levels could be used without discomfort and with consequent improvement in the effectiveness of the music.

The spectacular type of effect sequences, hurricanes, battles, and so forth, which of course call for increased reproducer gain, are also improved by acoustic spread.

Since it appears that all those sequences that may require increased reproducer volume are also benefited by acoustic spread, it was decided that the system would be arranged so that as the control tone was increased it would first provide acoustic spread by fading in the supplementary side speakers and then control the volume of the entire system.



a *b* *c*

(*Courtesy Warner Bros. Pictures, Inc.*)

FIG. 3. Composite release print with sprocket-hole control track: (*a*) Minimum modulation. (*b*) Intermediate modulation. (*c*) Maximum modulation.

An elementary block diagram of such a system is shown in Fig. 1. The control circuits are designed so that with the minimum control signal, unit *I* has a gain that is less than its maximum gain, and unit *II* is off. This represents the dialog reproducing condition (screen speaker operating, side speakers off). For music or effect reproduction at normal levels, the control signal amplitude may be increased to about 50 per cent, operating unit *II* and turning on the side speakers. Any further increase in control tone amplitude has no effect upon the gain of unit *II*. Unit *I* is designed so that its gain (which represents the overall system gain) is unchanged by the increase of the control signal to 50 per cent, but a further increase (from 50 to 100 per cent) will increase its gain, and thus increase the loudness of both screen and side speakers. The relation between speaker outputs and control tone amplitude is shown in Fig. 2.

This system requires a single-frequency control tone variable only in amplitude. Such a tone might be recorded on the portion of the film outside the sprocket-holes, between the sound-track and the picture, or standards could be changed and a portion of the sound-track area utilized. However, the proposal of C. M. Burrill to use the sprocket-hole area appears to be the most practicable since it requires no changes in existing standards. Such a track can be recorded and printed very easily, and can be reproduced by a very simple and inexpensive attachment to the sound-head.

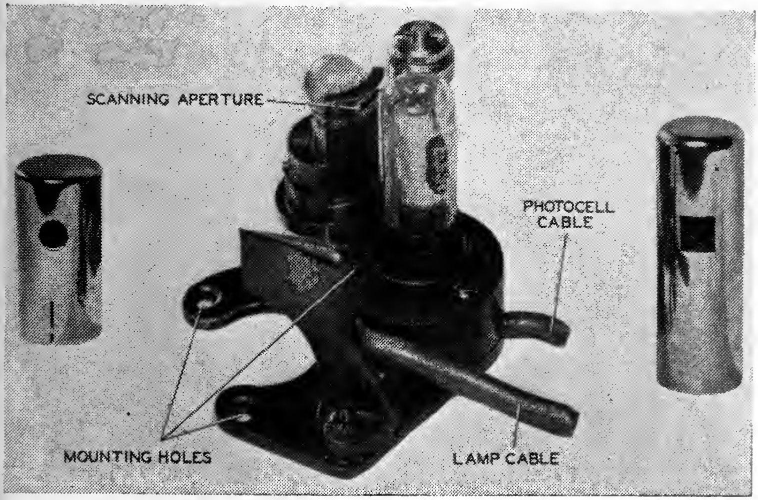


FIG. 4. Sprocket-hole control track scanning system.

When the sprocket-hole area is scanned, a 96-cycle tone is generated. The positive half-wave will have an amplitude dependent upon the amount of light passing through the hole, while the negative half-wave amplitude will be determined by the light passing through the "lands" (the spaces between the sprocket-holes). Accordingly, the 96-cycle control tone may be varied in amplitude simply by changing the transmission of the "lands." Maximum signal is obtained when the "lands" are all black, and minimum when they are clear. Fig. 3 is a photograph of three portions of a composite release prints showing the track for minimum, maximum, and intermediate values of control tone.

Since the track occupies the entire width of the sprocket-hole area and the frequency to be reproduced is low, a very large aperture may be used. This makes possible the very simple scanning system shown in Fig. 4. The lamp is rated at 6.5 volts, 0.43 ampere, and because of the large aperture, furnishes more than sufficient light without the use of any lenses. The signal output of this simple scanning system is higher than that from a normal sound-track scanned by a standard optical system, thus allowing the use of a reasonably low-gain amplifier.

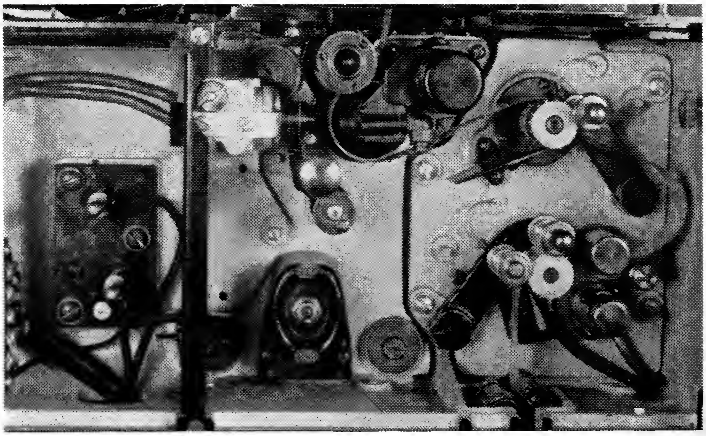


FIG. 5. Sprocket-hole control track scanning system mounted in a standard sound-head.

A further advantage of this track lies in the large tolerances allowable in recording, processing, and reproducing. It will be noted that it has not been necessary to provide any lateral guide adjustment of the scanning assembly. Fig. 5 shows the system mounted in a standard sound-head. The unit mounts around the hold-back sprocket and requires practically no modification to the sound-head.

In any reproducing system it is desirable that the signal amplitude be independent of exciter lamp output or photocell sensitivity. Fortunately this result can be obtained in the reproduction of the control tone by a very simple method which makes use of the logarithmic relation existing between the grid current and the plate voltage of any vacuum tube.[8] With a circuit using this characteristic it is possible to vary the exciter lamp intensity by more than 5 to 1 with a change in output of less than 1.5 db. With a linear amplifier, this same variation in exciter lamp intensity would produce a change in output of over 14 db.

The system described above meets all the requirements laid down at the beginning of this discussion. By requiring only that all prints not recorded for control track reproduction have a clear sprocket-hole area, complete interchangeability of prints is obtained and it will not be necessary for exchanges to carry two types of prints for any picture. In addition, the system is simple; any modern system can be modified to provide multiple-speaker reproduction, and the improvement obtained is a real one.

Thanks and credit are due to Messrs. M. C. Batsel, C. M. Burrill, and A. R. Morgan for the ideas and original work upon which this system is based; to Messrs. J. L. Underhill, R. Bierwirth, L. Biberman, and J. Lehman for their help in the design and construction of the original equipment; to Messrs. E. W. Kellogg and J. E. Volkman for their assistance and ideas throughout the work; and to Warner Bros. Pictures, and the Hollywood staff of RCA Manufacturing Company, Inc., for the field testing of the system.

REFERENCES

[1] MAXFIELD, J. P.: "Demonstration of Stereophonic Recording with Motion Pictures," *J. Soc. Mot. Pict. Eng.*, **XXX** (Feb., 1938), No. 2, p. 131.

[2] OFFENHAUSER, W. H., JR., AND ISRAEL, J. J.: "Some Production Aspects of Binaural Recording for Sound Motion Pictures," *J. Soc. Mot. Pict. Eng.*, **XXXII** (Feb., 1939), No. 2, p. 139.

[3] FLETCHER, HARVEY: "Stereophonic Reproduction from Film," *Bell Laboratories Record*, **XVIII** (May, 1940), No. 9, p. 260.

[4] KOWALSKI, R. J.: "RCA's 'Fantasound' System as Used for Disney's 'Fantasia,'" *Internat. Project.* (Nov., 1940), p. 20.

[5] "Revision of SMPE Standards," *J. Soc. Mot. Pict. Eng.*, **XXX** (March, 1938), No. 3, p. 249.

[6] DIMMICK, G. L.: "The Eternal Road," *Electronics*, **10** (April, 1937), No. 4, p. 28.

[7] MUELLER, W. A.: "Audience Noise as a Limitation to the Permissible Volume Range of Dialog in Sound Motion Pictures," *J. Soc. Mot. Pict. Eng.*, **XXXV** (July, 1940), p. 48.

[8] PAYNE, E. L., AND STORY, J. G.: "A Portable Programme Meter," *The Wireless Engineer*, **XII** (Nov., 1935), No. 146, p. 588.

SOME THEORETICAL CONSIDERATIONS IN THE DESIGN OF SPROCKETS FOR CONTINUOUS FILM MOVEMENT*

J. S. CHANDLER**

Summary.—*After a brief introduction the paper gives a discussion of the steps of sprocket design with the ultimate aim of keeping the flutter to a minimum.*

First the selection of the proper sprocket-tooth pitch is considered, then the steps required in arriving at the proper basic tooth profile, and finally the modified tooth profile are illustrated by an example.

Curves of theoretical flutter versus *per cent of film shrinkage are given for several cases for a 24-tooth sprocket. The effect of number of teeth is also shown by curves.*

An analysis of film and friction forces gives a clue to proper film guide design.

A word about sprocket-tooth shapers and results obtained from an experimental sprocket conclude the paper.

The degree of accuracy and the directness of the method, as well as the resulting optimum performance, are noteworthy.

This paper gives an analysis of the mechanism of film engagement with sprocket-teeth, and proposes a method of determining the correct tooth profile for a given set-up.

In order to avoid confusion the convention represented by Fig. 1 will be adopted. An external net force, F, is exerted on the film toward the left. This is balanced by the force of the sprocket-teeth against the film. The direction of rotation is counter-clockwise. In other words, the sprocket under consideration is a "hold-back" sprocket. (The analysis will hold equally well for a "drive" sprocket by reversing the direction of rotation.) The film comes in contact with the base circle, B, of the sprocket at the point of tangency, P. Only the right-hand faces of the teeth come in contact with the film.

FILM PATH

As shown by Fig. 1 the lower surface of the film travels along path AP during tooth engagement. This may be any suitable curve, either convex upward or downward, or it may be a straight line.

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

The film path, in general, is fixed by the design of film shoe, stripper, roller, or other means, and in some cases may be determined wholly or in part by the film tension and stiffness. In order to simplify the analysis and the shoe construction, the film path, AP, is taken to be the arc of a circle (or a straight line) tangent to the base circle at P. The sprocket-base circle is a convenient reference circle and may not exist on the actual finished sprocket if other means of film support are provided.

The film may remain in contact with the base circle any arbitrary distance, say, PC, and then disengage from the teeth along any suitable path similar to or different from AP. The special case of $PC = 0$, as well as the general case, will be treated later in the paper.

In general, only one sprocket-tooth will touch the film at any given time except at the transition instant when two teeth will touch.

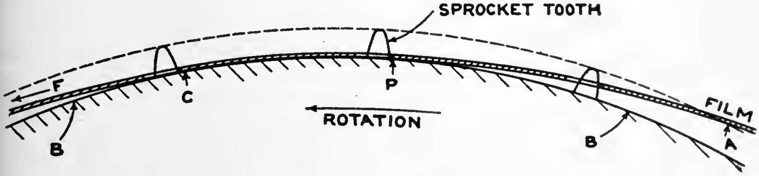

FIG. 1. Sketch of film and sprocket.

FLUTTER

The aim of the designer is to produce a sprocket that will move the film along as steadily as possible. Unsteady movement will produce density variations in the case of picture printers or "flutter" in the case of sound apparatus. For purposes of this paper, flutter will be considered as a measure of the unsteadiness and will be defined as the ratio between the unsteady film velocity component and the steady velocity component. If the film speed is 1 per cent higher than the average at a given instant, the flutter is 1 per cent at that instant. The flutter frequency will be that of the sprocket teeth, 24 cycles per second for 16-mm film and 96 cycles per second for 35-mm film. As a rough basis of comparison, the time average of the instantaneous flutter may be considered but is not to be taken as a measure of the subjective effect.

The determination of flutter is facilitated if we consider only velocities relative to the base circle of the sprocket, which is assumed to rotate at constant velocity. For this reason we will consider that the sprocket is stationary while the film moves around, winding on at the right and off at the left.

SPROCKET-TOOTH PITCH

The sprocket-tooth pitch is defined as the distance measured along the base circle between corresponding points on consecutive teeth. The sprocket must be designed to accommodate a certain range of film pitch caused by shrinkage or stretch after the perforating operation.

Let us consider two cases: In Case *I*, the tooth pitch equals the *maximum* film pitch expected. The tooth shape can be so designed that the film of minimum expected pitch first begins tooth contact at point *A* (Fig. 1). Thus, the entire path from *A* to *P* is available for accommodating the pitch range. The teeth act to slide the film to the right over the base circle.

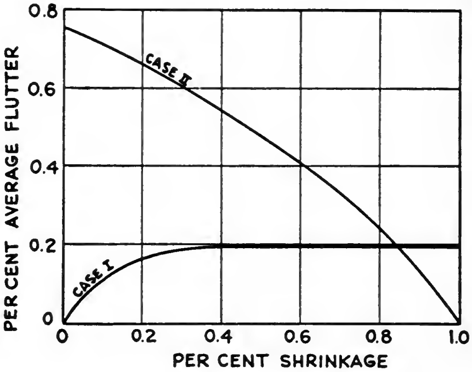

FIG. 2. Flutter *vs.* Shrinkage for two cases of a 24-tooth sprocket.

In Case *II* the tooth pitch is made equal to the *minimum* film pitch expected. The film of more than minimum pitch is permitted to slide to the left over the base circle as the perforations leave the teeth to the left of point *C* (Fig. 1). Because of the abrupt manner in which the film leaves the teeth, however, the pitch range must be accommodated during a relatively short time.

Fig. 2 gives the average theoretical flutter as a function of film shrinkage for a 16-mm, 24-tooth sprocket accommodating 1 per cent of shrinkage. Optimum tooth design is assumed in each case. Not only is the maximum average flutter 3.85 times greater for Case *II*, as the curves show, but owing to sharper peaks in Case *II*, the maximum instantaneous flutters are in the ratio of 5.20 to 1. Furthermore, the design of Case *II* will not work well as a drive sprocket (by reversal of rotation), since the film will tend to ride off or produce excessive friction against the guides.

It will be noted that the sprocket of Case *I* will serve as either a "hold-back" or a "drive" sprocket. If used as a "hold-back" sprocket, a guide above the film or additional balanced film tension is required to move the film down the tooth face. This may be avoided by using Case *II* for "hold-back" sprockets, but more unsteadiness of film movement results.

Hence, for flutter considerations, most, if not all, of the pitch range should be accommodated by the method of Case *I*. The tooth pitch should be equal to or just a little less than the maximum film pitch contemplated.

The first step in the sprocket design is to determine the base circle radius that will make the sprocket pitch equal to maximum film pitch for the number of teeth desired. The film thickness must be taken into consideration.

BASIC TOOTH SHAPE

For the second step in the design it is necessary to find the curve generated by a point on the film path when this path is rolled without slipping on the base circle. This is the well known epicycloid (or involute, in case the film path is a straight line). It is recommended that this curve be plotted from the parametric equations given in Appendix *I* for the three possible cases. The graphical method requires an awkwardly large scale to obtain sufficient accuracy.

The parameter in each case is the angle rolled through on the base circle. When angle θ is multiplied by a suitable constant, it gives the time required for the film to travel over the path from point (x, y) to P (Figs. 3, 4, and 5).

It is evident that one degree of freedom at the designer's command is the radius of curvature of the film path. In plotting the above curves it will be discovered that the second case of Appendix *I* gives the longest time of film engagement for a given tooth height. This is desirable in reducing flutter.

The value of $a = 0.5c$ for this case has been found to be a good basic assumption. A much larger value reduces the engagement time while a much smaller value causes the tooth to "lie down" and gives an impracticable shape. Appendix *II* gives values of x and y from equations *3* and *4* of Appendix *I* for $c = 1$ and $a = 0.5$.

The epicycloid curve gives the path traveled by a point on the film (such as the edge of a perforation) relative to the sprocket if the film does not slip over the base circle. But, as we have seen, all film but that of one particular pitch must slip over the base circle. The tooth shape, therefore, can not be that of the generated epicycloid but must be suitably modified to produce the desired slipping.

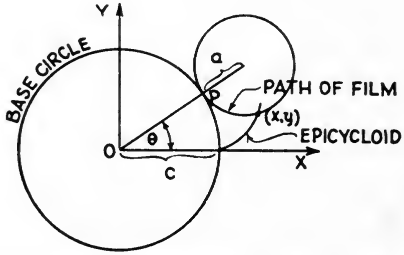

FIG. 3. Generation of epicycloid, Case *I*.

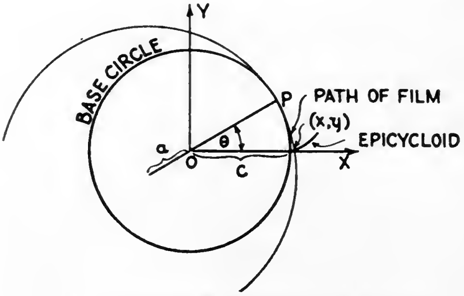

FIG. 4. Generation of epicycloid, Case *II*.

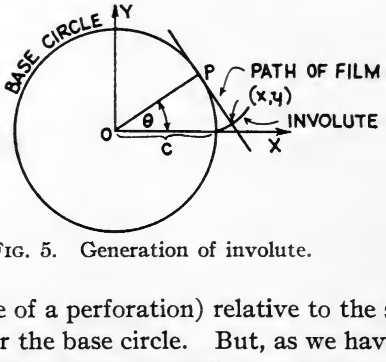

FIG. 5. Generation of involute.

MODIFIED TOOTH SHAPE

The designer may exercise his ingenuity in modifying the tooth shape; one film pitch may be favored more than the others if he so desires.

In order to illustrate the entire design procedure, as well as to give one method of modifying the tooth form, the following example will be used: Let it be desired to design a 24-tooth sprocket for 16-mm film, the film pitch to vary from 0.300 inch to 0.297 inch, or from 0 per cent to 1 per cent shrinkage. (The shrinkage range will vary in practice according to equipment and film.)

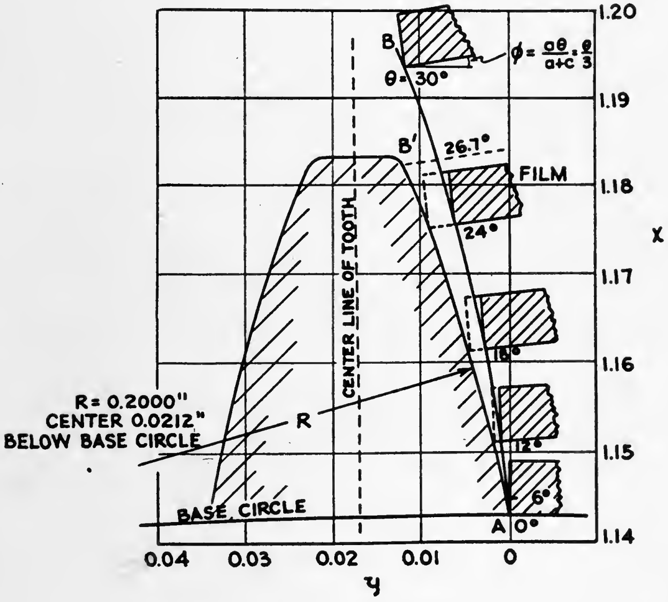

FIG. 6. Tooth layout.

Step I. Radius of Base Circle.—By allowing 0.006-inch film thickness and matching to maximum film pitch, the base circle radius, c, comes out as $\frac{0.300(24)}{2\pi} - 0.003 = 1.143$ inches.

Step II. Basic Tooth Shape.—By multiplying the coördinates given in Appendix *II* by 1.143 and plotting them, we obtain the epicycloid curve AB of Fig. 6 as the basic tooth shape. The values of θ are marked on the curve. A scale of about 100:1 or larger may conveniently be used. The picture is more complete if the base circle is drawn in from equation *7* or from equations *8* and *9*.

$$x^2 + y^2 = c^2 \tag{7}$$

$$x = c(\cos \theta) \tag{8}$$

$$y = c(\sin \theta) \tag{9}$$

The film may also be sketched in in various positions, noting that it makes the angle ϕ with the Y axis, where

$$\phi = a\theta/(a + c) \tag{10}$$

Step III. Modification of Tooth Shape.—First, the permissible working height of the tooth is determined by noting its base width and the general shape. The tooth width is dependent upon the number of teeth in "mesh." For this example the width at base is taken as 0.034 inch and the working height as 0.040 inch.

This tooth height is found to correspond to $\theta = 26.7$ degrees by reading from a curve of x plotted against θ (not shown). In other words, we have available 26.7 degrees of rotation in which to take care of films having from 0 per cent to 1 per cent shrinkage.

We must now prepare a schedule of deductions, D, or distances which the basic tooth shape must be moved to the left, as a function of θ.

The following procedure is recommended but is not the only one which may be followed. Let the curve of D plotted against θ take the form of a perabola with its nose at the origin, or

$$D = A\theta^2 \tag{11}$$

The value of A is determined by the fact that the distance measured along the film path between the tip of one tooth and the next tooth, which is 15 degrees to the left, must equal the minimum film pitch or 0.297 inch. In other words, D at 26.7 degrees is 0.003 inch more than D at 11.7 degrees. This places the value of A at $5.21(10^{-6})$. Fig. 7 gives the schedule of deductions thus determined.

These deductions are laid off along the film to the left of curve AB to determine curve AB' of Fig. 6.

The left-hand face of the tooth should give uniform film clearance along its length. This is dependent upon the film-disengaging path. The tooth of Fig. 6 is symmetrical.

Step IV. Radius of Tooth face.—The design of the sprocket has been completed in the previous three steps. However, since in actual construction the tooth profile must conform to the arc of a circle, the designer must establish the radius of this arc and its center location. This may be done either graphically from Fig. 6 or analytically. An arc can be found which fits the curve AB' remarkably well. Any deviation of the arc from the curve simply means that a slightly different schedule of deductions is enforced. The performance of the sprocket is but slightly altered. For the example at hand, a radius of 0.2000 inch with a center located 0.0212 inch below the base circle was found suitable.

It may be desirable in some cases to specify the radius of the generating circle for the involute that best approximates the desired tooth profile. This can be done by trial and error and, for our example, this radius is 1.118 inches. The involute approximation is not as good as the circular arc approximation because the radius of curvature of the involute is about 80 per cent too great.

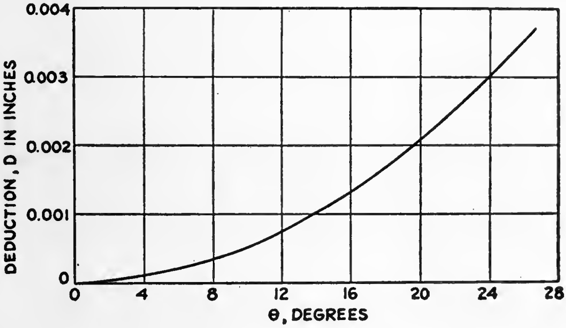

FIG. 7. Schedule of deductions.

FLUTTER DETERMINATIONS

It is of considerable interest to investigate the flutter that might theoretically be expected from the sprocket as a function of the film shrinkage.

If the curve of Fig. 7 is replotted on a time base, remembering that 15 degrees is equivalent to $^1/_{24}$ second, we have a displacement curve. The slope of the displacement curve gives the velocity. Determined mathematically we find that velocity

$$v = 1.350\, t, \tag{12}$$

where t = time in seconds.

Film of any given shrinkage is under the influence of one tooth for $^1/_{24}$ second when the next perforation engages the next tooth and the same cycle of velocities is repeated. If we substitute $t = {}^1/_{24}$ in equation *12*, we obtain $v = 0.0563$ inch per second, one-half of which is 0.0281 inch per second. Therefore, the film may be considered as having an unsteady velocity component which varies linearly from plus 0.0281 inch per second to minus 0.0281 inch per second every $^1/_{24}$ second. The arithmetical time average of such a component is 0.01405 inch per second. Since the steady component of film velocity is 7.2 inches per second, the average flutter is 0.195 per cent.

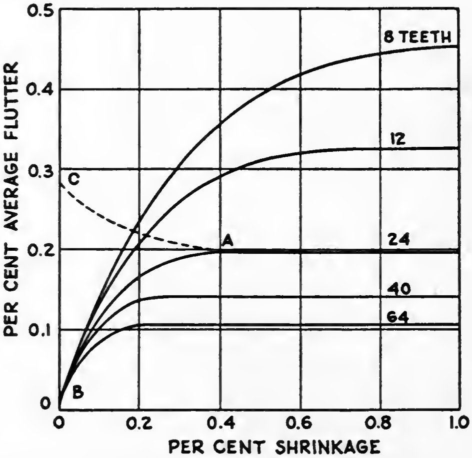

FIG. 8. Flutter *vs.* Shrinkage for sprockets of different numbers of teeth.

From Fig. 7, it will be seen that $\theta = 15$ degrees the deduction *D* is 0.00118 inch, which corresponds to a shrinkage of 0.394 per cent. Film of this shrinkage will rest against the teeth during rotation from $\theta = 15$ degrees to $\theta = 0$ degrees. For film of 0.394 per cent to 1 per cent shrinkage the flutter will be 0.195 per cent as calculated above and as shown by Fig. 8. However, for film from 0 per cent to 0.394 per cent shrinkage, the tooth contact is carried to the left of point *P* (Fig. 1) for part of the cycle. If *PC* (Fig. 1) is equal to or greater than the film pitch, the velocity during this part of the cycle is zero relative to the base circle. This determines the portion of the flutter curve as shown from *A* to *B* in Fig. 8. If *PC* (Fig. 1) = 0, the film begins to move up the tooth for the part of its cycle to the left of *P*. This permits the film to slide to the *left* over the base circle during this time; for the rest of the cycle it slides to the *right* under the action of the tooth to the right of *P*. Thus, the flutter can not become zero but is that shown by line *AC* of Fig. 8. The maximum instantaneous flutter is no longer just twice the average flutter but is higher. The sprocket may be designed for a greater range of shrinkage so that this portion of the curve is avoided if so desired.

EFFECT OF NUMBER OF TEETH

Fig. 8 gives the "theoretical flutter" curves for sprockets of 8, 12, 40, and 64 teeth as well as the 24-tooth sprocket. These curves were calculated for *PC* greater than the film pitch, for a working tooth height of 0.040 inch, and for a shoe radius = 1.5 times the base circle radius. The curves apply to 16-mm film only. In some cases a better design might result by reducing the shoe radius to give more angle of contact. With more teeth in mesh the working height might have to be reduced because of narrower teeth.

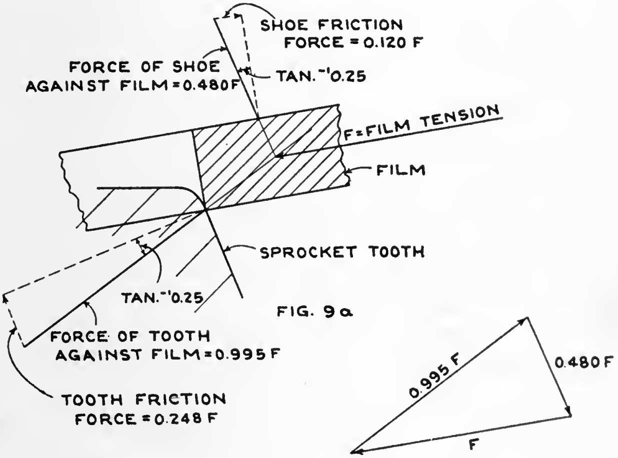

FIG. 9a

FIG. 9b

FIG. 9. Tooth and shoe friction force diagram.

An analysis of the curves shows that the maximum average flutter varies nearly inversely as the 0.7 power of the number of teeth. In other words, increasing the number of teeth for a small sprocket gives more improvement than for a large sprocket.

FRICTION FORCES

The term "theoretical flutter" was used in the preceding section because it is recognized that other sources of flutter exist and the calculated values may not be attained in practice. Two additional sources of flutter will be considered here: (*1*) friction of film against tooth and (*2*) friction of film against guide shoe. Fig. 9(*a*) shows a portion of the film as it is just beginning tooth engagement at the top of the tooth of Fig. 6. If we assume a coefficient of friction of 0.25, the forces of tooth against film and of shoe against film make an angle of $\tan^{-1} 0.25$ with their respective normals. The magnitudes of these forces relative to the film force, F, are determined by the force triangle of Fig. 9(*b*).

If such a force analysis is made for the different film positions it will be found that the tooth force remains substantially equal to F, while the shoe force varies from $0.480F$ to $0.434F$. As the tooth face slopes more to the left with a decrease in the ratio of a to c (Appendix *I*), the film shoe force increases.

The force analysis also shows that the film guide must be above the film to hold it down. If the sprocket is to act as a drive sprocket, the tooth and shoe forces fall on the other side of their respective normals, and the guide must be below the film to support it.

In calculating the force of the film against the shoe, it is well to note that there is an additional radial force toward the center owing to the curvature of the film path. Neglecting the stiffness of the film this radial force $= F/r$ per unit length of film, where F is the film tension and r is the radius of curvature. For the 24-tooth sprocket example, the radial force $= 0.175F$ for a film length equal to the pitch.

It is the varying nature of friction which imposes a varying load on the sprocket or causes the film to proceed by jerks and thus introduces flutter.

SPROCKET-TOOTH SHAPER

The usual method of hobbing sprocket teeth leaves tool marks across the face of the tooth. This may cause the film to catch as it moves up or down the tooth. For some experimental work, we have used a tooth shaper in which the cutting stroke is downward from the top of the tooth. With this machine a very smooth tooth surface can be obtained, and the remaining tool marks offer the least resistance to film movement.

CONCLUSIONS

An 8-tooth experimental 16-mm sprocket was designed according to the procedure just described. It was possible to obtain consistently a flutter meter reading as low as 0.7 per cent for a film of 0.5 per cent shrinkage. The flutter meter was calibrated to read $\pi/2$ times the average flutter. The average flutter, therefore, was 0.45 per cent, which is in reasonable agreement with Fig. 8.

It is hoped that the method will be more thoroughly tested by experimentation and that it will prove helpful in tackling the problem of sprocket design.

APPENDIX I

Case I. Film path is an arc or circle convex downward (see Fig. 3).

$$x = (a + c) \cos \theta - a \cos \left[\left(1 + \frac{c}{a}\right)\theta\right] \tag{1}$$

$$y = (a + c) \sin \theta - a \sin\left[\left(1 + \frac{c}{a}\right)\theta\right] \tag{2}$$

Case II. Film path is an arc of circle convex upward (see Fig. 4).

$$x = (a + c) \cos \frac{a\theta}{a + c} - a \cos \theta \tag{3}$$

$$y = (a + c) \sin \frac{a\theta}{a + c} - a \sin \theta \tag{4}$$

Case III. Film path is a straight line (see Fig. 5).

$$x = c(\cos \theta + \text{rad } \theta \sin \theta) \tag{5}$$

$$y = c(\sin \theta - \text{rad } \theta \cos \theta) \tag{6}$$

where rad $\theta = \theta$ measured in radians.

APPENDIX II

θ, deg.	6	12	18	24	30	36
x	1.00183	1.00726	1.01625	1.02863	1.04420	1.06272
y	0.00008	0.00068	0.00229	0.00539	0.01048	0.01797

θ, deg	42	48	54	60
x	1.08388	1.10732	1.13269	1.15954
y	0.02831	0.04189	0.05902	0.08001

DISCUSSION

MR. FRIEDL, JR.: Is there any established figure for the optimum shrinkage for 16 and 35-mm positive prints as circulated for general use?

MR. CHANDLER: I do not know about the shrinkage to be expected from 16 and 35-mm film. There will undoubtedly exist individual cases of extreme shrinkage. I believe that the sprocket should be designed for the great bulk of the cases falling within a moderate shrinkage range, reserving a small portion of the tooth height to be rounded off so that the extreme cases can be handled without regard to the flutter in these cases.

DR. CARVER: The average shrinkage of 35-mm cellulose nitrate film is about 0.3 per cent, of 16-mm cellulose acetate film about 0.6 per cent.

MR. FRIEDL, JR.: In 35-mm sound-film reproduction we are not very conscious of flutter, but sprockets are not used today to pull film past the sound-gate. Various devices using damped rotary inertia gates like the Rotary Stabilizer have made the matching of the perforation pitch and tooth pitch less critical.

MR. KELLOGG: I am surprised at the small amount of flutter shown on the curves, especially in cases where large numbers of teeth were used.

MR. CHANDLER: The flutter curves of Fig. 8 represent the unsteady velocity of the film owing to the action of the teeth against it. The film has a certain velocity of slip relative to the base circle. This velocity of slip varies between two extreme values in a definite periodic manner, thus determining the flutter. The velocity of slip may become zero for a portion of the cycle for films of certain shrinkage. For the example of the 24-tooth sprocket, the velocity of slip over the the base circle is zero for a portion of each cycle for films of less than 0.394 per cent shrinkage (curve *AB*, Fig. 8), while for films of more than 0.394 per cent shrinkage the velocity of slip never becomes zero.

A METHOD FOR DESIGNING FILM SPROCKETS*

W. G. HILL AND C. L. SCHAEFER**

Summary.—*A method is described for determining the sprocket-tooth pitch and consequently the base diameter, the tooth profile shape and tooth dimensions of film moving sprockets together with the tooth location transverse to the direction of film travel. The method assumes that the film dimensions are known or can be determined. Computations are given for a 35-mm 32-tooth sprocket and data showing the allowable film stretch or shrink for various numbers of teeth in mesh.*

Film moving sprockets can be classified into three groups according to their use and extent of film shrinkage which they must accommodate.

(*I*) Sprockets where little or no shrinkage is encountered. Associated with this group are: film manufacturing machines, such as perforators, examining machines, *etc.*

(*II*) Sprockets for use with aged undeveloped film, where moderate shrinkage must be accommodated: cameras, printers, recorders, *etc.*

(*III*) Sprockets for use with developed film, where considerable shrinkage may be present: printers, projectors, *etc.*

For any particular group the main considerations in sprocket design are: the pitch or distance between teeth, which of course determines the base diameter of the sprocket wheel; the tooth shape; and the distance between the rows of teeth. Dimensions referring to relieved areas for pictures and sound-track, also reference to flanges for guiding the film edges, should not in our opinion be included in the design method. These points are not related to sprockets in general, but apply to special cases. Furthermore, factors that determine such dimensions are not definite, and the introduction of a new process might result in entirely different requirements. It is our belief that such construction details should be left to the discretion of the designer.

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received April 14, 1941.

** Agfa Ansco, Binghamton, N. Y.

Since the perforating standards for film are well established and there is reason to believe that no changes will be made in the principal dimensions, we have expressed the base diameter for the sprocket in terms of film pitch. It will be recognized, then, that as the shrinkage characteristics of motion picture film change, and they no doubt will through improvements in manufacturing, the method of sprocket design is not altered. Another point that should be mentioned is that for any motion picture film, for instance 16-mm, classified in group *I*, and a sprocket of a definite number of teeth and with anywhere from 1 to 10 teeth in mesh, the same sprocket is used. This means that the same cutter can be used in forming the teeth of such sprockets. American Sprocket Standard Z22.6-1941 for 16-mm film calls for different tooth thicknesses for each different number of teeth in mesh, which means that different cutters must be used.

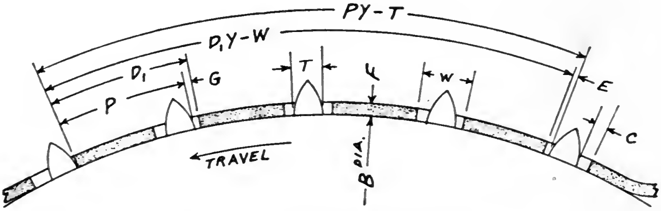

FIG. 1. Hold-back sprockets.

B, base sprocket dia. $= \dfrac{(D_1 - G)N}{3.1416} - F$

D_1, film perforation pitch $= D - DS$

D, nominal pitch of freshly perforated film

S, shrinkage

G, clearance of second tooth in mesh

N, number of teeth on sprocket

F, film thickness

Y, number of teeth in mesh minus one

P, sprocket-tooth pitch

Fig. 1 represents a hold-back or take-up sprocket; the sprocket is shown rotating counter-clockwise, the film feeding from a loop onto the sprocket at the right, and under tension as it leaves engagement at the left. It will be noticed that the clearance *G* has been so chosen that the tooth pitch is less than the film perforation pitch. This is because for best operation it is deemed advisable to relate the film and sprocket pitch in such a manner that the film is always free to pass onto the sprocket teeth and have the disengaging tooth carry the load.

D_1 is the perforation pitch of the film that is to operate on the sprocket and is equal to D, the nominal pitch of freshly perforated film minus $D \times S$, where S represents film shrinkage. Assuming that the film bends on a neutral plane midway between the base and emulsion surfaces, the tooth pitch P at this plane then equals $(D_1 - G)$. If N represents the number of teeth on the sprocket and F is the film thickness, then the sprocket base diameter as shown equals $(D_1 - G)N/\pi - F$. The actual value of G should, of course, be determined by the use for which the sprocket is intended but should be as small as practicable to insure that the film will run smoothly over the sprocket and reduce what is known as "sprocket-tooth frequency." For 10 or less teeth in mesh we have taken G equal to 0.001 inch and for 11 to 20 teeth, 0.0008 inch. The tooth thickness T is also reduced for more than 10 teeth in mesh.

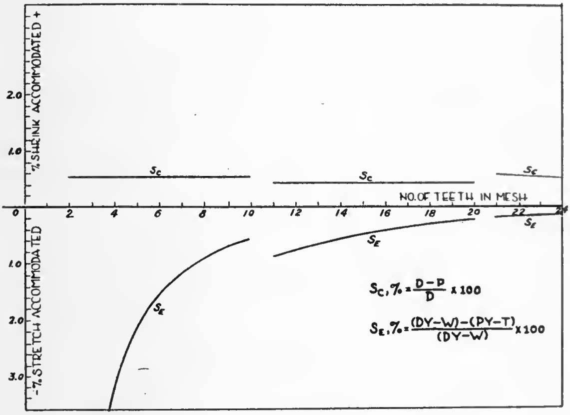

FIG. 2. 35-mm hold-back sprocket.

Although in general practice 20 teeth or more in mesh will seldom be used, some means of design for such cases should be considered. It will be recognized that for large numbers of teeth in mesh, the wide limits of shrink and stretch will not be permissible. This is true because the thickness of teeth T, for which there must be a practical minimum, has a direct bearing on the allowable film stretch or shrinkage. In view of these facts, we have, for these cases of more than 20 teeth in mesh, set what we believe is a minimum tooth thickness of $W - 0.028$ inch by fixing C as 0.020 inch and E as 0.008 inch, and allowed G to vary, G being equal to the constant C divided by

Y. This means, for instance, that for 16-mm sprockets with more than 20 teeth in mesh, the tooth thickness becomes 0.022 inch. The value of *G*, determined by the number of teeth in mesh, can then be substituted in the equation and the base diameter determined.

If now for the moment, the film as shown on the sprocket is assumed to be freshly perforated stock, the amount of film shrinkage accommodated is the ratio of $D-P$ to D and the film stretch accommodated is equal to the quantity $(DY-W)-(PY-T)$ divided by $(DY-W)$, where Y equals one minus the number of teeth in mesh.

Fig. 2 is a graphic representation for allowable film shrinkage *vs.* teeth in mesh for 35-mm hold-back sprockets. For 2 to 10 teeth in mesh G = 0.001 inch and the tooth thickness T = 0.055 inch; for 11 to 20, G = 0.0008 inch and the tooth thickness T = 0.049 inch; for more than 20 teeth in mesh T = 0.045 inch and G varies. The tooth thickness has been reduced for the larger numbers of teeth in mesh so as to increase the range between the shrinkage and stretch curves. By decreasing the clearance G for 11 to 20 teeth in mesh both curves have been lowered somewhat and thus the clearance increased at E for the teeth entering engagement. For a definite known number of teeth in mesh, the curves show the amount of stretch or shrinkage which will be accommodated before interference occurs. For instance, regardless of the total number of teeth on the sprocket, a sprocket with 6 teeth in mesh will take film which has

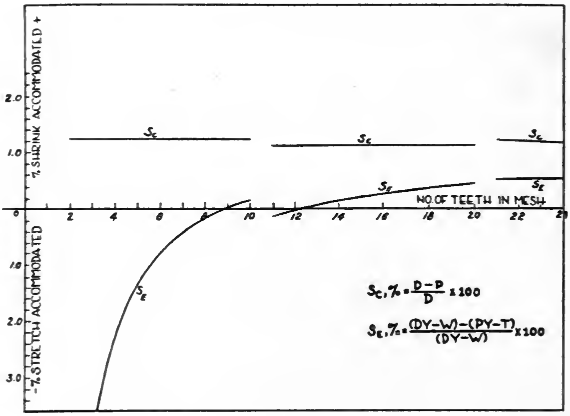

FIG. 3. 35-mm hold-back sprocket designed for 0.70% shrinkage.

stretched 1.51 per cent or shrunk 0.54 per cent. These shrinkage factors, of course, refer to freshly perforated stock.

If we examine the curves (Fig. 3) for sprockets designed to take film that has shrunk 0.70 per cent, we find the curves the same as the previous set but displaced. The stretch curve S_E now crosses the zero line and becomes positive between 8 and 9 teeth in mesh. This may be interpreted, for example, for 10 teeth in mesh, simply that the film must shrink at least 0.17 per cent from freshly perforated film dimensions if interference is not to be encountered but may shrink as much as 1.23 per cent. To show the amount of film slip on the sprocket for each tooth leaving engagement, let it be assumed that film which has shrunk 1.0 per cent is operating on the sprocket. Then the vertical distance from this point (1.0 per cent) to the S_C curve represents the slip which in this case is 0.23 per cent. For films with less shrinkage the slip of course will be greater.

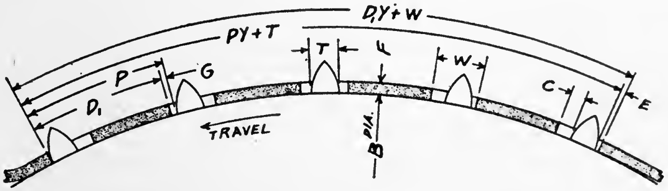

FIG. 4. Feed sprockets.

B, base sprocket dia. $= \dfrac{(D_1 + G)N}{3.1416} - F$
D_1, film perforation pitch $= D - DS$
D, nominal pitch of freshly perforated film
S, shrinkage
G, clearance of second tooth in mesh
N, number of teeth on sprocket
F, film thickness
Y, number of teeth in mesh minus one
P, sprocket-tooth pitch

Fig. 4, for feed sprockets, shows the sprocket rotating counterclockwise, receiving film from the right under tension and feeding into a loose loop on the left. In order that the film may pass freely onto the teeth, the sprocket-tooth pitch is greater than the perforation pitch. The sprocket base diameter then, as shown by the equation, equals $(D_1 + G)N/\pi - F$. In this case G, for 10 or less teeth in mesh, is taken equal to 0.0015 inch as against 0.0010 inch for hold-back sprockets.

The difference in the numerical value of G for holdback and feed sprockets is partially explained by the fact that for feed sprockets there is in general more tension on the film as it is wound on the sprocket and it is believed that instead of bending on a plane midway between the emulsion and base surfaces, it actually bends near the surface of the sprocket-wheel and in effect reduces G. Since it is difficult to ascertain or predict the exact location of the plane of bending, the values of G for feed sprockets have been increased as added assurance that the sprockets will function properly as feed members.

It will be noticed that in this case the percentage of film stretch accommodated, $(D-P)/D$, is independent of the number of teeth in mesh and the per cent of shrinkage accommodated varies with the number of teeth in mesh and the tooth thickness.

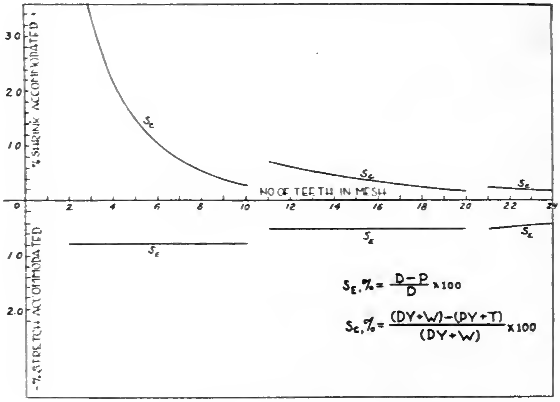

FIG. 5. 35-mm feed-sprocket.

In Fig. 5 the allowable film shrinkage curve S_C for feed sprockets now takes a shape similar to the stretch curve for hold-back sprockets. Decreasing the tooth thickness at 11 teeth in mesh increases the range between the two curves, and decreasing the clearance G permits greater film shrinkage. The amount of slip for each tooth leaving engagement for this case is represented by the vertical distance to the S_E curve.

The dimensions in a direction transverse to the film are given in Fig. 6. Again the dimensioning is related directly to the size of freshly perforated film, *V* being the distance between rows of perforations and *U* being the length of the perforations, both as taken from the film Standards. The clearance between perforations and teeth has been taken as 0.020 inch at the tooth base and 0.035 inch at the tooth tip. No effort has been made to show how the film might be guided by the sprocket-teeth or a combination of teeth and flange because in the opinion of the writers such practice is not advisable.

Figs. 7 and 8 show the relation of tooth base shapes to film perforations. In Fig. 7, for 16-mm, the tooth-base shape has been taken similar to the film perforation because only the one type of perforation is used. The 0.020-inch clearance between the perforation edges and the tooth allows a 0.042-inch flat as a bearing edge. In Fig. 8, for 35-mm sprockets, the form has been made to correspond more to the shape of the negative perforation. The reason for this is that 35-mm sprockets must accommodate both positive and negative types of perforation and the proposed shape satisfies this condition to a reasonable extent. The bearing edge of the tooth face in this case is approximately 0.060 inch.

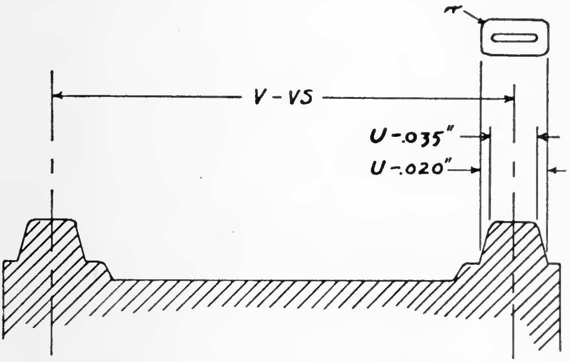

FIG. 6. Feed and hold-back sprockets.
S, per cent shrinkage from freshly perforated film
r, round corners with approximately 0.010-inch radius for 35-mm; 0.005-inch radius for 16- and 8-mm
V, center distance of freshly perforated film
U, length of perforation

For determining the tooth shape (Fig. 9), the method indicated is used for all types of sprockets. The values of *X* and *G* have been so chosen that the perforation leaving engagement is normally free of the tooth face after it is stripped about half of the tooth height.

Since the base diameter has already been determined the involute curve may be generated, and using the proper values of T, H, and X, the tooth face may be described by radius Q with its center at O, the point O being found by erecting a perpendicular at the midpoint of a straight line through MK and projecting this line to intersect the periphery of the base circle.

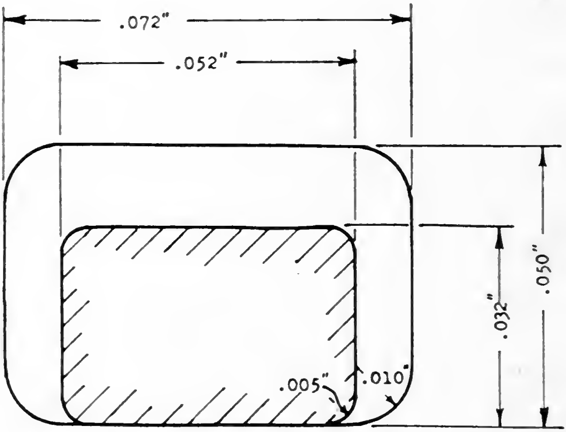

FIG. 7. Tooth base shape for 16-mm film sprockets.

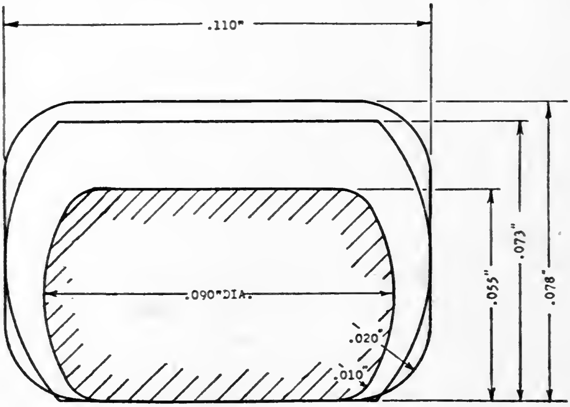

FIG. 8. Tooth base shape for 35-mm positive and negative film sprockets.

By means of the above-described method now let us follow through

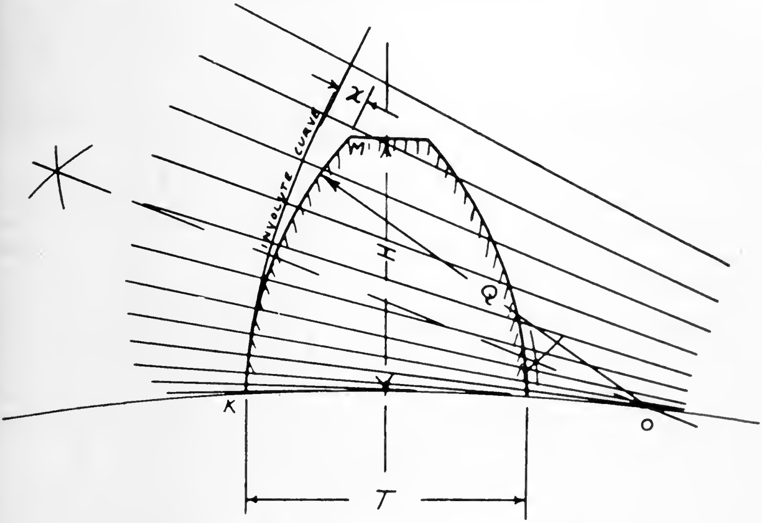

FIG. 9. Sprocket tooth shape

Film Size	T^*	H	X
35-mm	0.055	0.050	0.006
16-mm	0.032	0.032	0.004
8-mm	0.032	0.032	0.004

Radius Q to have its center at O on the base diameter with the arc passing through K and M.

* For 10 or less teeth in mesh. (Note.—Dimensions are given in inches)

a typical example for a sprocket running under the following conditions:

Sprocket: 32 teeth with 6 teeth in mesh to act as hold-back member
Film: 35-mm negative, 0.0055 inch thick; average film perforation pitch 0.1857 inch; perforation pitch of freshly perforated film 0.187 inch

$$B\text{, base dia.} = \frac{(D_1 - G)N}{3.1416} - F = \frac{(0.1857 - 0.001)32}{3.1416} - 0.0055 = 1.8850 \text{ inch}$$

$$S_C\text{, per cent shrinkage accommodated} = \frac{D - P}{D} \times 100 = \frac{0.187 - 0.1847}{0.187} \times 100 = 1.23$$

$$S_E\text{, per cent stretch accommodated} = \frac{(DY - W) - (PY - T)}{(DY - W)} \times 100 =$$

$$\frac{(0.187 \times 5 - 0.073) - (0.1847 \times 5 - 0.055)}{(0.187 \times 5 - 0.073)} \times 100 = -0.75$$

S, per cent shrinkage computed from freshly perforated stock as a basis =

$$\frac{0.187 - 0.1857}{0.187} \times 100 = 0.70$$

Dist. between rows of teeth = $V - VS = 1.109 - 1.109 \times 0.007 = 1.1012$ inch
Tooth base width = $U - 0.020 = 0.110 - 0.020 = 0.090$ inch
Tooth tip width = $U - 0.035 = 0.110 - 0.035 = 0.075$ inch
Corner tooth radius at base, $r = 0.010$ inch; for tooth profile shape refer to Fig. 9.

Other dimensions referring to items such as picture and sound areas will be determined by the particular use of the sprocket; discussion of these items is beyond the scope of this paper.

In conclusion it should be pointed out that by classifying sprockets in groups according to their use, by agreement on certain values for optimum performance, and by applying a method as outlined in this paper, a practical solution to the sprocket dimensioning problem and, ultimately, standards for film sprockets might be reached.

DISCUSSION

MR. FRIEDL, JR.: It is noted by the author that the matter of film guidance was not considered in the paper. In establishing the SMPE Recommended Practices for film dimensions, the subject of film guidance was taken into account. The standards are based on edge guiding.

MR. HILL: That question was considered beyond the scope of the paper, because the subject is very involved and deserves considerable attention. A complete investigation should be made of the means employed in guiding film through all stages from the time of perforating to projection, or sound reproduction.

MR. MAURER: The method of design presented in this paper leads to a varying range of shrinkage accommodation, depending on the number of teeth in mesh. Is it not preferable, when designing a sprocket for a given application, to take into account the actual shrinkage range that will be encountered and the number of teeth that will be in mesh, and design the sprocket in accordance with these specific conditions? In my experience this practice generally leads to a thicker and higher tooth than Mr. Hill and Mr. Schaeffer have proposed. I have considered this desirable because the larger tooth makes film threading easier, and the stronger tooth can perhaps be machined more accurately.

MR. HILL: Although it is theoretically possible to design sprockets in such a way, the changing of the tooth thickness for different numbers of teeth in mesh seems to complicate the problem unnecessarily. If, for a definite number of teeth in mesh, the sprocket can be designed with a tooth thickness so as to accommodate the desired film shrinkage, then there is no advantage in increasing the tooth thickness for a lesser number of teeth in mesh. The question of tooth thickness in connection with tooth strength and wear is not a major consideration, the ordinary tooth strength being more than sufficient.

MR. FRIEDL, JR.: How much film shrinkage might be expected in practice?

DR. CARVER: The average film shrinkage of cine positive as measured in the theaters will be about 0.3 per cent for a nitrate film and about 0.6 per cent for safety film.

IMPROVED MOTOR DRIVE FOR SELF-PHASING OF PROCESS PROJECTION EQUIPMENT*

HOMER TASKER**

Summary.—*Process projection photography requires that the shutter of the projector and that of the camera open and close simultaneously. The relation between the shutter speeds and the pole frequencies of normal motion picture motor systems is such that there may be one, four, or five incorrect shutter relationships for each correct one, if the motors are interlocked at random. Earlier methods of insuring correct phasing between camera and projector shutters did not take proper account of the economic importance of fast and reliable operation. This paper presents the results of a time and economic study indicating savings of many thousands of dollars annually per studio, accruing from the use of a motor system which automatically phases the shutters of camera and projector, and which has a very high degree of reliability. The design and performance features of such a motor system are described in their relation to earlier efforts along this same line, together with a report on production use of the new system.*

The economic and dramatic importance of process projection photography has been so great that motion picture managements have been inclined to overlook its cumbersome operation, even though wasteful of company time valued at $500 per hour and more. This is easily understood. Economically, the process often avoids the high cost of sending production units to locations and, dramatically, it often permits a story scope otherwise unachievable by microphone and camera at any price.

On the other hand, no amount of advantage can justify continued toleration of time-consuming features of this process if they can be improved upon. Among important past offenders is the motor system, and careful study has shown that the motor system which is the subject of this paper will effect economies of the order of $20,000 per year at this studio alone.

Although the system to be described here is an outgrowth of earlier work by Mr. Olin Dupy at MGM and Mr. Roy Otto at RKO, these earlier applications have not been described in print; hence this

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* Presented at the 1940 Spring Meeting at Hollywood, Calif.

** Paramount Pictures, Inc., Hollywood, Calif.

paper will describe the basic principle as well as the special features of the system as now being installed at Paramount.

A brief statement of the problem is necessary. Process projection photography normally involves the projection of a moving background scene upon a translucent screen in front of which are placed the actors involved, together with whatever foreground setting is needful to permit the whole to be welded into an effective motion picture scene.

The relationship of projector, screen, and camera is shown diagrammatically in the right-hand portion of Fig. 1. It is obvious that the shutter on the camera which sees both the foreground and the projected background must be open at the same time as that of the background projector and experience has proved that this relationship must be maintained with high accuracy. Random variations at rates which can be appreciated by the eye as flicker must not exceed ±6 degrees, while a fixed displacement of more than 15 degrees may cause serious loss of light.

Salient-pole synchronous motors, used in several studios for synchronous operation of recording machines and cameras, do not meet the requirements of synchronizing camera and projector in process projection because, for the currently used 60-cycle and 48-cycle motors there are, respectively, 10 and 4 different shutter relationships possible when the motors fall into step; only one of which is correct. Even though the shutters of camera and projector were carefully pre-aligned before starting, the accelerating times of the two machines would almost certainly be different so that phasing errors could not be avoided, except by provision of rather elaborate means for automatically phasing the shutters while running.

A 12-cycle synchronous motor system would provide the desired reliability of phasing but with serious penalties of bulk and weight of camera motor, plus the cost of generating a special frequency for this particular service. Use of these motors would necessitate extending the system to all studio camera operation or else changing motors on the camera as between process projection and normal motion picture service.

The normal a-c interlock motor system likewise has four incorrect interlocking positions for each right one but because it may be interlocked while at rest, shutter phasing is more controllable and hence this motor system has been universally used for process projection until the work of Dupy and Otto, mentioned above.

As applied to process projection photography this normal or "regular" interlock system (see Fig. 1) consists of a three-phase selsyn motor applied to each of the film-driving mechanisms plus another and larger three-phase selsyn unit direct-coupled to a suitable constant-speed driving source to form a "distributor" by which the whole system is rotated. As indicated in Fig. 1, the interlock connections are made by six-wire cables. The usual or normal speeds for such a system as used in the past are 1200 rpm for four-pole motors and 2400 rpm for two-pole motors, as indicated in this figure. Such motors interlock on every second pole. This condition gives rise to the fact that there are four incorrect interlocking positions for the camera motor, with respect to that of the projector, for each right one. Accordingly, with such a system it is necessary that the shutters be phased by hand at camera and projector before the motors are started.

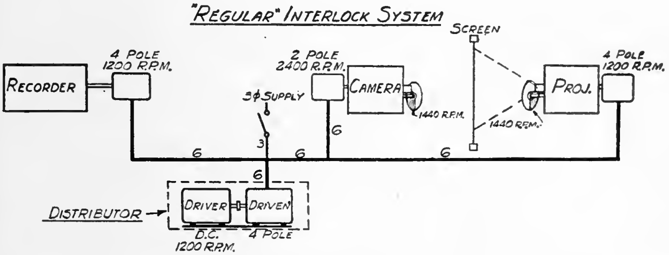

FIG. 1. Interlock connections.

If clutches are used to facilitate this phasing, the motor system must be interlocked (at rest) during this interval. If instead the drives are solidly pinned, the motors at camera and projector must be rotated from one to as many as five revolutions by hand to get motor and shutter into the proper mutual relationship. In either event, valuable time is lost because the phasing operation usually occurs when the director and the cast are ready and waiting to begin the next take. Furthermore, errors occur all too frequently, causing loss of complete takes.

These difficulties may be avoided by changing the speed of the interlock motors at camera and projector, and also the gearing between motor and shutter in each case, to such a value that there is exactly one motor interlock position for each complete revolution of the shutter. This requirement is met by two-pole a-c interlock motors geared 1:1 to the shutter shafts, and hence operated at 1440 rpm. It is also met by four-pole motors geared 1:2 and operated at 720 rpm. From the standpoint of operating speed and reliability this is the ideal arrangement for process projection because it eliminates all delays of pre-alignment and all hazard of poorly tightened clutches, etc.

This system requires, however, what amounts to an abnormal motor speed, *viz.*, 720 rpm for four-pole units of the system and 1440 rpm for two-pole units. There is also required a corresponding distributor or driving motor which is customarily four-pole and must, therefore, operate at 720 rpm. In this and other studios, the recording machine and cameras have heretofore been driven by a 1200-rpm (four-pole) motor. After weighing the comparative merits of introducing gears on the recording machine to accommodate the new speed against the addition of another distributor motor unit geared to 720 rpm, the latter was felt most desirable. This affords the basic arrangement shown in Fig. 2. The 1200-rpm distributor unit drives the recording machine and the 720-rpm distributor unit drives the camera and projector on process projection shots or the camera only on regular production. The numerals associated with the interconnecting cables indicate the number of wires in each. It will be noted that electrically there are two independent selsyn systems with a common three-wire stator energizing source. The rotor coupling of the two systems resides entirely in the mechanical connection afforded by the distributor gears.

In making the above change in the speed of the motors driving camera and projector, it is necessary that these motors deliver additional torque because of the higher gear ratio between motor and load.

Still further increase of torque was greatly desired because of past difficulty with flicker which was at times traceable to inadequate interlock between camera and projector. The steps taken to rewind these motors for very much higher torques than ever heretofore obtained in these particular frames are of sufficient interest to discuss here because they bring to light design factors bearing on motors for motion picture services which seem to have been overlooked.

The importance of small size and weight in motion picture camera motors is so great that full advantage is taken of their extremely intermittent duty. A motor which is satisfactory for the average "take" length of one minute, with two-minute intervals between, as in some danger of burning insulation if operated continuously for as much as ten or fifteen minutes on a camera which is more than normally stiff. Owing, however, to the rarity of scenes exceeding two or three minutes in length it was felt that there was sufficient margin of safety to permit increasing the torque enough to offset the proposed reduction in speed, but grave doubt was expressed as to the possibility of going beyond this point.

In order to examine this question experimentally without a series of expensive and time-consuming rewinds, one of these motors was operated on a test load equal to that of a normal camera and supplied with various excess voltages from a three-phase tapped transformer. Upon operating this motor at a constant speed of 1440 rpm and varying the input voltage (and hence the available interlock torque) we were immediately reminded of the rather elementary consideration that the mechanical power delivered by such a motor is represented by substantially in-phase electrical input power. In other words, as the voltage was increased the current decreased so long as the mechanical load remained constant. In consequence of this fact the copper losses of the motor actually reduced as the interlock was improved by increasing voltage; probably more than offsetting any increase in iron losses. The indications are that increased interlock tightness may be obtained in this way without any increase in heating so long as the load remains constant. The limit of such increase should occur when saturation sets in before the maximum torque actually required in service is obtained.

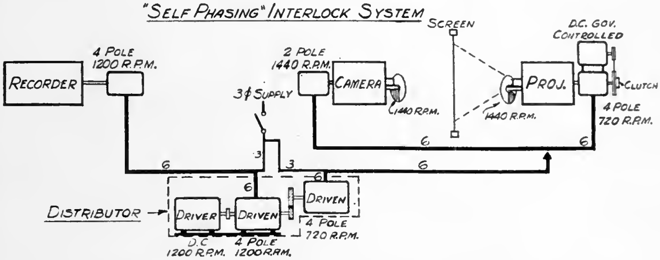

FIG. 2. Basic arrangement, employing additional distributive motor unit geared to 720 rpm.

It is true that with the higher applied voltage the motor is capable of delivering a great deal more power without falling out of step and that, if it were called upon to deliver this new maximum power, it would promptly overheat and burn the insulation. Fortunately, in the problems here considered, power of such excessive value can be demanded only in the case of a film buckle, and in this event the motor is instantly protected by the film buckle trip switch.

It is apparent that the results obtained by applying excessive voltage to the motor as described above are substantially duplicated upon rewinding the motor with fewer turns of heavier wire. In this case there is an increase in the exciting current but no increase in that portion of the current which represents mechanical power delivered to the load. Since both these currents pass through heavier wire of shorter length the total copper loss is substantially reduced, and so long as saturation is avoided within the normal requirements of the new motor it may be expected that heating will not increase.

Based on the above test data several motors were rewound for double their former torque. Heat tests on these motors not only bore out but somewhat exceeded expectations, as may be observed in Fig. 3. Of the three smooth curves arising from the origin, the upper one gives the performance of an unrewound motor on a continuous 1000-ft "take" at the normal motor speed of 2400 rpm. Temperature rise was measured by the copper resistance method.

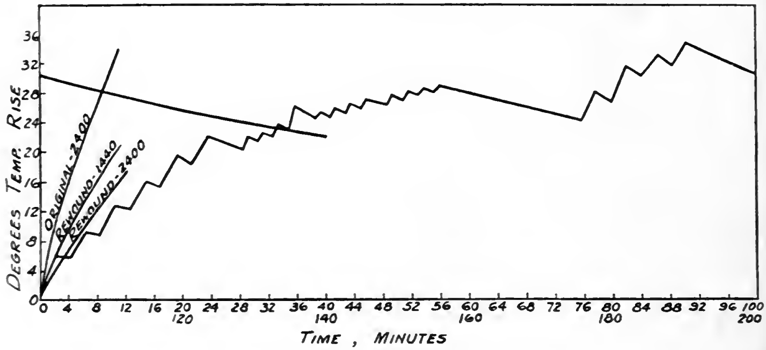

FIG. 3. Heat tests.

The lowermost of these three curves is an identical motor except for rewinding and indicates that the temperature rise is only half as great as before rewinding despite the fact that the latent power capacity of the motor is doubled. In consequence the rewound motors are far superior to their predecessors for process projection service for the dual reasons that they provide a much tighter interlock and operate at lower temperatures.

The reduction in speed required to accommodate the motor to the self-phasing system here described results in approximately 40 per cent increase in heating, as shown by the intermediate curve, but the end-result is still conservative as compared to the unrewound motors operating under the original conditions.

One of these rewound motors, operating at the new 1440-rpm speed, was put through one of the most severe production cycles ever encountered in practice. This is shown as the long, irregular line on Fig. 3. Operation through six 200-ft takes with two-minute rest periods between was followed by a series of twelve 60-ft closeups with one and one-half minute rest periods between. A ten-minute set-up period followed after which four additional 200-ft takes were made. Maximum temperature rise on this production run was $34^1/_2$°C as measured by the copper resistance method. This is very satisfactory as the motor is still well below a dangerous heating point and production requirements are seldom as severe as those given in this example.

Thus far, an elementary system has been described which has great advantages of rapidity and certainty in operation because it will always interlock with shutters in proper phase whenever the power is applied. To be a thoroughly adequate production tool, however, it must have other important features:

(*1*) There must be provision for running the projector alone for rehearsals.

(*2*) There must be provision for running the film on out at the end of a take or for rewinding it by back-tracking in the projector at the end of each rehearsal or take because unthreading the projector at the point where the take stops may scratch the film and spoil a subsequent take which may run a few feet farther.

(*3*) There must be simple provision for slating each production take.

(*4*) For silent shots there should be simple means for interlock operation of camera and projector alone, independent of the sound system.

(*5*) For such silent operation speeds 20 per cent above and 50 per cent below normal should be readily available and positively controllable by the projectionist. Nevertheless the normal 24-frame speed should be instantly available without supervision on his part, and without attention on his part.

(*6*) There should be a minimum number of switches or patches to change when changing from silent operation to operation from the sound recording system.

(*7*) There should be a minimum of special equipments to be set up when the process projection booth is moved from one stage to another.

(*8*) The entire system, including the necessary controls and switches, should involve a minimum of maintenance.

(*9*) Control of the system should be available at the camera position, both for rehearsals and for silent takes.

A system is shown in Fig. 2 which meets all these requirements when it is associated with the controls shown in the schematic diagram of Fig. 4.

It will be seen that the process projector is equipped with two motors. One is a d-c motor, equipped with a governor to control its speed at the standard 24 frames per second, plus a rheostat and tachometer for control of its speed above and below normal. The other is an interlock motor of the type described above. In the present application, the space available dictated that the two motors be mounted one above the other. In order to relieve the interlock motor of the burden of dragging the d-c motor when making normal sound shots an over-riding clutch is used.

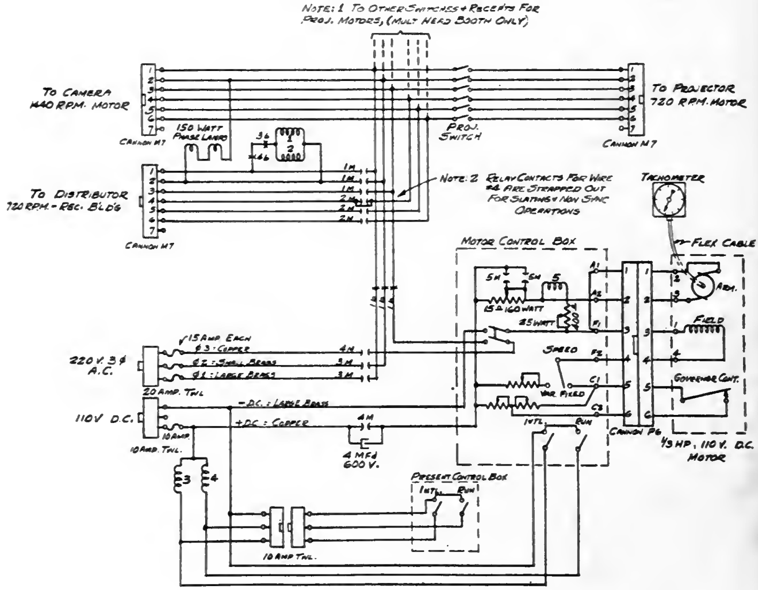

FIG. 4. System of Fig. 2 with associated controls.

Formerly rehearsals and silent shots involved the use of a separate local distributor equipment which was dolly-mounted, moved from stage to stage with the projection booth, and plugged in as required. This awkward and bulky apparatus is replaced by the new dual motor arrangement mounted directly and permanently on the projector. Operation is then as follows:

(*a*) *Rehearsals.*—The projectionist (or the stage crew *via* the remote control) throws the "Run" switch which applies power to the d-c motor which picks up the interlock motor through the overrunning clutch and drives the projector at the governor controlled speed of 24 frames per second. If some other speed is required it is obtained by the projectionist with the aid of field rheostat and tachometer after throwing the "Speed" switch to "Variable."

(*b*) *Run Outs, Etc.*—The projectionist throws the "Run" switch to run out at the end of a take. When fully reversible projectors become available at this studio, he will be able to rewind the film in the projector by merely throwing this switch to the reverse position. At that time, a centrifugal or magnetic clutch will be substituted for the overrunning clutch.

(*c*) When silent takes involving only the camera and projector (and not the sound recorder) are to be made, the interlock motors of projector and camera, taken together, become a complete independent interlock system through the application of local three-phase supply. This is accomplished with the utmost convenience and without any preliminary changes merely by throwing first the "Interlock" and then the "Run" switch, either at the remote position or in the projection booth. In other words, the difference between a rehearsal and a take is simply that for the latter, the "Interlock" switch was operated in addition to and before operating the "Run" switch.

(*d*) When a take is to be made which involves sound, the recordist operates the interlock controls in the recording building in the usual way, and as he does so, relays in the projection booth operate to connect this interlock voltage on through to projector and camera motors. The purpose of these relays is to isolate recorder and sound department distributor from the system during silent shots yet to instantly interconnect the entire system for sound shots. The relays used are idential with those employed at this studio for a number of years in connection with our previous method of slating. They involve very moderate maintenance.

(*e*) Slating no longer requires separate operation of the camera between takes as it is adequately cared for by the new camera slating device described by Mr. F. C. Gilbert.[1] This device performs its function while the system is coming up to speed.

Three months of experience with a trial installation of this equipment has proved its reliability, speed, and efficiency. The convenient controls speed up rehearsals. The complete absence of pre-phasing speeds up takes and reduces strain on directors and talent. The increased certainty of good results reduces the number of takes made, and it appears likely that the complete time studies made in the course of considering this motor system will result in subsequent improvements of equipment and technic which will permit additional savings of from $20,000 to $30,000 per year.

Finally, if process projection photography is to become a thoroughly efficient studio tool, it must not only be capable of swift, easy, and reliable operation in itself, but changes necessary to undertake this type of photography or return to normal photography without projection must be so simple that the two may be intermingled several times in a given production day. To this end it is very desirable that the same camera motor remain on the camera at all times; hence we are arranging to use only 1440-rpm camera motors and to supply only 720-rpm distributor service to the stages at all times. This means, of course, that such auxiliary motor-driven facilities as playback machines must also employ the new motor speeds. The costs of such changes, however, are negligible as compared to the benefits to be derived from a single standardized system for all studio production services.

REFERENCE

[1] GILBERT, F. C.: "Scene-Slating Attachment for Motion Picture Cameras," *J. Soc. Mot. Pict. Eng.*, **XXXVI** (April, 1941), p. 355.

BLACK LIGHT FOR THEATER AUDITORIUMS*

H. J. CHANON** AND F. M. FALGE†

Summary.*—The demand for near-ultraviolet radiation, commonly called "black light," in the production of luminescent effects has shown the need of a technical approach to the problem. New technics of measurement, design information, and data on sources and materials are necessary to insure most effective use of these new media.*

This paper covers suggestions for energizing fluorescent carpet, decorative wall and ceiling murals, and other decorative applications. Data are presented on sources of radiation, standard filters for absorbing the visible light emitted by the sources, and the relative response characteristics of various types of luminescent materials. The effect of extraneous visible light in masking the brightness produced by fluorescence is discussed. Methods for measuring the near-ultraviolet energy from mercury light sources in the field as well as in the laboratory are explained.

"Black light" is the popular term applied to the phenomenon of luminescence or the conversion of invisible near-ultraviolet energy to radiation in the visible portion of the spectrum by means of fluorescent or phosphorescent materials. Although theaters have employed this phenomenon for many years in spectacular stage productions, the lack of convenient sources and materials prevented its application in theaters primarily engaged in the presentation of motion pictures. New lamps and materials have made possible decorative and utilitarian applications as well as the spectacular, and the field is now of interest to all types of theaters. Theater operators, architects, designers and decorators, lighting engineers, and technicians require design information, new technics of measurement, as well as data on sources and materials to enable them to design objectively for a definite brightness and pattern in theater interiors.

Luminescence occurs when fluorescent or phosphorescent materials are exposed to near-ultraviolet radiation in the region of 3200 to 4000 Å. Luminescence may likewise be stimulated by energy in the visible range, that is, above 4000 Å. However, in this case, the

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brightness produced by fluorescence is not apparent as it is masked by the visible light from the exciting source and the effect is of little or no value in the theater.

When luminescence exists only *during* the period of excitation by the near-ultraviolet source, the effect is called fluorescence and when it persists for a period *after* the exciting energy is removed it is called phosphorescence. Materials having phosphorescent characteristics are sometimes more desirable for certain effects, although in general, either type is suitable for use in the theater.

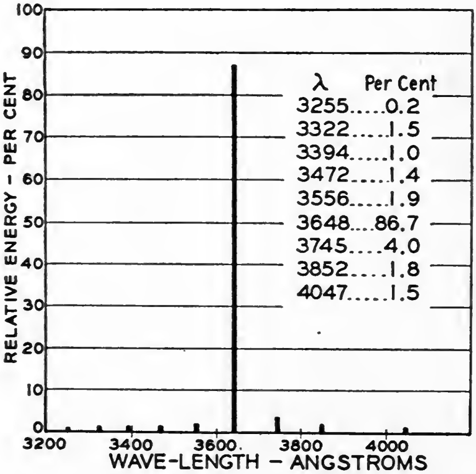

FIG. 1. Near-ultraviolet energy radiation normal to a 100-watt mercury lamp of the capillary type equipped with a Corning No. *587* filter. (Energy measurements by B. T. Barnes.)

SOURCES AND FILTERS

There are many sources of near-ultraviolet radiating energy in varying degrees. The 100-watt and 250-watt capillary mercury lamps supply the need for small relatively potent sources of low wattage. Where long throws are required, the carbon arc, because of its high intensity, is generally used. The 1000-watt water-cooled capillary mercury lamp may also be employed. Filament lamps, particularly the photoflood types having high filament temperatures, likewise produce moderate amounts of near-ultraviolet energy. Unlike mercury sources, which can not be turned on and off quickly, filament lamps can be used on flashers or dimmers in applications where this service may be desirable and high output in near-ultraviolet energy is not required. The blue fluorescent lamp, which has considerable energy below 4000 Å, has been found very satisfactory for some applications. The $2^1/_2$-watt argon glow lamp produces near-ultraviolet energy in small amounts suitable for some uses.

The energy radiation from a 100-watt mercury vapor lamp of the capillary type equipped with a Corning No. *587* filter is shown in Fig. 1. Most of the energy emitted is in the region of 3650 Å, the band of maximum response for the majority of the commercial materials employed for black-light effects.

Data on the transmission characteristics of several Corning filters which transmit near-ultraviolet radiation are shown in Table I. All these filters have a maximum transmission at 3650 Å and practically zero transmission below 3100 Å. The values in the table represent the percentage of normally incident radiation transmitted by representative filters of 5-mm thickness.

TABLE I

Per Cent Transmission of Corning Glass Filters 5 mm. Thick

	Wavelength in Angstroms	Type of Filter					
		584	*585*	*586*	*587*	*588*	*597*
Near ultraviolet	3020	0	0	0	0.5	0	0
	3130	3	2	0	4	5	3
	3340	42	48	5	31	40	44
	3650*	65	82	27	59	72	80
Visible	4050	0	70	0	1	18	14
	4358	0	37	0	0	0	0
	5461	0	0	0	0	0	0
	5770	0	0	0	0	0	0
	5961	0	0	0	0	0	0
	6908	0	2	0	0	6	1

* Maximum response of most luminescent materials.

For most black-light applications the best filter is one which has high transmission in the region of 3650 Å but absorbs most of the visible radiation. Table I shows that Corning filters Nos. *584*, *587*, and *597* have these desirable transmission characteristics. Filter No. *585* transmits considerable blue and some red light and may, therefore, be suitable for special effects where visible light in this region is not detrimental to the fluorescent pattern obtained. Where fluorescent materials must be observed in complete darkness it has been found that filter No. *586* is most applicable. Filter No. *587*, known as Heat Resisting Red Purple Ultra, has been employed in the majority of theater black-light applications.

The visible radiation transmitted by some of these filters is of a predominant color, usually violet in character, and is therefore of uncertain value in providing seeing at the low levels of general illumination in theater auditoriums. For such illumination it is better to employ visible light, essentially white in character, from other sources. Good control of this lighting is required for least impairment of the fluorescent decorative patterns.

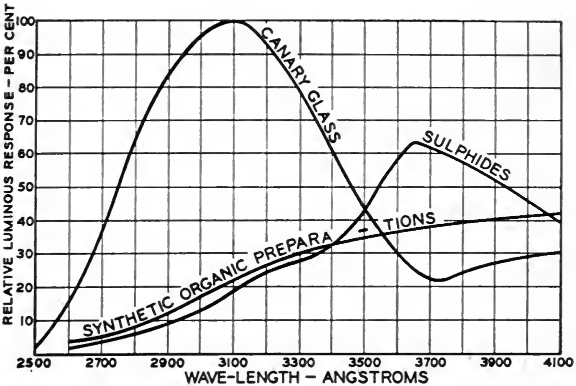

FIG. 2. Relative luminous response of luminescent materials to radiation of different wavelengths. The curves for the sulfides and synthetic organic preparations show typical average values for all colors. The canary (uranium) glass is Corning No. *375* with vaporized aluminum backing and with the face of the glass ground.

LUMINESCENT MATERIALS

Fluorescent materials for black light are usually synthetic organic materials—the majority of sulfides are phosphorescent. Fig. 2 shows the average response for these two groups as compiled from data for materials having different color responses. It is not unusual to have a pronounced resonant effect at some of the principal mercury lines; this effect has been eliminated for simplicity. Fig. 2 shows also the response characteristic of fluorescent Canary glass, the material selected in this study as a reference standard. Although this glass has a low response at 3650 Å, its permanence and availability counterbalance this objection. The section of this paper "Technic of Measurement" deals with the use of this material as a reference standard.

Measurements taken on about fifty different samples of fluorescent lacquer enamels indicate that the average relative efficiency of producing color by fluorescence is as shown in Table II.

TABLE II

Relative Response of Representative Fluorescent Lacquer Enamels

Color	Relative Brightness
White	100
Red	38
Orange	55
Yellow	88
Green	42
Blue	34
Violet	18

The colors in Table II were classified according to hues, as each of them was made up in various shades and tints. With the exception yellow is the brightest color; orange and green are next highest in efficiency; and red, blue, and violet are lowest. This characteristic is similar in shape to the response curve of the human eye. The eye is most sensitive to radiation in the green, yellow, and orange regions of the spectrum.

Lacquer materials, both opaque and transparent, are available for black-light effects. The majority of the former appear colored under visible light and this color is enhanced and may appear as another shade when energized with near-ultraviolet. A few appear colorless under the visible and glow in saturated color when energized. In applying the transparent materials it is important to provide light-reflecting backgrounds which increase the brightness of the resulting effect considerably.

In addition to lacquer enamels, many other fluorescent materials are now available. Some of these are plastics, papers, fabrics, inks, dyes, and water colors, each of which has specific applications. The choice of material depends on the use for which it is to be employed. The brightness of the material depends on three factors:

(*1*) The amount of near-ultraviolet energy falling on the material; this is affected by the energy distribution of the light source and by the transmission characteristics of the filter.

(*2*) The efficiency of the material in converting near-ultraviolet energy into visible light.

(*3*) The response of the eye to the color produced.

TECHNIC OF MEASUREMENT

Requisites common to all types of measuring equipment used in the field are simplicity, portability, and the ability to maintain calibration. For field as well as laboratory measurements of black-light sources and their effects, a method incorporating the use of a brightness meter and a foot-candle meter was found to be practicable when used in conjunction with a reproducible fluorescent material having unchanging characteristics. The material chosen as a reference standard (Fig. 3) was a two-inch square of Corning No. *375* fluorescent Canary glass 5 mm thick. This glass, which contains uranium, has particularly stable characteristics. It was found that when a piece of this glass is half covered with an opaque material and the whole is exposed for a long period of time to ultraviolet radiation, fluorescent brightness measurements on the two portions show no difference. Being a glass of considerable thickness it is sturdy and will withstand handling. The response of this material to ultraviolet energy is shown in Fig. 2.

Because of the low response of fluorescent Canary glass to energy in the 3650 Å band, it was found desirable to increase its brightness by means of an aluminized back and edge coating. To protect the aluminum surface, a black coating of protective lacquer can be applied if desirable. To minimize specular reflection the front surface of the glass was ground with No. 100 carborundum. This reference standard was used in laboratory and field measurements as a means of determining the radiation upon luminescent materials and the distribution of the near-ultraviolet radiation of sources.

The full-range brightness of the reference standard can be measured by means of the Luckiesh-Taylor brightness meter shown in Fig. 3. The advantage of this combination lies in the ability to measure the low levels of radiation often used for exciting fluorescent and phosphorescent materials in dimly lighted interiors.

The reference standard can be calibrated by exposing it to a standardized source of near-ultraviolet radiation equipped with a filter to absorb the visible light. The energy from the source transmitted by the filter can be calibrated in microwatts per square-inch or in milliwatts per steradian. With a reference standard prepared as described above, and a capillary type of mercury light-source equipped with a Corning No. *587* filter, the energy to produce a brightness of one foot-lambert was found to be 240 microwatts per square-inch. Knowing the near-ultraviolet energy distribution of the mercury source, and measuring the brightness of the reference standard with the Luckiesh-Taylor brightness meter, it is possible to compute any other value of incident near-ultraviolet energy within an accuracy of ±5 per cent. An investigation showed that within the range of zero to 40 foot-lamberts, or an energy value equal to approximately 10,000 microwatts per square-inch, there is no saturation; that is, for every increase in incident energy there is a corresponding increase in brightness of the reference standard.

The barrier type of foot-candle meter, such as the General Electric light meter, may likewise be utilized to measure near-ultraviolet radiation. A 5-mm piece of Corning No. *587* glass ground on the outside surface is clipped over the cell (Fig. 3). A deflection of one foot-candle on the meter is produced by an energy value of 54 microwatts per square-inch. The deflection is directly proportional up to 75 foot-candles, the highest value checked, which is the full range of the meter without multipliers.

In a darkened room, where all the ultraviolet sources are equipped with filters and practically no visible light is present, the sensitivity of the light-meter to near-ultraviolet energy can be increased by removing the clip-on filter. Under these conditions one foot-candle deflection is produced by an energy value of 27 microwatts per square-inch.

Where mercury sources are employed with filters such as the Corning No. *587* type, the energy in the incident visible light is negligible as compared to the near-ultraviolet energy. However, when the energy from filament lamp sources is being measured an error is introduced because of the greater percentage of visible light passed by the filter. For this type of measurement, the brightness produced by visible light can be conveniently obtained by measuring the brightness of a magnesium oxide disk (Fig. 3), or any other non-fluorescent material of known reflection factor. This value, subtracted from the brightness of the reference standard, is an approximate measure of the brightness produced by fluorescence.

APPLICATIONS

General.—The use of fluorescent-treated murals, medallions, drapes, *etc.*, introduces a new type of decorative treatment as well as a new form of utilitarian lighting for theater interiors. This approach makes possible the use of large expanses which may embrace the entire ceiling or walls, or the use of localized treatment. In either approach, the near-ultraviolet energy, which is invisible to the eye before it strikes the fluorescent material, is converted into visible light and follows the same laws as ordinary light. The radiation may be controlled by properly selected materials, and shielded in the same way as the energy from the familiar filament type of light-source.

Since black-light sources are relatively inconspicuous, the problem of shielding and locating them is generally simpler. While the beam or flood of black light may overlap a particular pattern or area, the light emission is confined to the surfaces upon which the fluorescent material is applied.

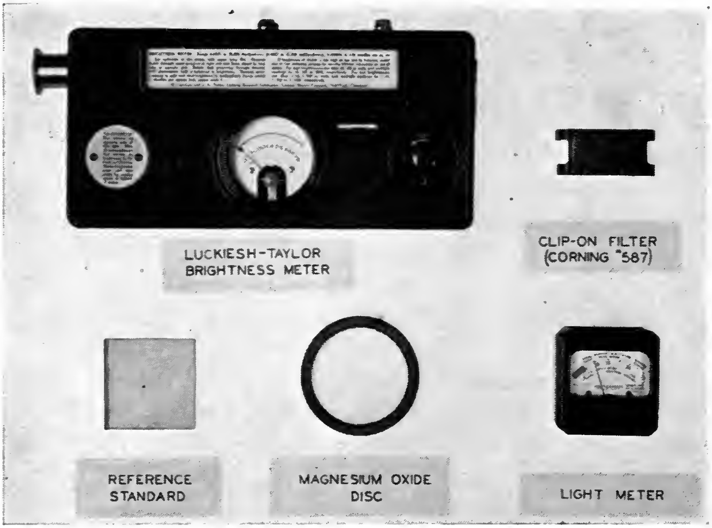

FIG. 3. Equipment for making measurements in the application of near-ultraviolet radiation for luminescence.

During the process of treating surfaces with fluorescent material it is well to observe the colors and their relative effect under black light in surroundings as nearly similar as possible to the auditorium. This procedure is often helpful in determining satisfactory placement for the black-light units, as well as in determining the amount of energy which will be required. Because of the variation in response of various fluorescent materials and the different efficiencies of equipment, only a general range of energy can be suggested here. For the 100-watt type *H-4* and the 250-watt type *H-5* mercury sources equipped with Corning No. *587* filters, the order of 0.5 to 1.0 watts per sq-ft gives a basis for estimating the approximate number of units required for average throws in the theater.

There is another factor which influences the effectiveness of luminescence called "masking." Masking light is any visible light which reaches the luminescent material and nullifies the luminescent effect. This is a subjective matter and will vary with individuals and various field conditions. The fluorescent materials which are now available have high response, and with reasonable care the masking light should not be a problem. This is particularly true in theater interiors and locations where low levels of general illumination are present. In theater foyers and in advertising the masking light becomes an important factor.

FIG. 4. Fluorescent mural over exit door at front of auditorium. Black-light unit below mural in architectural element over door.

Treatment of Large Areas.—Large fluorescent-treated wall or ceiling areas of fairly uniform low brightness, which are not broken up by designs that produce high contrast, create an atmosphere under which pictures may be viewed advantageously. The utilization of black light is generally the best under such conditions. From a complete blue sky ceiling, for example, enough near-ultraviolet energy may be converted into visible light by the fluorescent material to result in a low order of illumination throughout the entire auditorium. In this case the color of the illumination will predominate in blue, and if a more natural color for the appearance of clothes and people is desired, it may be necessary to offset the blue by well controlled down-lighting from a separate system of filament sources. The quality of the illumination is dependent upon the colors of fluorescent materials used and their distribution throughout the auditorium. In general, the warmer, more flattering tones are preferred.

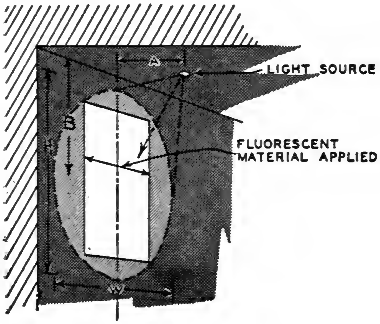

FIG. 5. One method of energizing wall panels treated with fluorescent material. See Table III for coverage with equipment having beam spread of approximately 30 degrees.

The placement of the black-light sources under these conditions is similar to that of general auditorium lighting. The sources can be concealed in coves below the ceiling line and aimed for most uniform distribution of energy. More uniform distribution is obtained as the distance of the source from the ceiling is increased. Wall urns, pilasters, and other architectural elements offer suitable locations.

Light-Emitting Decorations.—Individual wall murals or patterns can be rendered in sharp or graded outline with fluorescent materials. Variations in brightness as well as in color can be obtained readily. There is no need to control the black-light beam to fit the decoration exactly. It is therefore particularly applicable to intricate designs.

Light-emitting murals on the proscenium wall can be utilized to relieve the high contrast between the screen and surrounding areas and at the same time produce a decorative effect. A simple arrangement for energizing fluorescent-treated murals is shown in Fig. 4. Here the space above the exit doors has been utilized to conceal a 100-watt mercury lamp and suitable equipment.

Where the proscenium wall does not lend itself so readily to placement of the energizing source below the mural, a simple installation of a unit recessed in the ceiling can be made as shown in Fig. 5. More uniform illumination of the panel is possible by this method as more latitude in dimension *A* is usually practicable. Table III indicates coverage for different dimensions from a single unit having a 30-degree beam-spread.

FIG. 6. A striking effect simulating an outdoor scene is obtained with these wall murals due to the illusion of depth imparted by a blue background. The highlights on the gazelles are in warmer colors, amber and gold, and although the mural is flat, the appearance is similar to that of a three-dimensional object in a niche.

TABLE III

Approximate Coverage for Reflector of 30-Degree Spread, Used as in Fig. 5. (All Values Are in Feet)

A	*B*	*H*	*W*	Radiated Area (Sq-Ft)
8	10	13	7	64
	15	26	9	185
	20	56	12	510
12	10	12	8	76
	15	19	10	180
	20	31	13	310

Fig. 6 shows an installation of side-wall murals energized as suggested in Fig. 5. Fluorescent colors having high response were selected for use on the gazelles; thus they were accentuated in the higher brightness even though they were farthest removed from the energizing source.

Continuous decorative bands or panels (Fig. 7) may be energized by units of the type shown for carpet illumination (Fig. 10). The rectangular shape distribution with a beam-spread of approximately 10 × 80 degrees is desirable for this application. The coverage obtained for various sizes of murals and for different locations of the unit from the wall are shown in Table IV.

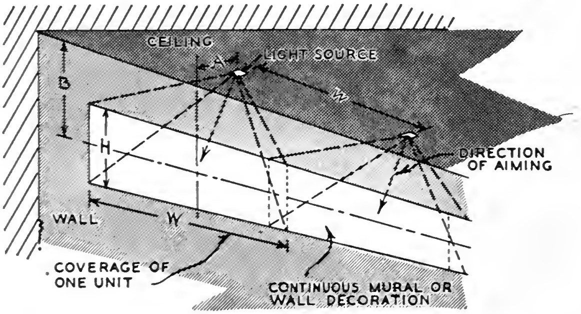

FIG. 7. Rectangular beam of black light more nearly fits panels of the same proportion. Downlighting unit such as shown in Fig. 10 is particularly applicable for continuous murals. See Table IV for coverage with equipment having beam spread of 10 degrees × 80 degrees.

TABLE IV

Approximate Coverage for Reflector with Rectangle Beam-Spread of 10° × 80°, Used as in Fig. 7. (All Values Are in Feet)

A	*B*	*H*	*W*	Radiated Area (Sq-Ft)
4	10	5	14	70
	15	12	20	240
	20	23	26	600
8	10	4	16	64
	15	7	22	154
	20	10	28	280
12	10	4	20	80
	15	6	25	150
	20	8	30	240

Energizing Fluorescent Carpet.—Self-luminous carpet, in addition to its decorative effect, is of value as a means of traffic or directional lighting. In contrast to the successive spots of light as produced by aisle illumination with low-wattage filament lamps recessed or attached to the seats, fluorescent carpet can be made to glow uniformly in well designed black-light installations.

In order to use the energy most efficiently, it is desirable to confine it as much as practicable to the fluorescent carpet. An effective method is to use downlighting equipment recessed in or suspended from the ceiling of an auditorium. Fig. 8 shows a cross-section of a typical theater auditorium with equipment placed directly over the aisles. In confining the near-ultraviolet to the aisle, annoying fluorescence of eyeballs and tinted spectacles is minimized. In either case the individual may not be able to see clearly because of the resulting haze. Some cosmetics and fabrics, as well as teeth, nails, and skin blemishes likewise fluoresce, and this occasionally may have embarrassing aspects. All the above-mentioned effects can be controlled by the introduction of some masking light.

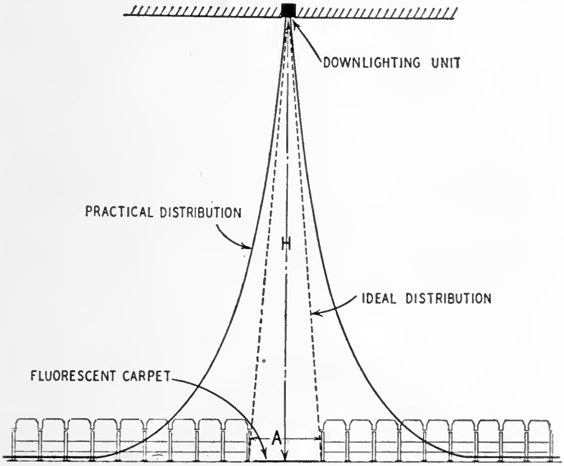

FIG. 8. It is desirable to confine the near-ultraviolet energy as much as possible to the aisle. Maximum efficiency can be thus assured and the spill of near-ultraviolet energy is minimized.

A reflector of parabolic contour has the property of collecting light from a source at the focus and redirecting it into a concentrated beam in the case of the paraboloid, or into a thin wedge in the case of a parabolic trough. A concentrated beam would be applicable from above if units were installed at very close spacing. This spacing can be increased by directing the beam through a prismatic lens which spreads the light along the aisle but not crosswise. Such a prism glass is included in the unit in Fig. 9. A parabolic trough redirects the light to a rectangular area of greater relative length without the intervention of any spreading glass (Fig. 10).

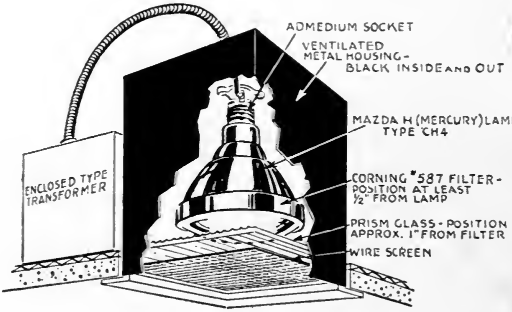

FIG. 9. A downlighting unit employing an integral projector type 100-watt mercury lamp. Recommended for the lower ceilings where a high degree of control is not necessary and where a low order of general illumination exists in the auditorium.

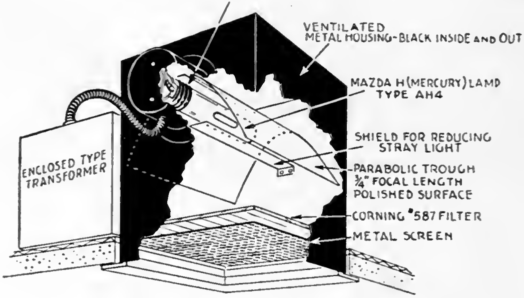

FIG. 10. A parabolic trough downlighting unit employing a 100-watt mercury lamp, type *AH-4*. This unit directs a ribbon of near-ultraviolet energy to the fluorescent carpet.

The lamp in Fig. 9 is of the capillary mercury type (100-watt *CH-4*) with integral reflector of paraboloidal form producing a relatively concentrated distribution. A Corning No. *587* filter screens out the major part of the visible radiation. Considerable energy is absorbed in the filter and it is therefore recommended that a coarse wire screen be included below the filter as protection in the event of glass failure. For fanning out the radiation along the aisle it is desirable to select a prism glass which directs more of the rays toward the front of the auditorium than to the back.

FIG. 11. Fluorescent carpet patterns, shown as illuminated with (*top row*) visible light and (*bottom row*) black light. Pattern *B* has approximately 50 per cent more brightness than *A* or *C*.

In Fig. 10 the light-source is identical with that in Fig. 9. However, it is incorporated in a tubular instead of a projector bulb. The lamp is placed in a separate parabolic trough so that it lies in the focal axis and off-center with respect to the opening of the reflector. This directs a greater proportion of the energy toward the front of the auditorium, as in the unit in Fig. 9, thus producing greater shielding for the audience from both the near-ultraviolet and the small amount of visible violet light transmitted by the filter.

Tests of response have been made on three patterns of fluorescent carpet. In Fig. 11 their appearance is indicated when illuminated with visible light and with black light. Since different colors are employed to make up the patterns, certain parts of the carpet will be brighter than others. Patterns *A* and *C* have approximately the same general brightness, whereas pattern *B* is fully 50 per cent brighter. Experiments in an auditorium, with equipments of the type suggested in Figs. 9 and 10, and with carpet types *A* and *C*, furnished the data on spacing for the different mounting heights given in Table V.

TABLE V

Spacing Requirements for Fluorescent Carpet Downlighting Units

Unit	Ceiling Height (Feet)	Spacing (Feet)
Fig. 9 or Fig. 10	20	18–20
Same	25	22–26
Fig. 10	30	28–32
Same	35	24–28
Same	40	20–24
Same	50	16–18*
Same	60	14–16*

* Spacings can be doubled if twin units are employed at each location. This may be desirable in some architectural and decorative treatments.

The use of a $2^1/_2$-watt argon glow-lamp in regular aisle lights which operate on standard lighting circuits without a transformer has a number of shortcomings. The near-ultraviolet energy is of a low order and accurate control of the energy is not practicable. In addition, the effect is likely to appear as spotty, as the conventional method using visible light, unless one or more lamps are placed in every aisle seat.

The above suggestions for energizing fluorescent carpet do not cover all effective equipments and methods. Satisfactory carpet brightness has been reported where the only energy striking the carpet came, merely incidentally, from mercury units directed at sidewall or ceiling murals treated with fluorescent paints. However, where no use of fluorescence is contemplated other than on carpet, the downlighting systems suggested, or other designs which incorporate close control, will be found most effective.

The authors acknowledge their indebtedness to Prof. John O.

Kraehenbuehl of the University of Illinois and to Mr. C. M. Cutler of the General Electric Company, respectively, for their collaboration in the technical and application aspects discussed herein.

BIBLIOGRAPHY

KRAEHENBUEHL, JOHN O., AND CHANON, H. J.: "The Technology of Brightness Production by Near-Ultraviolet Radiation," *Trans. I. E. S.*, **36** (Feb., 1941), p. 151.

CUTLER, C. M., AND CHANON, H. J.: "What Theater Operators Should Know About Black Light," *Better Theatres* (June, July, Sept., 1940).

PORTER, L. C., AND DITCHMAN, J. P.: "Black Light and Fluorescent Materials," *Magazine of Light*, General Electric Company (May, 1936) p. 25.

FALGE, F. M.: "And Now 'Black Light': Another Tool of Showmanship," *Better Theatres* (April, 1938).

CURRENT LITERATURE OF INTEREST TO THE MOTION PICTURE ENGINEER

The editors present for convenient reference a list of articles dealing with subjects cognate to motion picture engineering published in a number of selected journals. Photostatic copies may be obtained from the Library of Congress, Washington, D. C., or from the New York Public Library, New York, N. Y. Micro copies of articles in magazines that are available may be obtained from the Bibliofilm Service, Department of Agriculture, Washington, D. C., at prevailing rates.

Academy of Motion Picture Arts & Sciences, Technical Bulletin

(May 31, 1941)

Theater Acoustic Recommendations. Prepared by The Theater Sound Standardization Committee of The Academy Research Council.

American Cinematographer

22 (June, 1941), No. 6

Controlling Color for Dramatic Effect (pp. 262–263, 288, 290)	R. Mamoulian

22 (July, 1941), No. 7

An Artist Looks at Technicolor Cinematography (pp. 318, 346)	D. MacGurrin
Using Arcs as Boosters (pp. 319, 346)	M. Krasner
The "Inkie's" Place in Technicolor Lighting (pp. 323, 348–349)	E. Palmer
"Synchro-Sunlight" Movies with Reflectors (pp. 328–329, 350–351)	G. Gaudio
Composition and Continuity for Natural-Color Filming (pp. 334–335, 353–354)	J. A. Sherlock

Educational Screen

20 (June, 1941), No. 6

Motion Pictures—Not for Theaters, Pt. 28 (pp. 241–242)	A. E. Krows

Electronic Engineering

14 (June, 1941), No. 160

The Preparation of Sound-Film Track (pp. 255–257, 281)	R. H. Cricks
The Design of Wide-Band Video Frequency Amplifiers. Pt. I—High-Frequency Correction by Series Inductance (pp. 258–261, 266)	C. E. Lockhart

International Photographer

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Animated Cartoon Photography (pp. 10, 25)	J. W. BURTON
The Kodatron (pp. 13–16)	

International Projectionist

16 (April, 1941), No. 4

More Data on Control-Track Sound (pp. 7–8, 10–11)	A. NADELL
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National Defense and Its Effect upon Projection Room Supplies (pp. 15–16, 27–30)	L. CHADBOURNE
Fatal Theater Fires in Iowa Reveal Lack of Regulation (p. 18)	G. HARTNETT

Kinematograph Weekly

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Increased Brilliance in Motion Pictures. Colour-Former Positive Process Results (pp. 23, 26)	T. THORNE BAKER

Kinotechnik

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Ein neues Doppelspalt-Mikrophotometer zur Ausmessung von Lichttonaufzeichungen (A New Double Slit Microphotometer for Measuring Sound Film Densities) (pp. 54–57)	A. NARATH AND K. SCHWARZ
Die Sucher-Parallaxe bei Normalfilm-Aufnahmeapparaten (Finder Parallaz in Standard Film Cameras) (pp. 57–65)	H. WEISE

Motion Picture Herald

143 (June 28, 1941), No. 13

Commercial Television Starts, but without Films from Majors (pp.65–66)

FIFTIETH SEMI-ANNUAL CONVENTION

OF THE

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HOTEL PENNSYLVANIA, NEW YORK, N. Y.
OCTOBER 20TH-23RD, INCLUSIVE

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Hotel Reservations and Rates

Reservations.—Early in September, room-reservation cards will be mailed to members of the Society. These cards should be returned as promptly as possible in order to be assured of satisfactory accommodations. Reservations are subject to cancellation if it is later found impossible to attend the Convention.

Hotel Rates.—Special *per diem* rates have been guaranteed by the Hotel Pennsylvania to SMPE delegates and their guests. These rates, European plan, will be as follows:

Room for one person	$3.50 to $8.00
Room for two persons, double bed	$5.00 to $8.00
Room for two persons, twin beds	$6.00 to $10.00
Parlor suites: living room, bedroom, and bath for one or two persons	$12.00, $14.00, and $15.00

Parking.—Parking accommodations will be available to those motoring to the Convention at the Hotel fireproof garage, at the rate of $1.25 for 24 hours, and $1.00 for 12 hours, including pick-up and delivery at the door of the Hotel.

Convention Registration.—The registration desk will be located on the 18th floor of the Hotel at the entrance of the *Salle Moderne* where the technical sessions will be held. All members and guests attending the Convention are expected to register and receive their badges and identification cards required for admission to all the sessions of the Convention, as well as to several *de luxe* motion picture theaters in the vicinity of the Hotel.

Technical Sessions

The technical sessions of the Convention will be held in the *Salle Moderne* on the 18th floor of the Hotel Pennsylvania. The Papers Committee plans to have a very attractive program of papers and presentations, the details of which will be published in a later issue of the JOURNAL.

Fiftieth Semi-Annual Banquet and Informal Get-Together Luncheon

The usual Informal Get-Together Luncheon of the Convention will be held in the Roof Garden of the Hotel on Monday, October 20th.

On Wednesday evening, October 22nd, will be held the Silver Anniversary Jubilee and Fiftieth Semi-Annual Banquet at the Hotel Pennsylvania. The annual presentations of the SMPE Progress Medal and the SMPE Journal Award will be made and officers-elect for 1942 will be introduced. The proceedings will conclude with entertainment and dancing.

Entertainment

Motion Pictures.—At the time of registering, passes will be issued to the delegates of the Convention admitting them to several *de luxe* motion picture theaters in the vicinity of the Hotel. The names of the theaters will be announced later.

Golf.—Golfing privileges at country clubs in the New York area may be arranged at the Convention headquarters. In the Lobby of the Hotel Pennsylvania will be a General Information Desk where information may be obtained regarding transportation to various points of interest.

Miscellaneous.—Many entertainment attractions are available in New York to the out-of-town visitor, information concerning which may be obtained at the General Information Desk in the Lobby of the Hotel. Other details of the entertainment program of the Convention will be announced in a later issue of the JOURNAL.

Ladies' Program

A specially attractive program for the ladies attending the Convention is being arranged by Mrs. O. F. Neu and Mrs. R. O. Strock, *Hostesses*, and the Ladies' Committee. A suite will be provided in the Hotel where the ladies will register and meet for the various events upon their program. Further details will be published in a succeeding issue of the JOURNAL.

PROGRAM

Monday, October 20th

9:00 a. m. *Hotel Roof;* Registration.

10:00 a. m. *Salle Moderne;* Technical session.

12:30 p. m. *Roof Garden;* Informal Get-Together Luncheon for members, their families, and guests. Brief addresses by prominent members of the industry.

2:00 p. m. *Salle Moderne;* Technical session.

8:00 p. m. *Salle Moderne;* Technical session.

Tuesday, October 21st

9:00 a. m. *Hotel Roof;* Registration.

9:30 a. m. *Salle Moderne;* Technical session.

2:00 p. m. *Salle Moderne;* Technical session.
Open evening.

Wednesday, October 22nd

9:00 a. m. *Hotel Roof;* Registration.

9:30 a. m. *Salle Moderne;* Technical and Business session.
Open afternoon.

8:30 p. m. Fiftieth Semi-Annual Banquet and Dance.
Introduction of officers-elect for 1942.
Presentation of the SMPE Progress Medal.
Presentation of the SMPE Journal Award.
Entertainment and dancing.

Thursday, October 23rd

10:00 a. m. *Salle Moderne;* Technical session.

2:00 p. m. *Salle Moderne;* Technical and business session.
Adjournment

W. C. KUNZMANN,
Convention Vice-President

SOCIETY ANNOUNCEMENTS

1941 FALL CONVENTION

NEW YORK, N. Y.

OCTOBER 20TH–23RD, INCLUSIVE

The 1941 Fall Convention will be held at New York, N. Y., with headquarters at the Hotel Pennsylvania.

Members are urged to make every effort to attend the Convention, as a very interesting program of papers and presentations is being arranged.

Details of the Convention will be found elsewhere in this issue of the Journal.

ADMISSION COMMITTEE

At a recent meeting of the Admissions Committee, the following applicants for membership were admitted into the Society in the Associate grade:

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1225 Vine St.,
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BACK NUMBERS OF THE TRANSACTIONS AND JOURNALS

Prior to January, 1930, the *Transactions* of the Society were published quarterly. A limited number of these *Transactions* are still available and will be sold at the prices listed below. Those who wish to avail themselves of the opportunity of acquiring these back numbers should do so quickly, as the supply will soon be exhausted, especially of the earlier numbers. It will be impossible to secure them later on as they will not be reprinted.

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	20	1.25		26	1.25		34	2.50
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	22	1.25		28	1.25		36	2.50
	23	1.25	1927	29	1.25	1929	37	3.00
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Beginning with the January, 1930, issue, the JOURNAL of the Society has been issued monthly, in two volumes per year, of six issues each. Back numbers of all issues are available at the price of $1.00 each, a complete yearly issue totalling $12.00. Single copies of the current issue may be obtained for $1.00 each. Orders for back numbers of *Transactions* and JOURNALS should be placed through the General Office of the Society and should be accompanied by check or money-order.

SOCIETY SUPPLIES

The following are available from the General Office of the Society, at the prices noted. Orders should be accompanied by remittances.

Aims and Accomplishments.—An index of the *Transactions* from October, 1916, to December, 1929, containing summaries of all articles, and author and classified indexes. One dollar each.

Journal Index.—An index of the JOURNAL from January, 1930, to December, 1935, containing author and classified indexes. One dollar each.

Motion Picture Standards.—Reprints of the *American Standards and Recommended Practices* as published in the March, 1941, issue of the JOURNAL; 50 cents each.

Membership Certificates.—Engrossed, for framing, containing member's name, grade of membership, and date of admission. One dollar each.

Journal Binders.—Black fabrikoid binders, lettered in gold, holding a year's issue of the JOURNAL. Two dollars each. Member's name and the volume number lettered in gold upon the backbone at an additional charge of fifty cents each.

Test-Films.—See advertisement in this issue of the JOURNAL.

JOURNAL

OF THE SOCIETY OF

MOTION PICTURE ENGINEERS

Volume XXXVII **September, 1941**

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JOURNAL
OF THE SOCIETY OF
MOTION PICTURE ENGINEERS

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 subscription 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.

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*Term expires December 31, 1941.

**Term expires December 31, 1942.

NEW AND OLD ASPECTS OF THE ORIGINS OF 96-CYCLE DISTORTION*

J. O. BAKER AND R. O. DREW**

Summary.—*The work of previous investigations is reviewed and correlated with the results obtained in a comprehensive study of 96-cycle distortion due to the presence of sprocket-holes adjacent to the sound-track. This distortion has been known for some time. Much improvement has been made by the adoption of the magnetic-drive recorder, the non-slip printer, and the rotary stabilizer sound-head for the purpose of overcoming the problem of slippage.*

Recording sound on doubly perforated film will introduce 96-cycle disturbances of both amplitude and frequency modulation because of the film flexure and possible variations of film speed at the sprocket-hole rate.

Processing sound records on doubly perforated film will introduce a 96-cycle hum and amplitude modulation depending upon the processing technic.

Printing sound records on doubly perforated film introduces 96-cycle hum and disturbances of both amplitude and frequency modulation, due to film flexure and variations of film speed at sprocket-hole rate.

Reproducing sound records on doubly perforated film introduces 96-cycle disturbances because of film flexure.

Since it has been proved that the presence of the sprocket-holes adjacent to the sound-track is the source of all 96-cycle distortion, and the omission of the sprocket-holes entirely eliminates this distortion, it becomes obvious that singly perforated film should be used throughout all phases of sound recording and reproduction if complete freedom from 96-cycle distortion is to be obtained.

Substantial improvement can be realized if the singly perforated film is employed only for the original negative, master positive, and re-recorded negative, and doubly perforated film for the release prints. The use of singly perforated film throughout all phases has a decided advantage of providing additional space, without affecting the picture dimensions for a double-width sound-track or two sound-tracks, one for control or other purposes.

Types of 96-Cycle Distortion.—If a film is given a uniform exposure, as, for example, in the recording of an unmodulated density track, it is not uncommon when the film is run through a reproducing machine to hear a faint tone of 96-cycle pitch. This means that there are

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received June 5, 1941.

** RCA Manufacturing Co., Indianapolis, Ind.

fluctuations in the density at the rate of 96 per second. They may be too small to measure with an ordinary densitometer, but they can be measured by means of a wave analyzer. This 96-cycle tone is absent if the exposure is so low that the film is almost transparent, and with very high densities there is practically no 96-cycle output, since the total amount of light transmitted is small. The maximum tone is produced if the film is a light gray, such as to transmit approximately half of the incident light. Since variable-width recordings consist of clear areas and substantially black areas, they are not ordinarily subject to 96-cycle hum, except when the film is improperly guided.

If a constant tone (for example, 1000 cps) is recorded on a variable-density track and means provided for measuring rapid fluctuations in the amplitude of the reproduced tone, it will usually be found that the 1000-cycle tone rises and falls in amplitude at the rate of 96 times per second. This effect, like the density modulation, is generally negligible in variable-area recordings.

A "flutter bridge" is a device which measures departures from normal frequency of a reproduced tone. For example, a constant 3000-cycle tone may be recorded, and when it is reproduced its pitch or frequency may vary periodically between 2994 and 3006 cycles per second. Flutter-bridge measurements show that recordings on 35-mm film are rarely entirely free from some flutter or frequency modulation at the rate of 96 cycles per second. This is equally true of variable-density and variable-area recordings.

The density modulation, amplitude modulation, and frequency modulation are present in the sound-tracks as first recorded, or in the sound negatives. The operation of duplicating by printing introduces further causes of 96-cycle distortion and while these may occasionally cause some compensating or neutralizing effect, so that the print film has less of the 96-cycle distortion than the negative, ordinarily the effects are cumulative, and prints have more distortion than the negatives.

REVIEW OF PREVIOUS INVESTIGATIONS

The influence of sprocket-holes upon the recorded sound in 35-mm films has been known for some time. One effect, which was early observed and steps taken to correct, was the slippage of the film when passing over a toothed sprocket. While a sprocket could be designed to operate without slippage for a film with a given sprocket-hole pitch, it would not be satisfactory for all films due to shrinkage which varies with the age and the condition of the film. Some of the steps taken to overcome the problem of shrinkage were the magnetic drive recorder[1] which utilized a drum without sprocket-teeth, and suitable damping to insure uniform passage of the film past the recording point; the non-slip printer[2] which also employed a smooth drum, whose diameter is calculated so that with suitable compensating loop-formers, the negative and positive film could contact each other at the printing point without slippage; and the rotary stabilizer sound-head[3] which likewise carried the film past the scanning point over a rotating drum whose motion was smoothed by the rotary stabilizer.

The adoption of the smooth drum instead of a sprocket for obtaining uniform film motion in the recording, printing, and reproducing of sound made considerable improvement in the quality, thus eliminating the 96-cycle hum. The presence of the sprocket-holes adjacent to the sound-track still introduces 96-cycle flutter in variable-area sound. Both the 96-cycle hum and 96-cycle flutter are present in variable-density sound.

Effect of Sprocket-Hole Pitch in Printing.—J. Crabtree[4] studied the production of sound-film prints from variable-density negatives by a sprocket printer from the viewpoint of high-frequency response and uniformity of product.

96-Cycle Distortion by Film Processing.—The influence of sprocket-holes upon the development of a variable-density sound-track was observed and reported upon by Frayne and Pagliarulo[5] in 1936. They summarize their work as follows:

> An unmodulated sound-track shows 96-cycle modulation on development. The effect is a maximum at the edge of the sprocket-holes and diminishes exponentially for a distance of approximately 30 mils into the sound-track. A film modulated by a constant frequency shows 96-cycle amplitude and frequency modulation over the same area. Both effects are introduced principally during processing of the film. A film having no sprocket-holes on the sound-track side is entirely free of these effects. The conclusion is that processing standards in many laboratories require improvement to eliminate distortions of this type.

96-Cycle Distortion Due to Deformation Next to Sprocket-Holes.—Crabtree and Herriott[6] made a study of the film distortion at the sprocket-holes when the film is flexed around a curved surface. They presented a series of photographs of the image of a parallel-line fluctuations in the density at the rate of 96 per second. They may be too small to measure with an ordinary densitometer, but they can be measured by means of a wave analyzer. This 96-cycle tone is absent if the exposure is so low that the film is almost transparent, and with very high densities there is practically no 96-cycle output, since the total amount of light transmitted is small. The maximum tone is produced if the film is a light gray, such as to transmit approximately half of the incident light. Since variable-width recordings consist of clear areas and substantially black areas, they are not ordinarily subject to 96-cycle hum, except when the film is improperly guided.

If a constant tone (for example, 1000 cps) is recorded on a variable-density track and means provided for measuring rapid fluctuations in the amplitude of the reproduced tone, it will usually be found that the 1000-cycle tone rises and falls in amplitude at the rate of 96 times per second. This effect, like the density modulation, is generally negligible in variable-area recordings.

A "flutter bridge" is a device which measures departures from normal frequency of a reproduced tone. For example, a constant 3000-cycle tone may be recorded, and when it is reproduced its pitch or frequency may vary periodically between 2994 and 3006 cycles per second. Flutter-bridge measurements show that recordings on 35-mm film are rarely entirely free from some flutter or frequency modulation at the rate of 96 cycles per second. This is equally true of variable-density and variable-area recordings.

The density modulation, amplitude modulation, and frequency modulation are present in the sound-tracks as first recorded, or in the sound negatives. The operation of duplicating by printing introduces further causes of 96-cycle distortion and while these may occasionally cause some compensating or neutralizing effect, so that the print film has less of the 96-cycle distortion than the negative, ordinarily the effects are cumulative, and prints have more distortion than the negatives.

REVIEW OF PREVIOUS INVESTIGATIONS

The influence of sprocket-holes upon the recorded sound in 35-mm films has been known for some time. One effect, which was early observed and steps taken to correct, was the slippage of the film when passing over a toothed sprocket. While a sprocket could be designed to operate without slippage for a film with a given sprocket-hole pitch, it would not be satisfactory for all films due to shrinkage which varies with the age and the condition of the film. Some of the steps taken to overcome the problem of shrinkage were the magnetic drive recorder[1] which utilized a drum without sprocket-teeth, and suitable damping to insure uniform passage of the film past the recording point; the non-slip printer[2] which also employed a smooth drum, whose diameter is calculated so that with suitable compensating loop-formers, the negative and positive film could contact each other at the printing point without slippage; and the rotary stabilizer sound-head[3] which likewise carried the film past the scanning point over a rotating drum whose motion was smoothed by the rotary stabilizer.

The adoption of the smooth drum instead of a sprocket for obtaining uniform film motion in the recording, printing, and reproducing of sound made considerable improvement in the quality, thus eliminating the 96-cycle hum. The presence of the sprocket-holes adjacent to the sound-track still introduces 96-cycle flutter in variable-area sound. Both the 96-cycle hum and 96-cycle flutter are present in variable-density sound.

Effect of Sprocket-Hole Pitch in Printing.—J. Crabtree[4] studied the production of sound-film prints from variable-density negatives by a sprocket printer from the viewpoint of high-frequency response and uniformity of product.

96-Cycle Distortion by Film Processing.—The influence of sprocket-holes upon the development of a variable-density sound-track was observed and reported upon by Frayne and Pagliarulo[5] in 1936. They summarize their work as follows:

> An unmodulated sound-track shows 96-cycle modulation on development. The effect is a maximum at the edge of the sprocket-holes and diminishes exponentially for a distance of approximately 30 mils into the sound-track. A film modulated by a constant frequency shows 96-cycle amplitude and frequency modulation over the same area. Both effects are introduced principally during processing of the film. A film having no sprocket-holes on the sound-track side is entirely free of these effects. The conclusion is that processing standards in many laboratories require improvement to eliminate distortions of this type.

96-Cycle Distortion Due to Deformation Next to Sprocket-Holes.—Crabtree and Herriott[6] made a study of the film distortion at the sprocket-holes when the film is flexed around a curved surface. They presented a series of photographs of the image of a parallel-line screen reflected from the emulsion surface of 35-mm film when flexed around drums of different diameters and sprockets of various sizes.

Measures for Reducing 96-Cycle Distortion.—Steps have been taken to minimize the distortion, for instance:

(*a*) Constant-speed drum for recording, printing, and reproducing.

(*b*) Standardization of sprocket-hole dimensions for sound negative and positive film stock.

(*c*) The reduction of the maximum film shrinkage from 1.5 per cent to 0.4 per cent.

(*d*) More thorough agitation of developer solutions to reduce the density variation during processing.

There still remains the problem of flexure of the film and the mismatching of negative and positive perforations in non-slip printing.

ANALYSIS

Flutter Is Not Due to Changes in Speed of the Film Drum.—Tests by the authors completely confirm the conclusions reported by Frayne and Pagliarulo, namely, that if the sprocket-holes on the sound-track side are omitted, none of the 96-cycle distortions appear. Our tests, which are described in more detail later, were made using singly perforated film, the recording being done on a machine of the magnetic drive type in which average film speed is controlled by sprockets but the film is carried past the optical system on a smooth drum. Such a test proves that there are no 96-cycle fluctuations in the speed of the film as a whole (or, in other words, in the speed of the drum) but that the 96-cycle flutter which the doubly perforated film exhibits must be a purely local effect of the proximity of the perforations.

Since there is no mystery in the appearance of 96-cycle flutter when the recording or reproducing machines are of the sprocket-propulsion type, it will be assumed throughout the remainder of this paper that there is no 96-cycle flutter in the speed of the drum which carries the film, and our investigation is of the other possible causes of the flutter.

Density Variations.—Variations in density are produced, first, by exposure variations due to the polygoning effect of the film when flexed around a curved surface, and, second, by the increased agitation of the developer at the sprocket-holes in processing.

Density variations at the sprocket-hole rate results in hum or a 96-cycle tone which is superimposed on the recorded modulation. In the case of variable-density recordings, the increased agitation at the sprocket-holes also increases the gamma which produces an amplitude variation of the recorded modulation. Density variations or changes in gamma will, of course, have little effect upon variable-area recordings.

In discussing the causes of density fluctuations consideration needs to be given only to unmodulated sound records. The increased agitation of the developer at the sprocket-holes will increase the developer speed at that region and, assuming the exposure to be uniform, microdensitometer measurements would show a maximum density opposite the center of the sprocket-holes, provided there were no directional effects. If directional effects are in evidence, then the maximum density will be shifted to one side of the center of the sprocket-hole. The exposure, however, may not be uniform. The film stiffness varies along its length depending upon the cross-section, and will be greater in the region between successive sprocket-holes than it will be at the sprocket-holes. Hence, when flexed around a curved surface, the film will be closer to that surface where the film stiffness is greatest (Fig. 1). The effect of this is a shorter radius from the center of rotation of the drum at this point and a longer radius at the sprocket-

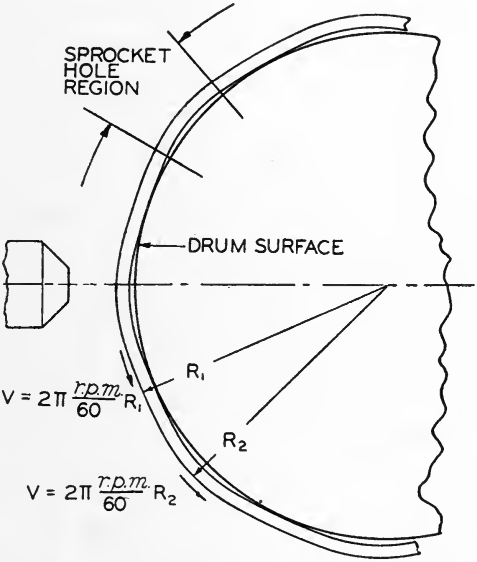

FIG. 1. Polygoning of film when flexed around a drum.

holes. With the drum rotating at a constant angular velocity the film is undergoing a speed variation at the sprocket-hole rate proportional to the variations in its distance from the axis. Since exposure of the film is dependent upon the product of the intensity of exposing light and exposure time, it is easily seen that the exposure of the film will be less at the sprocket-holes than between the sprocket-holes. The effect of variations in negative exposure is probably small compared to the developer effect, but whatever there is it will tend to counteract the latter.

The exposure and developing effects will hold for either negative or positive. However, in the case of the positive there is the additional effect of the varying transparency of the negative.

Density Variations in Printing.—As outlined in the preceding section a negative will have density variations along the sound-track at the sprocket-hole rate of 96 cycles. For the sake of simplicity, assume the variation to be symmetrical with respect to the sprocket-holes, that is, a maximum density at the center of the hole and a minimum at the center of the region between two adjacent sprocket-holes. Neglecting for the moment the effect of polygoning in the printer, the positive exposure will vary in inverse relationship to the density of the negative. Thus, for the case of negative and print sprocket-holes in register, such as printing on a sprocket printer, the exposure of the positive will be least at the center of its sprocket-holes and greatest at the center of the region between sprocket-holes. Upon development of the positive, the sprocket-hole region will develop faster and the increased development will tend to compensate for the underexposure. The net result will be that the regions of maximum density in the print may be opposite the sprocket-holes, or between the sprocket-holes, depending upon whether the effect of exposure variations or development variations predominates; or there may be no measurable 96-cycle hum at all in the print, if the effects balance.

In the case of negative and positive sprocket-holes out of register, as occurs part of the time in printing on a non-slip printer, the positive exposure is greatest at the sprocket-holes and least in between. The result in this case is a 96-cycle component in the positive which is the cumulative effect of variations in the print exposure, and the greater development which the print receives next the sprocket-holes.

When prints are made on a non-slip printer the relative positions of the negative and positive sprocket-holes can not be predicted, and may slowly change from in register to out of register. Therefore, prints made on non-slip printers have been more frequently criticized on the score of hum than prints made on sprocket printers.

The explanations just given do not take account of directional effects in development. These may tend to obscure the relationships, so that the advantages of printing with sprocket-holes in registration are not as definite as would be expected.

The disadvantage of the non-slip printer for making variable-density prints on the score of giving higher hum levels, would disappear if singly perforated film were used for negatives, since a print made on it would have only the 96-cycle distortion introduced by print processing while the print made on a sprocket printer would have a 96-cycle distortion produced by slippage as well as that due to processing.

Amplitude Modulation.—When a tone is recorded on a variable-density system and reproduced, the amplitude of the reproduced tone is proportional to the difference in transmissions at the peak and valley of the wave. High gamma, by increasing contrast, produces a greater difference between maximum and minimum density, but not necessarily a greater difference between maximum and minimum transmission. The density difference corresponds to the ratio of maximum to minimum transmissions, but a high ratio means a large absolute difference only when the average transmission is high. Thus it is quite common to reduce the output level of a variable-density print by printing it darker than normal.

In the case of a negative the increased development next to the sprocket-holes tends to give greater contrast but since it also makes the negative denser at these places the output of recorded tone may be either greater or less opposite the sprocket-holes than in between, depending upon which effect predominates. When this same negative is printed, however, on a printer which keeps the sprocket-holes in registration, the high contrast in the negative is passed on to the print, and the denser negative area, which goes with the high contrasts, produces a lighter print. Both effects then tend to increase the amplitude of the output tone opposite the sprocket-holes. It has already been explained that if a print is made with sprocket-holes in registration the development effects in negative and print may neutralize so far as average print density is concerned. If this occurs such a print may show little or no hum, but the additive effects of increased contrast in negative and print would tend to produce considerably greater amplitude of recorded tone opposite the sprocket-holes.

In the case of variable-area recording similar factors are at play, but their effects will be negligibly small except at very high frequencies, where fogging between waves becomes a factor of importance. Thus in recording a 9000-cycle wave considerable amplitude modulation as well as hum may result from unequal development of negative and print around the sprocket-holes.

96-Cycle Distortion by Frequency Modulation.—It has been shown how 96-cycle density modulation can appear in an unmodulated sound-track due to density variations. If a signal frequency is recorded on a sound-track adjacent to the sprocket-holes, a 96-cycle frequency modulation is introduced. Frequency modulation will occur whenever the speed of the film is not constant in its travel past the recording point. Constant speed is not attainable when recording on a sprocket or on a skid or drum where the film is propelled by a sprocket unless the sprocket-teeth and the sprocket-holes of the film match perfectly as shown by previous investigation.[1,4] Frequency modulation, however, may occur when recording on a constant-speed drum, due to the unequal flexing of the film previously discussed. The frequency modulation does not result in a hum or 96-cycle tone, but in distortion of the recorded waves, and becomes of considerable consequence especially when considering high frequencies.

Varying Contact in Printing.—Printing from a negative containing 96-cycle frequency modulation will transfer this modulation from the negative to the print and add more 96-cycle distortion, for the reasons that the positive stock polygons in a manner similar to that of the negative. The polygoning of the two films hinders the contacting of the two emulsions at every point along the length of the sound-track. As a result, wherever the two emulsions are not in contact a spreading of the negative image on the positive reduces the resolution and, consequently, the amplitude, particularly of high-frequency waves. Thus an amplitude modulation is introduced which is yet different from that due to density variations. In addition to the amplitude variations, there will be a filling in of the clear areas between the high-frequency waves, which, since it gets better and worse at the rate of 96 cycles per second, will produce a hum.

96-Cycle Flutter in Printing.—A doubly perforated negative containing a 1000-cycle note with a known amount of 96-cycle frequency modulation was printed on a non-synchronous non-slip printer. In this printer the raw stock and the negative were carried on a smooth drum, with the negative outside. Since this arrangement is the opposite of that which would tend to compensate for negative shrinkage, the negative slowly crept ahead of the print, causing the sprocket-holes to be alternately in and out of registration. The 96-cycle frequency modulation component of the print was observed on a flutter bridge. The amplitude of the 96-cycle flutter varied between maximum and minimum values. The observations showed that the maximum occurred when the sprocket-holes of negative and print were in register, and the minimum when the sprocket-holes were out of register.

It must be borne in mind that there is a difference between the 96-cycle flutter obtained in this experiment and that which would be obtained with a standard non-slip printer. In the case of the non-synchronous non-slip printer just described the variation of 96-cycle print output is of a periodic nature varying between definite maximum and minimum values. In a standard non-slip printer the flexure of the print stock takes a certain form depending upon the amount of shrinkage of the negative. This form will be maintained so long as the shrinkage is uniform along the length of film. Therefore, the amount of 96-cycle flutter introduced in the printing process will assume a certain value and will maintain that value at least for considerable periods of time. Thus, the 96-cycle flutter of the print may be of any value ranging between the maximum and minimum depending upon the amount of negative shrinkage.

96-Cycle Distortion in Reproduction.—Both hum and frequency modulation are generated in the reproducing. This distortion originates from several sources, namely:

(*1*) Stray light through sprocket-holes.

(*2*) Reflections within the emulsion and film base, which are affected by the perforations.

(*3*) The polygoning of the film which produces unequal film speed past the scanning point. There is also a stretching of the emulsion where the curvature is greatest, or, in other words, opposite the perforations.

EXPERIMENTAL PROCEDURE

The experimental work reported here was directed to the:

(*1*) Determination of the effects of exposure and development upon the magnitude of the several types of 96-cycle distortion, using standard (doubly perforated) film, for both density and area tracks,

(2) Determination of whether any of the 96-cycle flutter is due to imperfect mechanical filtering of the disturbances occurring at the sprocket, or whether the effects are entirely local and due to the proximity of the sprocket-holes in the sound-track.

(3) Effects of printing with sprocket-holes in register or out of register upon the hum, amplitude modulation, and the flutter.

(4) Determination of the hum and flutter introduced in reproduction, using a machine having no 96-cycle flutter in its drum rotation.

Recording.—Recordings of both variable-area and variable-density records were made of 1000-cycle and 9000-cycle tones and of unmodulated tracks.

The variable-density records were recorded with white light and the variable-area records with ultraviolet light.

The recorder was of the magnetic-drive type, adjusted to produce a minimum of flutter in the recording.

The unmodulated tracks were used to study density modulation especially in the case of the variable-density records.

A 1000-cycle tone was recorded for the study of frequency modulation, this being the frequency for which our flutter bridge is designed.

A 9000-cycle frequency was recorded to study the effect of the 96-cycle disturbance upon very high frequencies.

Recordings were made on both double perforated and single perforated stock.

Processing.—The various recordings were then processed in a small developing machine having a 40-gallon developing tank with a circulation of the developer of 4 gallons per minute and a film speed through the developer of 10 feet per minute. Those are not ideal developing conditions, as they are conducive to exaggeration of sprocket-hole turbidity and directional effects. They are, however, quite suitable for the purpose of this investigation.

The variable-density negatives were processed in *D-76* developer for values of density ranging from 0.08 to 1.15 for gammas of 0.37, 0.60, and 0.75.

The variable-area negatives were processed in *D-16* developer to various densities ranging from 2.0 to 2.53 at a gamma of 2.3.

Printing.—The prints, with a few indicated exceptions, were made on the special non-slip laboratory printer already described, employing a three-inch drum and a heavy flywheel for constant film speed.

The variable-density records were printed with white light and the variable-area records with ultraviolet light.

The prints were printed for various values of density and all processed for a gamma of 2.13 in standard D-16 developer.

Reproducing.—Both negatives and prints were reproduced on a special sprocketless laboratory reproducer utilizing a 2-inch diameter drum and a heavy flywheel for imparting constant speed to the film. The film is pulled by the drum. An optical system, which gives a particularly uniform 1-mil scanning beam, was employed.

Wave Analysis.—All recordings were measured on a General Radio Type *736A* Wave-Analyzer for 96-cycle output and the sum and difference frequencies of the recorded frequency and 96 cycles. Assurance was made in every case that the readings observed were of the frequencies under consideration and not simply noise. The noise was measured by tuning the analyzer a few cycles off the desired frequency.

A 4-cycle band-pass filter was used for measurements of the unmodulated tracks and of the 1000-cycle records. A 20-cycle band-pass filter was used for the measurements of the 9000-cycle record. The speed of the reproducer was sufficiently constant to obtain practically constant readings from the records in question.

Flutter Analysis.—The 1000-cycle records were the only ones which could be utilized for the detection of 96 cycles on the flutter bridge. The particular flutter bridge used employs two tuned circuits, one of which shows maximum at 950 cycles and the other at 1050 cycles. The deviations of the input frequency from 1000 cycles are measured by the difference between the voltages across the two tunings. This arrangement is relatively insensitive to small fluctuations in the amplitude of the input current, but to reduce still further errors due to such variations, a limiter was placed ahead of the flutter bridge to insure constant amplitude input to the bridge. A 96-cycle band-pass filter was employed also in conjunction with the bridge to suppress flutter of other frequencies, and thus make it easier to estimate the 96-cycle flutter.

Density Variations.—For the determination of the variations in density along the sound-track, the reproducer described above was used and rotated by hand to bring various sections of the track under the scanning beam. The transmission of the film was determined from readings of photocell output as read by means of an ultra-sensitive d-c meter.

96-Cycle Hum Due to Optical Conditions of Reproduction.—An unexposed film taken fresh from its original container was processed according to standard variable-area technic, and except for a fog value of 0.02, was entirely free of any other density. This film was

TABLE I

Variable Density Negatives

Rows of Perforations	Gamma	Density	Mod. Freq.	Densitometric Level—Decibels			
				90 Cps	96 Cps	102 Cps	1000 Cps
Double	0.37	0.13	1000	−60	−46	−60	−9
		0.13	0	−60	−44	−60	0
		0.46	1000	−60	−39.5	−60	−2.5
		0.46	0	−61	−38.8	−61	0
		0.61	1000	−61	−38.4	−61	−5
		0.61	0	−62	−41	−62	0
Single	0.37	0.08	1000	−64.5	−64.5	−64.5	−7.8
		0.08	0	−64.5	−64.5	−64.5	0
		0.38	1000	−64.5	−64.5	−64.5	−2.4
		0.38	0	−65	−65	−65	0
		0.56	1000	−66	−66	−66	−4.2
		0.56	0	−68	−68	−68	0
Double	0.60	0.20	1000	−65	−45	−65	−3
		0.20	0	−65	−43	−65	...
		0.56	1000	−65	−45	−65	−2
		0.56	0	−64.5	−44	−64.5	...
		0.78	1000	−66	−45	−66	−4
		0.78	0	−67	−46.8	−67	...
Single	0.60	0.18	1000	−70.3	−70.3	−70.3	−3.2
		0.18	0	−68	−68	−68	...
		0.53	1000	−70.3	−70.3	−70.3	−1.8
		0.53	0	−70.3	−70.3	−70.3	...
		0.76	1000	−70.3	−70.3	−70.3	−4.2
		0.76	0	−74	−74	−74	...
Double	0.75	0.26	1000	−63	−44.4	−63	−2.0
		0.26	0	−61	−41.4	−61	...
		0.66	1000	−64.4	−46	−64.4	−1.3
		0.66	0	−68	−44	−68	...
		0.92	1000	−68	−46	−68	−3.0
		0.92	0	−69	−46	−69	...
		1.15	1000	−68	−47	−68	−8.0
		1.15	0	−74	−50.3	−74	...
Single	0.75	0.26	1000	−68	−68	−68	−1.0
		0.26	0	−70	−70	−70	0
		0.64	1000	−71	−71	−71	−1.0
		0.64	0	−74	−74	−74	0
		0.86	1000	−71	−71	−71	−2.2
		0.86	0	−74	−74	−74	0
		1.09	1000	−74	−74	−74	−7.2
		1.09	0	−80	−80	−80	0

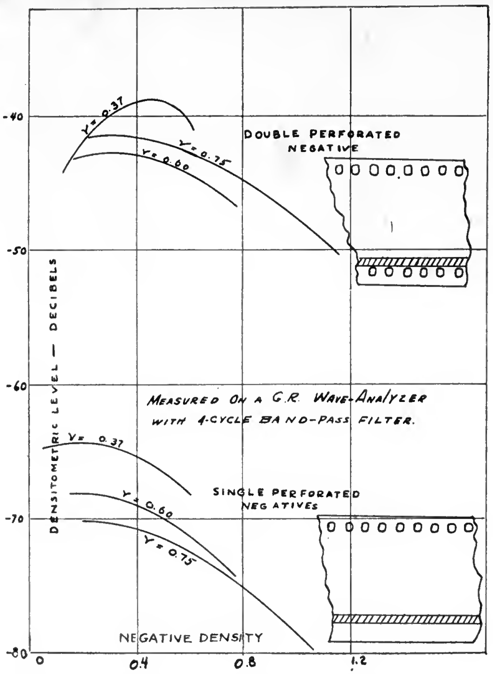

FIG. 2. Density modulation or hum levels for unmodulated variable-density negatives.

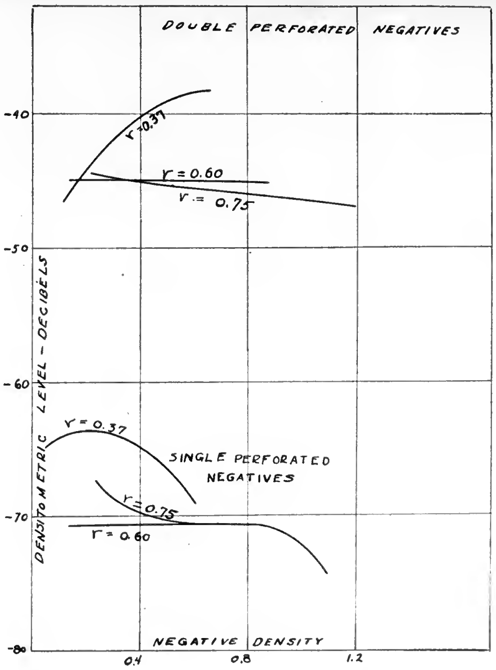

FIG. 3. Hum levels for 1000-cycle variable-density negatives.

measured for 96 cycles and used as a negative for making prints which were also measured.

To be certain that the fog density was not being modulated, a piece of film was fixed without being developed and measurements of 96 cycles made thereon.

Some of the singly perforated negatives, after having been measured and used for the necessary prints, were returned to the Eastman Kodak Company and perforated on the unperforated side. They were then again measured for their 96-cycle content on both the wave analyzer and the flutter bridge. In this test, all sources of 96-cycle distortion except those which occur in reproduction were eliminated.

RESULTS OF INVESTIGATION

Variable-Density Negatives.—A series of variable-density negatives using the penumbra-galvanometer system were recorded with 1000-cycle modulation and without modulation. The same film emulsion was used throughout, but differed in the respect that part of the negatives was made on the standard sound-recording stock with a double row of perforations, and part on a stock with the perforations on the sound-track side omitted. Both stocks were processed simultaneously to three values of gamma, 0.37, 0.60, and 0.75, in *D-76* negative developer at 65°F. The densities obtained varied from 0.08 to 1.15. The amplitude of the 1000-cycle recording was adjusted for approximately 90 per cent.

The results obtained for the negatives from readings made on a General Radio, Wave-Analyzer are given in Table I. The analyzer readings are converted to terms of "densitometric level" which is the name we have adopted to express the light-modulating ability of the film itself, independently of any reproducing system. Zero level is the output of an ideal variable-density film carrying a track of 0.70-inch amplitude, which according to present standards is 100 per cent modulation.

The following points should be noted:

(*1*) With the singly perforated film the 96-cycle output is the same as that at 92 or 100 cycles, or, in other words, when the analyzer is set for 96 cycles there is only the slight response due to general film noise. This is true whether a 1000-cycle tone is recorded or not.

(*2*) With double perforations the 96-cycle hum is from 20 to 23 db above the noise.

(*3*) Differences in density and gamma make only a minor difference in the hum. As would be expected, high density gives reduced hum, but it also gives low output of the recorded tone.

Fig. 2 is a set of curves of the 96-cycle values of Table I plotted against negative density for both doubly perforated and singly perforated unmodulated negatives.

Fig. 3 is a similar set of curves for the 1000-cycle negatives.

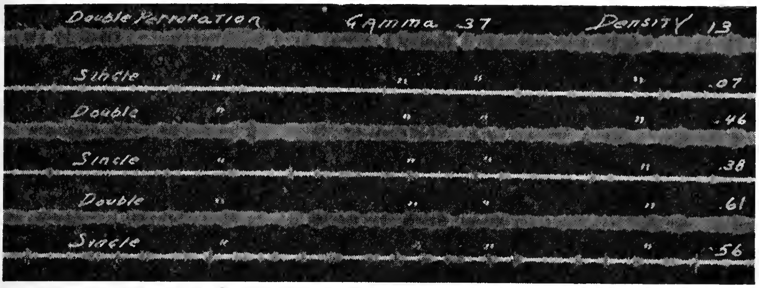

FIG. 4. Comparison of doubly and singly perforated film for 96-cycle frequency modulation for variable-density 1000-cycle records developed to various densities at a gamma of 0.37.

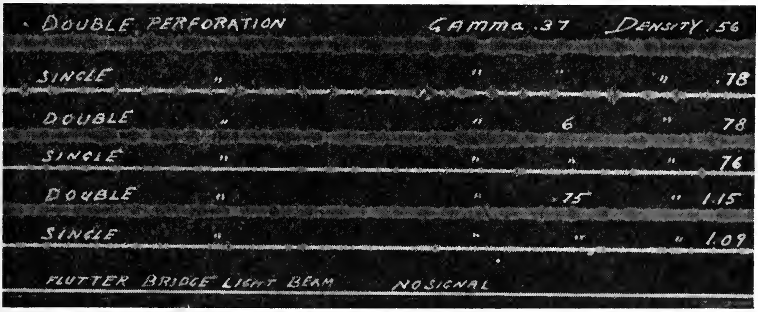

FIG. 5. Comparison of doubly and singly perforated film for 96-cycle frequency modulation for variable-density 1000-cycle records developed to various densities and gammas.

Figs. 4 and 5 are oscillograms of the 1000-cycle variable-density negatives for both the doubly and singly perforated films. It will be noted that the traces obtained from the singly perforated film differ from the static trace of the "wow-meter" light-beam only by the noise present in the film.

Variable-Area Negatives.—Recordings were made on an unmodulated full-width exposed track, 1000 cycles and 9000 cycles, using the galvanometer bilateral system on doubly perforated stock and processed for three values of negative density of 2.0, 2.3, and 2.53 at a gamma of 2.3 in *D-16* positive developer at 68°F. These negatives were measured with the wave-analyzer and also with the flutter bridge.

The results obtained for the negatives from readings on a Type *736-A* General Radio Wave-Analyzer are given in Table II.

TABLE II

Variable Area Negative—Gamma 2.3 Double Perforated Stock

Density	Mod. Freq.	90 Cps	96 Cps	102 Cps	904 Cps	1000 Cps	1096 Cps
2.0	0	−66	−55	−66			
2.3	0	−76.4	−54.4	−70.5			
2.53	0	−70.5	−52	−70.5			
0.02	0	−56.5	−51	−58.4			
2.0	1000	−62	−50.8	−63	−46	−4.0	−47.3
2.3		−62	−50.8	−62	−45.2	−3.0	−46.8
2.53		−64.5	−49.3	−64.5	−46.8	−4.5	−47.3
					8904 Cps	9000 Cps	9096 Cps
2.0	9000	−59	−35	−60	−32.5	−17.6	−32.5
2.3		−58.4	−36	−59	−37	−20.4	−37
2.53		−56.5	−37	−53.6	−40	−25	−40

The values of Table II above are shown graphically in Fig. 6. With zero or 1000-cycle modulation the 96-cycle hum is from 5 to 8 db less than in the case of the variable-density negatives. The 904 and 1096-cycle sidebands of the 1000-cycle recording could be due either to amplitude or frequency modulation. Variable area tracks are not subject to much amplitude modulation (except at very high frequencies) and the magnitude of the sidebands measured (about 43 db below the recorded tone) is what would result from a frequency modulation of about 0.03 per cent which is about that indicated in the flutter record of Fig. 4. Hence the sidebands may be ascribed primarily to frequency modulation, although there may be a nearly equal amount (in terms of sideband amplitude) of amplitude modulation. In the case of the 9000-cycle recording, the tone level is from 14 to 20 below that of the 1000-cycle recording, while the sidebands are about 9 db higher. This is practically pure amplitude modulation. There is also a large density modulation (96-cycle output) in the 9000-cycle recording, more than in the case of the unmodulated density track. This is due for the most part to the higher development of an area negative. In the case of prints made from these negatives there might be little difference between the hum from the 9000-cycle area track and the unmodulated density track, but it should be remem-

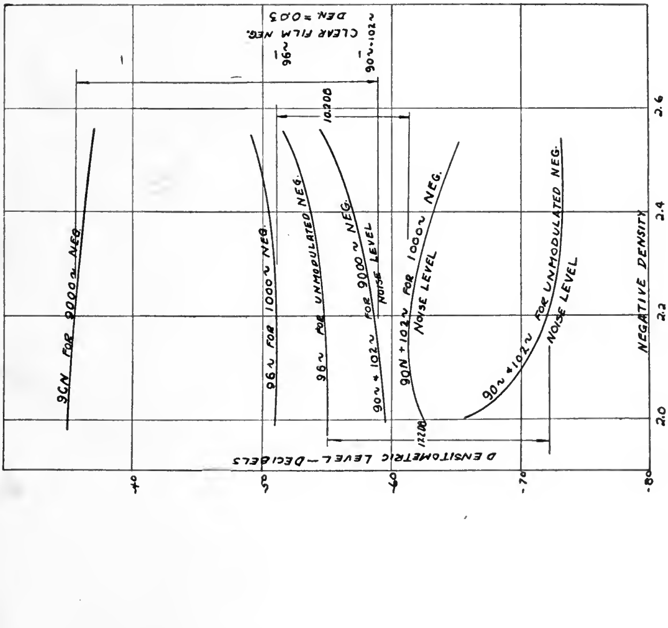

FIG. 6. Increase in hum and noise level with increase in frequency.

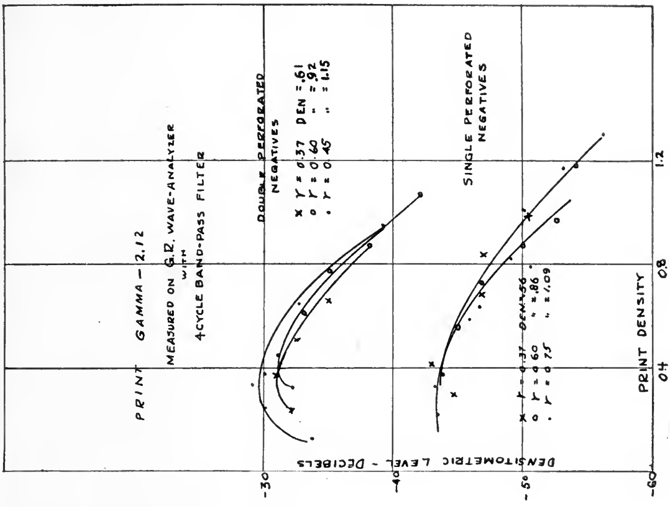

FIG. 7. Hum levels of unmodulated density prints.

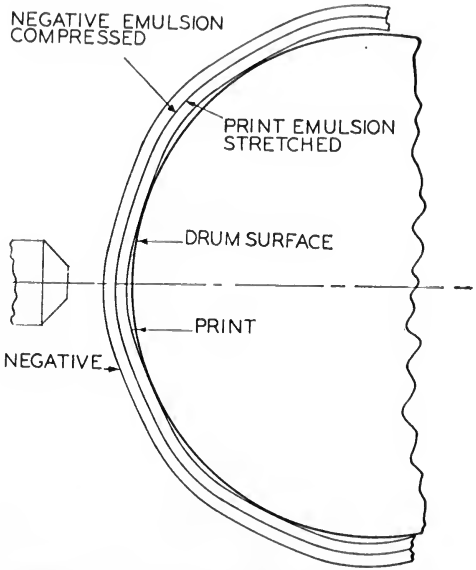

FIG. 8(*a*). Conditions during printing when the negative and print sprocket-holes are in register.

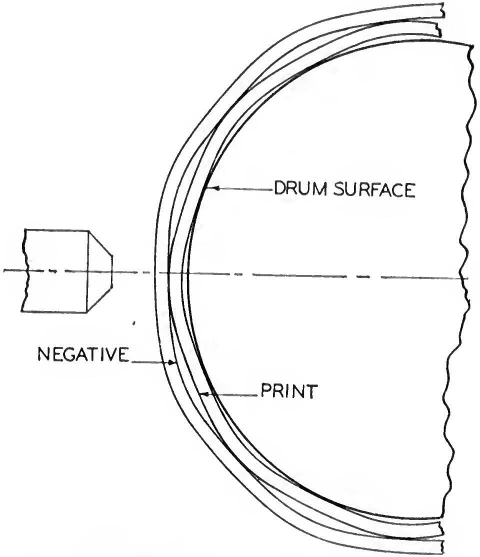

FIG. 8(*b*). Conditions during printing when the negative and print sprocket-holes are out of register.

bered that the strong hum in the area track occurs only in case of continuous recording of high frequencies.

Variable-Density Prints.—A portion of the unmodulated variable-density negatives was printed with white light on the non-slip printer and processed to a gamma of 2.13 in standard *D-16* positive developer at 65°F. Both doubly and singly perforated negatives were printed and measured on the General Radio Type *736-A* Wave-Analyzer for the 96-cycle amplitude modulation component. The ground-noise was checked and found to be considerably lower than the 96-cycle readings, and it was thought unnecessary to repeat the readings. Fig. 7 is a set of curves showing the results of these measurements for those negatives having a density which had previously been found to be the best value for the least amount of harmonic distortion when printed to an average density of approximately 0.6. Within the limits of experimental error, these curves indicate that the choice of negative density and gamma has little effect upon the 96-cycle distortion due to density modulation. The prints made from the doubly perforated negatives have approximately 12 db more 96-cycle distortion than those made from the singly perforated negatives.

Effect of Printing upon Flutter.—We have seen that whenever a film is bent around a circular support it bends more opposite the holes and less between, forming what we might describe as a "polygon." This is illustrated in Fig. 1. This has some effect on the linear speed and the exposure. The effect of the linear speed variations upon flutter is, however, probably less than the effect of stretching or compressing the emulsion by the bending.

For the purpose of discussing the effects in printing, we may assume that the 1000-cycle waves on the negative are of uniform pitch when the film is straight. Fig. 8(*a*) shows the conditions during printing when the sprocket-holes are in register. In this case we have assumed that the negative is on the outside, which was the condition in our experimental work. It will be seen in Fig. 8(*a*) that where the curvature is sharpest the emulsion side of the negative will be compressed and the emulsion of the print stretched. When the print is developed and held straight, waves opposite the sprocket-holes will be compressed, as compared with their pitch during printing, and this will add to the effect of the compressed waves upon the negative during the printing operation. Thus, printing in register would tend to result in higher reproduced frequency when scanning the track opposite the perforations, than when scanning the part in between.

Fig. 8(*b*) shows the conditions with the sprocket-hole staggered during printing. Here the compressed waves of the negative are opposite the unstretched emulsion of the raw stock and the uncompressed negative waves are opposite the stretched raw-stock emulsion. This tends to neutralize the flutter due to polygon bending during printing.

Fig. 9 shows an oscillogram taken on the flutter bridge with the negative slowly progressing with respect to the print so that the sprocket-holes are alternately in and out of register. The print was carefully examined for the location of in-register and out-of-register points of the negative and print sprocket-holes and inked lines were drawn across the track for reference. For the in-register con-

FIG. 9. Variations in 96-cycle frequency modulation with negative and print sprocket-holes passing in and out of register.

TABLE III

Doubly Perforated Negative
Gamma = 0.60, Density = 0.56

Freq.	Print Den.	Printer	Print Perforations	90 Cps	96 Cps	102 Cps	904 Cps	1000 Cps	1096 Cps
1000	0.64	B & H	Double	−60	−43	−60	−38.5	−8.5	−38.5
	0.60	Non-Slip	Double	−60	37–46	−60	38–54	−8.0	38–54
	0.53	Non-Slip	Single	−67	−43	−67	−39	−6.8	−39
0	0.64	B & H	Double	−60	−40	−60			
0	0.60	Non-Slip	Double	−62	39–50	−62			
0	0.53	Non-Slip	Single	−66	−42	−66			

Data for the Negative

Freq.	Print Den.	Printer	Print Perforations	90 Cps	96 Cps	102 Cps	904 Cps	1000 Cps	1096 Cps
1000				−65	−45	−65	−44	−2	−44
0				−65	−44	−65			

dition, a single line was used and for the out-of-register condition, two lines. These lines produce a disturbance in the flutter bridge of the in-register and out-of-register condition on the oscillograms. It will be noted that printing with the sprocket-holes in register is best for minimizing hum while printing them out of register is best for minimizing flutter.

Two of the variable-density doubly perforated negatives were printed on a Bell & Howell printer, with the row of teeth next the sound-track removed from the printing sprocket. A comparison of the 96-cycle distortion occurring in prints made on the Bell & Howell and on the non-slip printer is given in Table III.

TABLE IV

Variable-Area Doubly Perforated Negatives Gamma = 2.30
Variable-Area Doubly Perforated Prints Gamma = 2.13

Freq.	Neg. Den.	Print Den.	90 Cps	96 Cps	102 Cps	904 Cps	1000 Cps	1096 Cps
1000	2.0	0.92	−63	−41–44 db	−63			
1000	2.3	0.92	−63	42–45	−64	42–45	−4	42–45
1000	2.53	0.92	−62	43–46	−63	41–45	−3.8	41–45
0	0.02	0.92	−66	44–48	−66			
1000	2.0	1.17	−63	43–47	−63	41–45	−3.8	41–45
1000	2.3	1.17	−68	44–47	−68	42–46	−3.9	42–46
1000	2.53	1.17	−70	43–48	−70	41–47	−4.0	41–47
0	0.02	1.17	−68	49–52	−68			
1000	2.0	1.32	−65	43–46	−65	39–45	−3.7	39–45
1000	2.3	1.32	−65	43–48	−65	40–45	−3.7	40–45
1000	2.53	1.32	−65	44–48	−65	39–45	−3.0	30–45
0	0.02	1.32	−70	50–54	−70			
1000	2.0	1.57	−66	42–46	−66	39–44	−3.4	39–44
1000	2.3	1.57	−66	42–46	−66	37–45	−3.3	37–45
1000	2.53	1.57	−66	42–46	−66	38–44	−2.7	38–44
0	0.02	1.57	−75	54–56	−74			
1000	2.0	1.68	−68	41–46	−68	41–46	−3.3	41–46
1000	2.3	1.68	−68	41–46	−68	38–45	−2.9	38–45
1000	2.53	1.68	−69	42–46	−69	39–45	−2.8	39–45
0	0.02	1.68	−74	57–59	−74			
1000	2.0	1.83	−66	41–46	−66	39–45	−3.4	39–45
1000	2.3	1.83	−66	42–46	−66	39–45	−2.8	39–45
1000	2.53	1.83	−66	41–46	−66	38–46	−2.7	38–46
0	0.02	1.83	−80	58–60	−80			
1000	2.0	2.04	−62	39–48	−62	39–45	−3.5	39–45
1000	2.3	2.04	−62	31–46	−62	40–46	−4.5	40–46
1000	2.53	2.04	−63	39–45	−63	38–45	−2.7	38–45
0	0.02	2.04	−80	59–62	−80			

Freq.	Neg. Den.	Print Den.	90 Cps	96 Cps	102 Cps	8904 Cps	9000 Cps	9096 Cps
9000	2.0	0.92	−57	33–39	−57	30–37	−18	30–37
9000	2.3	0.92	−50	32–37	−50	30–36	−17	30–36
9000	2.53	0.92	−50	31–37	−30	31–38	−19	31–38
9000	2.0	1.17	−50	30–37	−50	29–38	−16	29–38
9000	2.3	1.17	−50	30–36	−50	28–34	−16	28–34
9000	2.53	1.17	−53	20–36	−53	29–35	−17	29–35
9000	2.0	1.32	−56	30–35	−56	29–35	−15	29–34
9000	2.3	1.32	−55.5	30–36	−55.5	28–36	−15	28–36
9000	2.53	1.32	−55	29–34	−55	29–35	−16.2	29–35
9000	2.0	1.57	−56	28–35	−55	29–35	−15	29–35
9000	2.3	1.57	−56	28–35	−56	27–33	−15	27–33
9000	2.53	1.57	−55	27–34	−55	30–37	−16	30–37
9000	2.0	1.68	−58	28–35	−58	28–34	−15	28–34
9000	2.3	1.68	−56.5	28–34	−56.5	29–33	−15	29–33
9000	2.53	1.68	−54	28–34	−54	29–33	−16.2	29–33
9000	2.0	1.83	−53	29–36	−53	30–35	−16	30–35
9000	2.3	1.83	−56	29–36	−56	29–34	−15	29–34
9000	2.53	1.83	−53	27–34	−53	30–34	−15	30–34
9000	2.0	2.04	−49	28–37	−49	29–36	−17	29–36
9000	2.3	2.04	−51	28–36	−51	30–35	−14	30–35
9000	2.53	2.04	−52	28–35	−52	30–35	−15	30–35

Variable-Area Prints.—The variable-area negatives were printed on the non-slip printer to a series of print densities ranging from 0.92 to 2.04. These prints were made on doubly perforated positive stock for determining the effect of negative and print densities upon the 96-cycle distortion. The results of the wave-analyzer measurements are given in Table IV.

The results of these measurements show that there is very little change in the amount of 96-cycle distortion with changes in either the negative or print densities for any given frequency.

The 96-cycle density modulation is approximately 25 db above the ground noise as measured at 90 and 102 cycles, and about 40 db below the 1000-cycle output.

The 904 and 1096-cycle sidebands are of about the magnitude to be expected from the frequency modulation shown by the flutter bridge. This means that the amplitude modulation is at least lower than that corresponding to the measured sidebands.

With a recorded frequency of 9000 cycles, the amplitude modulation component of the 96-cycle distortion is 10 db greater than that for 1000 cycles and 25 db greater than that for the unmodulated track. The magnitude of the 8904 and 9096-cycle sidebands is somewhat greater than that which corresponds to the measured flutter, which means that there is considerable amplitude modulation. The signal has been reduced considerably so that its magnitude is only 15 db greater than the 96-cycle distortion. It is well to point out at this time that these results are pessimistic because of the processing conditions which are conducive to producing 96-cycle amplitude modulation. This increase of 96-cycle distortion and ground noise with frequency is clearly indicated in Fig. 10.

Other data of Table IV are plotted in Figs. 11, 12, 13, 14. The curves in these figures show the 96-cycle density modulation for the two conditions of the negative and print sprocket-holes *in* and *out* of register and the ground-noise level.

96-Cycle Distortion in Reproduction.—To show the introduction of 96-cycle distortion in the output of a perfect film, two procedures were adopted: (*a*) a film was fixed but not developed in order to clear it and to insure its freedom from even a fog density; and (*b*) singly perforated film was recorded, processed, measured, and returned to the Eastman Kodak Company for adding perforations to the sound-track side.

The clear film exhibited measurable 96-cycle hum in the reproduction. In order to obtain an idea of the source of the hum, a flat barrier 2 mils thick, 10 mils wide, and 90 mils long was interposed in the light-beam at two positions adjacent the film: (*a*) in front of the film between the objective lens of the optical system and the sound-track; and (*b*) behind the film, between the sound-track and the photocell. By careful placement of this barrier it was possible to intercept all the useful scanning portion of the light-beam.

The results of the three measurements, with the barrier in the two positions described, and with no barrier, are given in Table V.

TABLE V

96-Cycle Distortion Introduced by Clear Film in Reproduction

Position of Barrier	90 Cps	96 Cps	102 Cps	Photocell Current Amps	Per Cent
None	−62	−52	−62	3.80	100
Front of Film	−80	−63	−80	0.14	3.7
Rear of Film	−80	−56	−80	0.18	4.7

There is, of course, some stray light from the optical system around the scanning point. This is responsible for the slight hum when the main beam is cut off in front. The greater hum when the barrier is

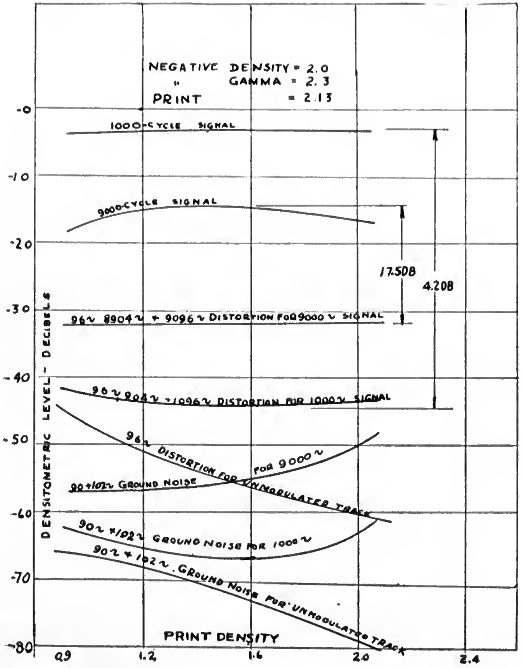

FIG. 10. Useful output, hum, ground noise, and sidebands for 9000-cycle variable-area prints.

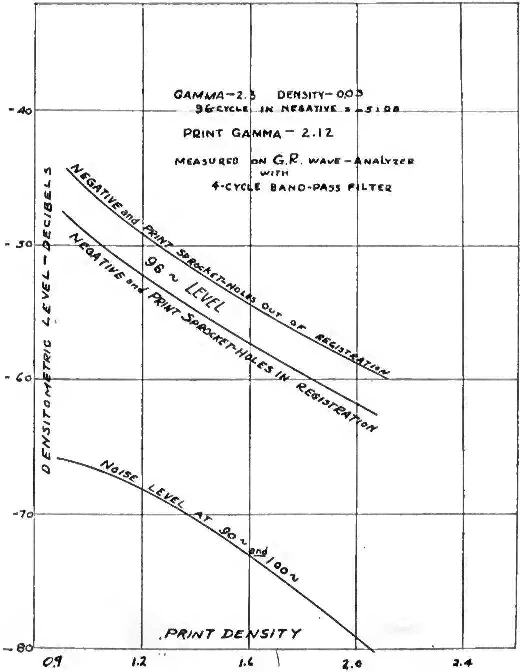

FIG. 11. Effect of in-register and out-of-register printing for prints made from clear film negatives (doubly perforated).

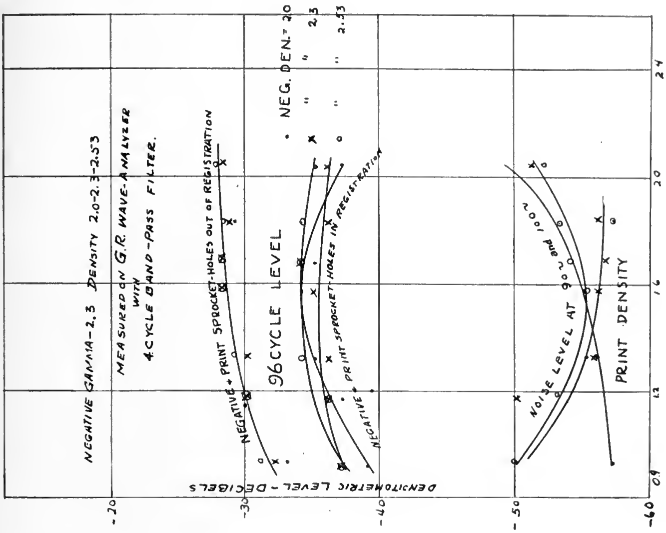

FIG. 13. Effect of in-register and out-of-register printing on hum, for variable-area prints.

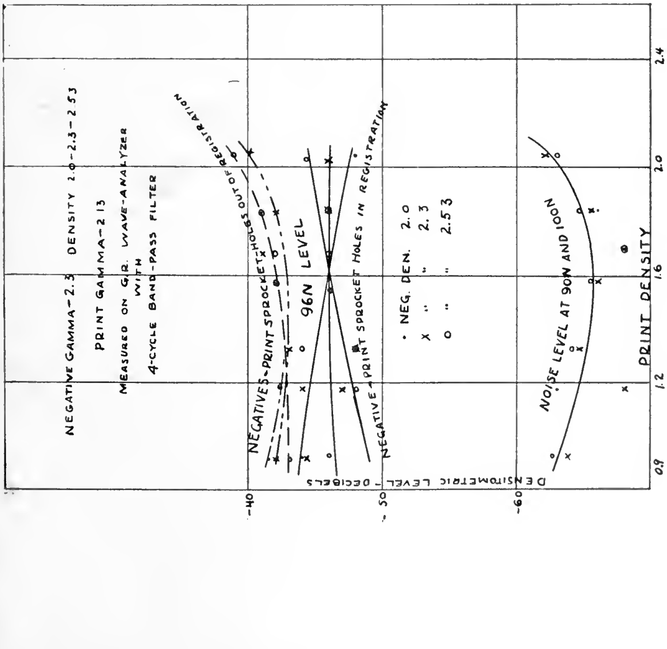

FIG. 12. Effect of in-register and out-of-register printing for 1000-cycle variable-area prints.

between the film and the photocell is probably due to light reflected within the film base. The barrier must have cut off a portion of this reflected light, for the hum is still higher when the barrier is removed. In any case the hum in these tests is very low, *i. e.*, some 50 db below full modulation.

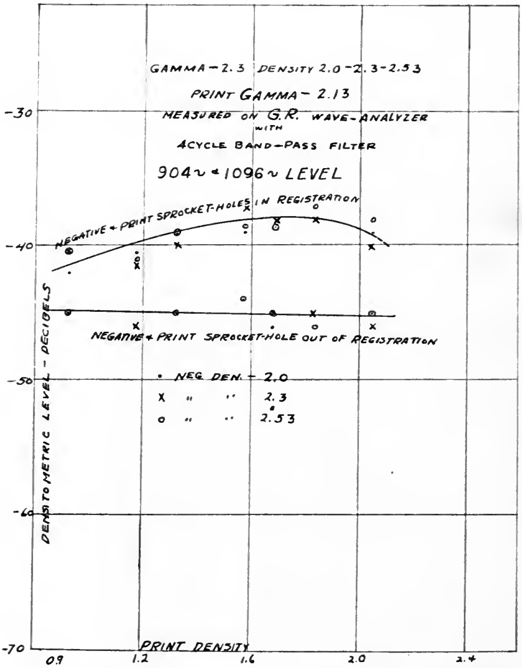

FIG. 14. Hum levels for 1000-cycle variable-area prints.

The wave-analyzer measurements on the unperforated film showed that it was entirely free from 96-cycle distortion before the sound-track was perforated. After the perforations were added, 96-cycle distortion was observed. Table VI shows the results of the measurements before and after perforating.

The data given in the Tables V and VI show that perforating the film before reproduction raised the 96-cycle output from a level of −66 to −80 (which was the same as the ground-noise readings) to about −56 level. This was true whether or not the film carried a

TABLE VI

Gamma	Density	Freq.	90 Cps	96 Cps	102 Cps	904 Cps	1000 Cps	1096 Cps
				Before Perforating				
0.37	0.56	1000	−66	−66	−66	−65	−5.0	−65
0.60	0.76	1000	−70.3	−70.3	−70.3	−68	−4.3	−68
0.75	1.09	1000	−74	−74	−74	−71	−7.2	−71
0.37	0.56	0	−68	−68	−68			
0.60	0.76	0	−74	−74	−74			
0.75	1.09	0	−80	−80	−80			
				After Perforating				
0.37	0.56	1000	−68	−55	−68	−57	−5.0	−56
0.60	0.76	1000	−66	−55	−66	−58	−4.1	−58
0.75	1.09	1000	−69	−56	−69	−58	−7.0	−58
0.37	0.56	0	−68	−58	−68			
0.60	0.76	0	−68	−58	−68			
0.75	1.09	0	−76	−56	−76			

1000-cycle tone. The 904-cycle and 1096-cycle sidebands in the 1000-cycle recordings which in this case are a measure of flutter, were raised from levels of −65 to −71 (which again is substantially ground-noise level) to about −57 db.

These tests show that the perforating of the sound-track side of a perfect film produces both 96-cycle hum and flutter. The hum is produced in the same way as demonstrated in the barrier experiment. The 96-cycle flutter is produced by the flexure of the film causing a local stretching of the emulsion at the sprocket-holes.

Film Flexure.—Crabtree[6] shows how the surface of the film is distorted in the region of the sprocket-holes and also shows in a sketch how the film will polygon when flexed around a curved surface. As a verification of this polygoning ef-

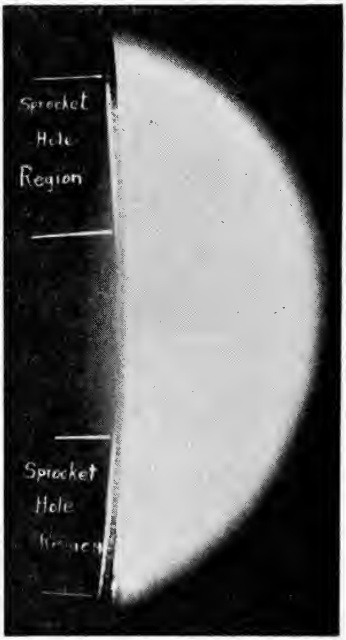

FIG. 15. Photomicrograph showing polygoning of 35-mm film when flexed around a 2-inch diameter drum (magnification 11×).

fect, a photomicrograph was made showing that the film contacts the drum between sprocket-holes and curves away from the drum at the sprocket-holes. Fig. 15 illustrates this effect when only a slight tension is applied to the film. When the tension is increased enough to insure contact at all points of the film, stresses are set up in the film which may be more detrimental to the sound-track and reproduced sound unless the same tension is employed in the recording, printing, and reproducing processes. Fig. 16 shows the photoelastic effect upon film when under tension.

FIG. 16. Photomicrograph showing stresses set up in 35-mm film. Tension is increased enough to insure contact at all points of the film.

It is apparent that the amount of flexure of the film has a direct bearing upon the quantity of 96-cycle distortion which may be introduced. The larger the radius of the curved surface around which the film is flexed, the less will be the amount of 96-cycle distortion. It is conceivable that a drum of infinite radius might introduce almost negligible 96-cycle distortion. This would point to a skid gate, but here another difficulty would be encountered: namely, uneven film motion due to friction between the film and the gate shoes.

CONCLUSION

Where doubly perforated film was used, 96-cycle disturbance was encountered in every step of the investigation from the recording through processing and printing to the reproduction. The variable-density system is much more subject to density and amplitude modulation than the variable-area system.

The tests did not separate the effect of polygon-bending in recording from the unequal development around the sprocket-holes, but the flutter measurements indicate variations too small to account for the observed density variations—whence development is unquestionably the major offender.

There is practically no 96-cycle flutter in the motion of the film as a whole, when the recording or reproducing machines employ well-designed mechanical filtering systems.

Printing is not ordinarily a direct cause of any but a very small amount of density and amplitude modulation, but printing conditions may frequently accentuate the distortions due to development.

Although we recognize that the adoption of singly perforated film can hardly be considered for release prints, the authors suggest that serious consideration be given to the possibility of employing it for original recordings, master prints, and for the sound-track negatives from which release prints are printed. Many printers now use only one row of sprocket-teeth on the sound-sprocket, and non-slip printers make no use of the perforations next to the sound-track.

REFERENCES

[1] KELLOGG, E. W.: "A New Recorder for Variable Area Recording," *J. Soc. Mot. Pict. Eng.*, **XV** (Nov., 1930), p. 653.

[2] BATSEL, C. N.: "A Non-Slip Sound Printer," *J. Soc. Mot. Pict. Eng.*, **XXIII** (Aug., 1934), No. 2, p. 100.

BEDFORD, A. V.: U. S. pat. No. 1,754,187.

[3] LOOMIS, F. J., AND REYNOLDS, E. W.: "A New High-Fidelity Sound-Head," *J. Soc. Mot. Pict. Eng.*, **XXV** (Nov., 1935), No. 5, p. 449.

[4] CRABTREE, J.: "Sound Film Printing," *J. Soc. Mot. Pict. Eng.*, **XXII** (Feb., 1934), No. 2, p. 98.

[5] FRAYNE, J. G., AND PAGLIARULO, V.: "The Influence of Sprocket-Holes upon the Development of Adjacent Sound-Track Areas," *J. Soc. Mot. Pict. Eng.*, **XXVIII** (March, 1937), No. 3, p. 235.

[6] CRABTREE, J., AND HERRIOTT, W.: "Film Perforation and 96-Cycle Frequency Modulation in Sound-Film Records," *J. Soc. Mot. Pict. Eng.*, **XXX** (Jan. 1938), No. 1, p. 25.

SOME PROPERTIES OF POLISHED GLASS SURFACES*

FRANK L. JONES**

Summary.—*The optical glasses made by combining silica with various other oxides are similar in that the silica will not dissolve in water or weak acids at the same rate as the other materials contained in the glass. This property of silicate glasses is involved in the accidental formation of colored stains on the surface of dense lead or barium glasses exposed to the weather, in the formation of surface haze on lenses exposed to tropical humidity, and in the formation of silica low-reflection films on glass by chemical treatment.*

Quantitative data have been collected on the tendency to form surface stains and on the rate of dimming for all the common types of optical glass. Surface stains do not harm a lens and may increase its efficiency. Any haze that forms on a lens exposed to a humid climate should be removed by careful cleaning.

Purposely formed silica surface films for increasing the transparency of glass are identical with the stains that form accidentally on dense lead and barium glasses except that they are of controlled thickness and may be stabilized to prevent any further increase in thickness. Chemical methods are now available for forming low-reflectivity surfaces on all of the common optical glasses. Proper heat treatment of these silica films will lower the rate of solution of the glass. The durability of a lens is greatly improved by this process.

The gain in light transmission that results when a silica surface film is formed by chemical treatment is less than that produced by films of low-refractive-index fluorides evaporated by the Cartwright and Turner method. There is no doubt but that both the evaporation process and the chemical process will be used in the optical industry. Each process has advantages depending on the circumstances of use.

The motion picture engineer manages and controls light by means of glass optical systems. Glass is thus one of his basic materials. The physical properties of glass are well known to the engineer. This paper is presented with the idea that the chemical properties of glass surfaces are less thoroughly understood but of equal interest and importance.

Optical glass used in projection lenses and camera lenses is practically all made by heating sand that is over 99 per cent silicon dioxide with other metal oxides until they unite to form a glass. The

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received April 14,1941.

** Bausch & Lomb Optical Co., Rochester, N. Y.

finished glass consists of a random network of strongly bonded silicon and oxygen atoms with other elements more loosely joined to the basic network. The glass compositions employed in making bottles, windows, and other commercial products usually contain calcium and sodium combined with silica. Optical glasses are more varied in composition. They may contain lead, barium, zinc, calcium, sodium, potassium, aluminum, boron, magnesium, antimony, or other elements. The basic ingredient, however, is generally silica. The large variety of compositions are the result of the optical engineers' need for glasses that vary in refractive index; in other words, in the speed limit they impose upon light as it enters the glass. As long as the basic material is silica, the glasses will have one characteristic chemical property. The silica will not dissolve in water at the same rate as the other materials contained in the glass. This characteristic of silicate glasses may seem unimportant but it is involved in the dimming of glass surfaces in tropical climates, it is involved in the formation of colored stains on lead and barium glasses, and in the chemical method for increasing the transparency of lenses. This paper will show the relationship between these seemingly different phenomena.

There are other methods by which elements originally in a glass surface can be removed or replaced but the action of water or water solutions is involved in most of those changes that occur in normal use. Water is present in the air as a vapor. It comes into contact with lenses when they are washed, when condensation of moisture takes place due to changes in temperature, or when a lens is touched with the fingers. Every time a lens comes into contact with water some reaction takes place. The glass acts as if the silica were a porous sponge with the more soluble oxides distributed through the pores. Under most circumstances contact with water does not disturb the basic silica network but does release the other constituents so that they are free to move out of the glass. Different elements vary in their speed of solution. Eventually a very thin surface layer becomes different in composition and refractive index from the body of the glass. As long as the silica network is not disturbed, the surface of the lens is not etched or roughened. Hydrogen ions from the water replace the metal atoms that leave the glass so the changed surface layer is not porous when examined with a microscope and does not scatter light. Since the silica network is the strong part of a glass structure, changes that do not damage the network do not noticeably reduce the hardness of a glass surface. If the surface silica layer is very thin, there is no visible change in the appearance of the glass. If the thickness of the silica film is greater than 0.05 micron interference effects between the light reflected at the top and bottom of the silica layer will cause the light reflected to be colored like that reflected from a layer of oil on water.

If the color develops accidentally, the user decides that the surface is stained and he may protest to the manufacturer of the lens. If the surface layer is formed purposely by the manufacturer, the lens is sold as chemically filmed for increased light transmission, and an extra charge is made. The Bausch & Lomb Optical Company has been interested in the study of these surface films so that they may be prevented from forming when not wanted and may be made to form quickly and evenly when wanted. It is hoped that an understanding of these modified surface layers will prevent the dissatisfaction of lens users who find that a thin film has formed accidentally and will show the value of purposely applied films.

SPONTANEOUS SILICATE FILM FORMATION ON GLASS IN CONTACT WITH WATER

Glass selected for lens systems is chosen primarily for its optical properties. Chemical stability is a secondary factor, but a limiting one, since no matter how useful the glass is in regard to index and dispersion, it can not be employed in an optical system if its polished surface will corrode and roughen in the environment in which it is used. All glass compositions used in optical work are selected from those capable of normal exposure to water without surface roughening. On the other hand, all types of glass, optical or otherwise, will give up a small portion of their more soluble components to water and those containing substantial amounts of lead or barium are likely to lose material to such a depth that they develop surface interference colors. There is ordinarily no damage to the surface polish since only part of the glass dissolves and the hard silica structure is not affected. The amount of liquid required is so small that fingerprints or moisture droplets due to condensation may start the process. The presence of an acid such as dissolved carbon dioxide or the acids found in perspiration greatly speeds the solution. Under normal conditions of use only dense barium crown glasses and the dense flint glasses are subject to such staining in use but any silicate glass will do so if kept in contact with acid water for a long enough period of time. Tests on optical glass have indicated that the most durable soda-lime-silica crown may require five million times as long as the least durable dense barium crown glass for a thick enough silica layer to form to produce a visible stain under a given set of conditions. It is easy to see why the soda-lime-silica crown never stains in actual use. The light transmission of a stained surface is equal to or greater than that of an unstained lens. The amount of light reflected by the surface is reduced so that the staining results in better contrast and less likelihood of ghost images. A stained lens that does not show surface pitting and corrosion is thus more efficient than a new unstained lens. This fact was discovered by H. D. Taylor, the English optical designer, in 1892 and has been general knowledge among opticians since that time. It has not been known by many users of lenses, however, and much argument has resulted whenever an attempt has been made to sell lenses with surface films or when the stains developed in use. The Germans have been more willing than others to recognize the good points of stained lenses, possibly because they call such stains "beauty marks" (Schönheits fehler). A lens should never be rejected merely because it has acquired a silica surface film.

SURFACE HAZE ON GLASS

If highly polished glass surfaces are exposed to humid air for long periods of time, a faint surface haze will develop. All glasses are subject to such dimming if exposed to a damp atmosphere but protected from contact with liquid water. The rate of dimming varies with different glasses. The chemical reaction is basically similar to that involved in the formation of surface films but the effect is very different. As in silica film formation one or more elements migrate out of the glass but, since there is not enough water present to dissolve and remove the elements released by the glass, they remain on the glass surface as microscopic crystals that scatter and reflect light. The efficiency of the lens is thus reduced by surface haze. Since the reaction with humid air is slow, the glass is rarely leached to sufficient depth for any decrease in surface reflection to result. The surface haze is easily removed with a damp cloth during the early stages of its formation with no damage to the lens surface.

In tropical climates conditions sometimes are so balanced that just the right amount of water collects on a lens surface to form a concentrated solution of the haze material. Such a solution may attack the silica of the glass and pit the surface permanently. Under tropical conditions frequent cleaning of the lens surfaces is necessary to prevent such surface damage. Anyone using lenses under conditions of high humidity should wipe the haze from exposed surfaces with a soft damp cloth at frequent intervals.

TABLE I

Durability Test Results for Optical Glass

Type of Glass	Type Refractive Index	Type ν_D Value	Dimming Test Class	Stain Test Class
Borosilicate crown	1.511	63	1.	1
	1.516	64	1.5	1
	1.516	64	1.	1
	1.517	64	1.	1
	1.518	64	1.5	1
Crown	1.523	59	1.5	1
	1.512	60	1.5	1
Light barium crown	1.572	57	2.	3
	1.572	57	2.	4
	1.573	57	1.5	3
	1.574	57	1.	1
Dense barium crown	1.608	59	3.5	5
	1.609	59	3.	5
	1.611	59	3.	5
	1.611	60	3.	5
	1.610	57	1.	4.5
	1.611	57	2.	5
	1.611	59	3.	5
	1.612	57	2.	5
Crown flint	1.526	51	3.	1
	1.528	52	1.	1
	1.528	52	1.	1
	1.529	52	1.	1
Barium flint	1.581	46	1.5	3
	1.583	47	1.	1
	1.584	46	1.	1
	1.588	46	2.	2.5
	1.605	44	2.	2
Extra dense flint	1.717	29	3.	3
	1.717	29	2.	3.5
	1.720	29	1.5	3
	1.721	29	2.	5
	1.648	34	3.	2
	1.649	34	2.	2
	1.650	34	2.	2
	1.650	34	2.	2

RATE OF STAINING AND DIMMING FOR GLASSES OF DIFFERENT TYPES

Laboratory tests for evaluating the tendency of a glass to form low-reflecting stains in contact with weakly acid water and to collect haze when exposed to humid air have been developed. In Table I most of the common types of optical glasses are classified in regard to their staining or dimming tendencies. The glasses are scored from 1 to 5 with class 1 being very resistant and class 5 being easily affected.

SILICATE FILM FORMATION BY CHEMICAL TREATMENT OF POLISHED GLASS SURFACES

Purposely formed silica films for increasing the transparency of glass are identical with the stains that form accidentally on dense lead and barium glasses except that they are of controlled thickness and may be stabilized against any further increase in thickness. A lens treated to provide the maximum transmission for white light will reflect so little green light that the surface of the lens will appear purple.

The silica surface has a hardness and scratch resistance comparable to that of the original glass. A lens that has been given a surface curvature to fit a test glass will pass the same inspection after processing.

The gain in light transmission that results when a silica surface is formed by chemical treatment is somewhat less than that produced by films of low-refractive-index fluorides evaporated by the Cartwright and Turner method. When the greatest possible gain in transmission is required, the evaporated fluoride films are preferable. When hardness and durability are of primary importance, silica films produced by chemical treatment are superior. The evaporated fluorides have little effect upon the ability of glass to withstand the attack of moisture. Properly heat-treated silica films lower the solubility of glass surfaces so that durability is greatly increased over that of untreated surfaces. There is little doubt that both the evaporation process and the chemical process will be used in the optical industry, with each having advantages in certain circumstances.

Since the possibility of increasing the light transmission of lenses by chemical treatment has been known for many years, it is difficult for most persons to understand why the process has not been more widely used. There were three main reasons for the delay: (*1*) customers would not accept lenses that showed surface color; (*2*) the chemical and physical principles involved in the process were not completely understood, so that the gain in transmission varied from one piece to another; (*3*) many types of optical glass could not be treated. Miss Blodgett of the General Electric Company's research laboratory worked out the relationship between film thickness, color, reflectivity, and light transmission for all types of surface films, and the publicity that followed her discoveries led to the present demand for treated lenses. Chemical study of the process at the Bausch & Lomb plant and at the Mellon Institute has resulted in practical plant processes for treating all the glasses made by the Company and for making the treated surfaces less subject to weathering than the original glass.

SOLUTION COMPOSITION USED TO PRODUCE SILICA SURFACE FILMS

Dilute solutions of the common strong acids will produce silica films on most glasses. Nitric acid is often used since its salts are soluble. Weaker acids, including phosphoric or boric acid, are used with those glasses that rate class 5 in the staining test, such as the dense barium crown types. Different solutions produce varying increases in light transmission of a given type of glass, indicating that a greater percentage of the soluble elements is removed by some solutions than by others.

All the commonly used types of optical glass containing silica can be given a silica surface film by chemical treatment. The improvement in light transmission produced by the process varies according to the refractive index of the base glass. Using a Mazda lamp as a light-source and a Martens type visual photometer to measure the light, a sheet of lead glass with a refractive index of 1.72 was found to transmit 86 per cent of the light striking the sheet normal to the surface. After the formation of a purple surface layer by acid treatment, the light transmission was 97 per cent. A borosilicate glass or a crown glass sheet with a refractive index of 1.52 will transmit 92 per cent of the light before treatment and 95 per cent after formation of a purple silica film. The gain in light transmission for optical glasses of intermediate index will fall between these two values. Soda-lime-silica crown glasses are bothersome to treat because of the long time required to form a film of the required thickness.

STABILIZATION OF SILICA FILMS

The initial rate of reaction between a clean glass surface and a water solution is governed by the composition of the glass, the composition of the solution, and the temperature. When a silica film has formed due to the removal of the more soluble constituents of the glass, the rate of reaction between the glass and the solution is more and more limited by the rate at which the solution can penetrate the silica layer already formed. In general, the protective effect of a silica layer is very roughly proportional to the percentage of silica in the original glass. The film produced on the glass containing a large amount of lead or barium has little protective effect, and the amount of lead or barium dissolved is practically proportional to time. The protective effect of the silica film is increased enormously, however, if the treated glass is removed from the solution and heated to densify the silica. The rate of solution can be reduced by this process to such a point that no further change in thickness of the silica film will occur in normal use. Thin silica films will react similarly to those thick enough to produce high transmission, so that, if desired, the surface stabilization may be obtained with films too thin to show interference color. There is a shrinkage of the surface layer during baking, so in practice a film slightly thicker than that desired is applied in the chemical treatment and the baking operation is controlled so that the finished lens has the correct film thickness.

Stabilization of the film by baking is necessary for two reasons. A film with an optical thickness $^1/_4$ the wavelength for which maximum light transmission is desired is most efficient, and any increase in film thickness with use would be detrimental. If dense barium crown glass is exposed constantly to outdoor weather and to tropical rains, there is some danger that the films may become many wavelengths in thickness and subsequent drying may cause the film to crack and shrink away from the base glass.

There are several points in the process of manufacturing lenses where invisibly thin silica films may be formed in an uneven pattern. It is therefore necessary to treat and stabilize lenses immediately after they are polished. A scientific detective could reconstruct the past history of a lens and its contacts with moisture, including fingerprints, water marks, and tray marks, by chemically treating glass that is not freshly polished. It is not ordinarily possible to produce uniform silica films on lenses that have been in use or storage.

Lenses to be treated to form silica films require a more perfect polish than other lenses. If the glass surface is ground and then polished only the minimum time required to remove all visible scratches, the chemical treatment will open up invisible scratches and make the scratch pattern again visible. If the glass is polished for a sufficient time after all visible scratches are removed, the treatment will not harm the polished surface.

PRACTICAL APPLICATION OF SILICA FILMS

The first Bausch & Lomb product on which lenses coated with silica films were used in commercial quantities was the *f*/2 Super Cinephor projection lens. The totally enclosed elements of this lens are coated with evaporated fluoride films, while the front and rear elements are given silica films by chemical treatment. These elements are baked after treatment so that the exposed surfaces will have the improved durability and permanence characteristic of a dense silica film.

Theoretically almost all optical instruments could be improved if made from elements coated to reduce surface reflection. The cost of treatment and the complications introduced when established manufacturing routines are changed make it necessary that each instrument be carefully studied to see whether coated lenses produce a noticeable and valuable improvement that will justify increasing production costs and selling prices. Investigations are now in progress on many lines of optical equipment. There is little doubt that more uses for coated lens systems will develop within the coming five years. It is hoped that this paper will help to spread the idea that a colored surface on a polished lens is not necessarily a defect.

RECENT IMPROVEMENTS IN NON-REFLECTIVE LENS COATING*

WILLIAM C. MILLER**

Summary.—*As early as 1892 it was known that the reflectivity of polished glass surfaces was reduced and the light transmission increased when a suitable film was present on the surface of the glass. Many efforts to produce such a film artificially met with only partial success. In the past five years, two different methods have been discovered that achieve the desired results. Only one of the processes, however, was satisfactory for commercial application. Great improvements have been made in the durability and weather resistance of the thin films deposited upon the lens surface by this method. Lenses coated by this improved process require no more careful handling than any good lens is entitled to; fingerprints and dust can be removed without detrimental effects to the coating. The thin films can not be scratched with anything less hard than a metal point. By this process, reflectivity can be reduced from an average of 5 per cent for untreated polished surfaces to as low as 0.5 per cent for treated ones. Experiments show that even greater reductions are possible and should be available in the near future.*

The general application of the lens-coating process to studio optical equipment is now just one year old. In view of the wide interest and attention that this process has aroused, a discussion of the results and a report of the improvements made in the process will be of interest. Unfortunately, time has not permitted the accumulation of exhaustive data. However, those that are available show that the new process is of vital importance in many fields and is already quite indispensable.

HISTORICAL

Although it had been known for many years that certain types of glass developed a tarnish after prolonged exposure to the air, it apparently was not until 1892 that any careful study of the effects of such tarnish was made. At that time H. Dennis Taylor, famous lens designer, made careful measurements upon several tarnished lenses that had come to his attention. The tarnish had the appearance of a

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received May 1, 1941.

** Vard Mechanical Laboratory, Pasadena, Calif.

metallic sheen and had always been considered to be highly detrimental. The results of Taylor's measurements and tests, however, showed that the tarnished lenses reflected less light from their polished surfaces than did identical new ones. This of itself was of great importance, but of still greater importance was the fact that the light that was no longer reflected by the polished surfaces was transmitted by the lenses. The tarnished lenses produced images measurably brighter than did identical new and untarnished lenses.

Taylor was so impressed with the potentialities of the discovery that he made extensive experiments to find means of producing this tarnish artificially on the surfaces of new lens elements. Unfortunately he met with only partial success, for the types of glass that he was able to treat proved to be limited. Furthermore, the reduction in reflectivity obtainable with many of the glasses was too slight to be of commercial value.

Many efforts were made in subsequent years to discover methods of artificially producing the desired results, but with only moderate success. Kollmorgen, Kellner, Wright, and Ferguson all made contributions to the art, but certain types of glass resisted all attempts to produce a tarnish of the desired nature.

All the processes developed up to that time were of the chemical type; that is, they depended upon the action of chemical solutions or concentrated salts upon the surface of the glass to produce the desired tarnish. Since this reaction took place with the glass itself, it was impossible to remove the effects of the treatment without completely refinishing the optical surface, a costly and time-consuming procedure. The greatest care was therefore necessary in the treatment of optical elements to insure satisfactory results, since an error meant refinishing the surface or making a new element. This treatment could not be safely attempted by anyone other than the makers of the original optical parts.

Since many varieties of glass are employed in the lenses in common use, and many of these glasses either could not be treated at all or could be treated with only moderate success, the application of the process was not widespread.

What was required to make the theory universally practical and applicable was a method of producing the tarnish upon lens surfaces irrespective of the type of glass from which the lenses were made and would yield reductions in reflectivity sufficiently great to justify the trouble and expense of application.

In view of the many years that elapsed with little or no successful development of the art, it is remarkable that two independent processes of quite a different nature should be announced within the short period of three years. The first announcement came in 1936 of a process discovered by Dr. John Strong[1] of the California Institute of Technology. Strong's process consisted of the deposition of a thin film of suitable material upon the surface of optical elements in a high vacuum. This thin film, when deposited under the correct conditions and to a specified thickness, effected reductions in the surface reflectivity as great as 85 per cent. The second announcement came in 1939 of a process discovered by Miss Katherine Blodgett[2] of the General Electric Laboratories. Miss Blodgett's process consisted of the formation of a soapy film of the required characteristics upon the surface of optical elements. Although the reductions in reflectivity achieved by this process were great, the extreme fragility of the film made the process impracticable for general use.

THEORETICAL

The theory of the reduction of surface reflection has been dealt with so thoroughly and competently by others in the literature[1, 2, 3 4] that it will be necessary to give only the general principles of the phenomenon here. The quantity of light reflected from the polished surface of a transparent material and, therefore, lost from the transmitted beam, depends upon such factors as the index of refraction of the material and the angle at which the light strikes the surface. If the angle of incidence is kept constant, then the index of refraction is the determining factor, and the higher the index the greater is the percentage of light reflected.

Light can be considered as traveling in a wave form. When a beam of light is reflected from two parallel polished surfaces of a transparent material, the light-waves can be made to supplement or oppose each other in the reflected beams by suitable adjustment of the separation of the reflecting surfaces. When these have an optical separation of $^1/_4$ of a wavelength, the waves in the two reflected beams oppose each other and cause destructive interference. The total ntensity of the reflected beam will be zero when, and only when, the two components are of equal intensity.

If we wish to reduce the reflectivity of the polished surfaces of an optical element and thereby increase their transmission, it can, therefore, be done by providing over the entire element two reflective surfaces separated by $^1/_4$ wavelength, both surfaces reflecting an equal amount of light. Under these conditions, the two beams will cancel each other. Although it was not clearly understood until the time of Dr. Strong's work, it was this interference phenomenon that accounted for the effects observed by Taylor and the others.

The most satisfactory method of producing the two reflective surfaces separated by the correct distance is to form upon the surface of an optical element a film of transparent material of such nature and of such refractive index that the light reflected from the contact surface where the film touches the glass equals that reflected from the upper surface. This index can be found with little trouble to be equal to about 1.25.

The effects that Taylor observed first were due to the formation of a film of approximately the required characteristics by the chemical action of the air with some of the constituents of the glass. The chemical methods that were subsequently developed all aimed at the artificial stimulation of such a film. The failure of the methods to produce more satisfactory results was due to the fact that a film of the required index could not be formed on all types of glass. Even the process developed by Strong missed perfection in that particular respect, for there is no suitable substance that can be applied in the form of a film having an index as low as the required 1.25.

All the processes—the chemical by Taylor, Kollmorgen, Kellner, Wright, and Ferguson; the evaporation by Strong; and the one by Miss Blodgett—fail in one other important respect which offers such natural obstacles that it may never be surmounted; that is, the thickness requirement. The film can be made of the required thickness for only one wavelength at a time and is, therefore, wrong for all others. Consequently, when white light is used, the reduction of reflectivity can be made a minimum for only one color; all others suffer greater amounts of reflection. Fortunately, the difference for other colors is not great, but it is sufficient to give treated surfaces a colored hue when viewed by reflected light. If all colors were reduced equally, the remaining small amount of reflected light would not display any predominant color.

Optical systems designed to work with light of some certain wavelength should be treated to give maximum transmission for that wavelength. Complying with this rule there are in use in the studios many violet recording systems that have been treated for maximum transmission at about 4000 Å.

At the writing of the previous paper[5] on this subject in April, 1940, the process had been in use experimentally for only a few months, but such great interest was shown in the possibilities of the process that a report was considered desirable at that time. Due to the newness of the process, however, little definite information based on actual production results could be given. At the present writing, however, some very interesting data are at hand, supplied through the courtesy of several of the studios in Hollywood.

Sound-recording systems consisting of ten air-glass surfaces have been treated both for violet and unfiltered light. A gain in transmission of 50 per cent was measured in nearly all cases. Since the tungsten recorder lamps are of necessity burned at or near their peak capacity, this 50 per cent increase in transmission in the optical train has made it possible to relieve the load on the lamps and thereby considerably increase the lamp life. In some instances the gains obtained by treatment of the lenses have been utilized, not to save current or lamp life, but to make possible the use of slower, finer-grained films.

A large number of motion picture camera lenses has been treated during the past year. Careful measurements made at one of the major studios on a 3-inch focus Cooke Speed Panchro lens at *f*/2.0 showed the transmission of the untreated lens to be 69.5 per cent. The transmission of the lens when treated was 95.1 per cent. In other words, the light loss had been reduced from nearly 30 per cent to less than 5 per cent. Another studio reports measurements showing a gain of 32 per cent due to treatment of another type of lens.

Of even greater interest than the increase in transmission is the improvement in the image quality due to this treatment. The increase in contrast and brilliance of pictures made with treated lenses is very noticeable. In work where the utmost in image quality is required, such as in process projection keys, the treatment is of great value and is widely used in several studios.

Due to the number of steps involved in the production of a finished process shot, it is necessary to apply every known means of reducing the losses of picture quality to a minimum. Since these are primarily losses of brilliance and contrast, the very features that treated lenses enhance, the application of this treatment to both the projection and camera lenses used in process work is of great value. Reports of the results obtained in this field are definitely satisfactory and gratifying.

Another of the major problems encountered in the process work is that of screen illumination. Constant efforts are being made to increase the light output of the projection systems used in this work. Gains of 10 to 20 per cent have been the subject for loud rejoicing. Yet actual tests by the studios have shown that by treating the projection lenses, gains as high as 30 per cent are to be had. One studio had a peak screen illumination of 24,000 lumens with untreated projection lenses. After treatment 30,000 lumens were obtained. This is an increase of 6000 lumens.

In straight production work the results are no less interesting. Treatment of lenses has so reduced ghosts and flares that it is now possible to apply hitherto unusable methods of set illumination. This is particularly true of low-key sets.

There have been several successful pictures made during the past year in which low-key lighting greatly enhanced the atmosphere of the picture. No small part of the success of these low-key scenes was due to the clarity and brilliance with which they were reproduced through the use of treated lenses. Intense local lighting did not mask out shadow detail or cause ghosts of any sort.

Of particular interest was one shot, made in a dark hallway, of two characters approaching cautiously with a flashlight. Quite by accident the flashlight was turned full into the lens of the camera. But contrary to expectation the shot was not ruined, for no flares appeared and the dimly lighted faces of the two characters could still be clearly seen over the brilliant image of the flashlight.

The reduction of flares or ghosts is so great that tests with treated and untreated Astro lenses shooting straight into the sun show a bare trace of one ghost with the treated lens which before treatment gave thirteen conspicuous ghosts.

As the results obtained with the treated lenses became available and comments and criticisms from the users drifted in, the need for more research work on the process became obvious. A harder and more durable treatment was definitely needed. The research program that was undertaken in our laboratories had for its objectives four primary aims. First, it was desired to produce films that were much harder than anything available at that time. The aim in this respect was to produce films which were just sufficiently softer than the underlying glass to permit the removal of the film without damage to the lens element should the removal be required. Second, this hardness must be obtained by means other than baking, for it was felt that to subject precision optical parts to high temperatures was decidedly detrimental. Third, the films must be sufficiently resistant to vapors to eliminate any tendency to fog in normal use. Fourth, the efficiency of the films must not be impaired while obtaining this increase in hardness.

Many months of intensive experimental work were devoted to this program. Several methods of improving the process were discovered, but the final method was so superior to any of the others that it was made the subject of patent application.

Where previously the removal of dust from a treated lens with a soft camel-hair brush had often resulted in damage to the coats, the new hard ones could be handled with no more care than any good optical element deserves. Test samples were subjected to very severe treatment. Finger marks were repeatedly placed on them and successfully wiped off. They were allowed to lie around the laboratory for long periods where they accumulated dust and dirt, which was then removed without damage to the treated surfaces.

Those acquainted with the fragility of the early coats would be astonished to witness demonstrations of the hardness of the coats when they are jabbed and scraped with wooden sticks, breathed upon, and wiped with cloths without damage. One of the most popular tests is to rub a sample through the hair to coat it with oil and then to return it to its original efficiency and unblemished state by rubbing it with a cleaning pad.

This welcome durability was obtained without loss of efficiency of the films, as was the intention. Coated surfaces reduce the reflectivity of polished glass to $^1/_8$ or less of the original value. Sample glass disks coated on both sides, but only in the center, give a most interesting demonstration of the efficiency of the films. When held between the observer and the sky, the treated central portion is decidedly brighter than the surrounding untreated area, due to the increased transmission. These same samples, held between the eye and some dark background such as black pavement, show a brilliant ring around the untreated edge where the bright sky is reflected in undiminished intensity. The treated center, however, appears quite dark and the pavement beyond can be seen without difficulty, whereas it is seen only indistinctly elsewhere through the glare of the reflected skylight.

A camera lens was treated for demonstration purposes so that only one-half of each element was coated, and the treated halves were lined up so that they were all on the same side when mounted in the barrel of the lens. Either by reflected or transmitted light the effect is most impressive. By reflected light, the iris diaphragm is barely visible through the glare of the light reflected from the untreated halves of the first four surfaces; while through the treated half it is clearly visible, as well as interior details of the lens mounting as far back as the last element. When viewed against the sky, the treated side of the lens is markedly brighter than the untreated half. When a dark object surrounded by a bright background is viewed through the lens by an observer in the dark, a good demonstration is obtained of the benefits of this treatment. The untreated half of the lens is seen illuminated by light from the bright background reflected and re-reflected between the untreated surfaces. The treated half is dark, however, since any light that reaches the eye has suffered at least two reflections from treated surfaces, and is, therefore, reduced to $^1/_{64}$ of the intensity of the light from the untreated surfaces. This demonstrates perfectly the reason for the improvement in picture quality obtained with treated lenses. The photographic film is no longer confronted with the glare of light reflected to it from the several surfaces of the lens.

A result of the research program not as yet made available to the public is an improvement in efficiency that has been found possible. The reflectivity of surfaces can be reduced from the present low value of 12.5 per cent (counting untreated surfaces as reflecting 100 per cent) to as low as 9 or 10 per cent. This may seem at first to be trivial, but actually it is relatively important. Samples with this new low reflectivity can be distinguished instantly from the others. It appears that this low reflectivity can be supplied with a film hardness as great as that described above. As soon as more searching tests have been made and the results found satisfactory, this improved coating will also be made available.

With such satisfactory results as these appearing in the short space of one year from only one laboratory, the future of the lens-coating process should be very promising. Certainly other improvements will be made from time to time. Still greater efficiency will be obtained, methods of treating larger and larger surfaces will be developed, and in the space of a few more years uncoated lenses will probably be things of the past. However, although the ultimate is not yet achieved, the process is so much improved over what it was a year ago it should find wide application in a multitude of fields.

REFERENCES

[1] STRONG, J.: "On a Method of Decreasing the Reflection from Non-Metallic Surfaces," *J. Opt. Soc. Amer.*, **26** (Jan., 1936), p. 73.

[2] BLODGETT, K. B.: "The Use of Interference to Extinguish the Reflection of Light from Glass," *Phys. Rev.*, **55** (April, 1939), p. 391.

[3] CARTWRIGHT, C. H., AND TURNER, A. F.: *Phys. Rev.*, **55** (1939), p. 595(A).

[4] CARTWRIGHT, C. H., AND TURNER, A. F.: "Treatment of Camera Lenses with Low-Reflecting Films," *J. Opt. Soc. Amer.*, **30** (Feb., 1940), p. 110.

[5] MILLER, W. C.: "Speed Up Your Lens Systems," *J. Soc. Mot. Pict. Eng.*, **XXXV** (July, 1940), p. 3.

DISCUSSION

DR. CARVER: At a demonstration last year in New York, of motion pictures projected with lenses coated with non-reflective layers, the most obvious effect was that of an increase in contrast. Now, the processing laboratories have worked out their methods of processing to give a contrast that they believe to be the most pleasing, using standard equipment. Do you know whether the laboratories have found it necessary to change their processing conditions in order to compensate for the increased contrast obtained with the treated lenses?

DR. TURNER: In some cases a change in processing methods was necessary, but it could be very easily accomplished.

MR. JOY: Has moisture any effect upon these treated surfaces?

MR. COOK: Not on the outside surfaces of the lenses, which are treated by a method that produces a very durable film on the glass.

NEW GADGETS FOR THE FILM LABORATORY*

B. ROBINSON AND M. LESHING**

***Summary.**—A description of an air squeegee for use on a continuous film processing machine is given. This squeegee was designed to eliminate water spots on the processed film and the design is such as to give ready access for cleaning and inspection. A waterproof tape splicer for patching leader to be used on a machine equipped with the squeegees mentioned is described. Patches made by this method have been found to be longer-lived than the conventional ones with metal clips and are responsible also for the use of less leader over a period of time.*

Before the advent of fine-grain material, our developing machines were equipped with chamois-covered rollers to take off excess moisture from the film before it entered the dry-box. These rollers were never very satisfactory, especially as to the cost of maintenance. In chamois alone the cost was about $1000 a year. There was always the possible danger that grit would stick to the chamois and ruin all the film passing over it. But, until the advent of the fine-grain materials, the lack of time and the usual inertia kept us from improving the unsatisfactory condition.

The very first week of using fine-grain film (in this instance we have in mind the master positive type) we ran across a situation which had to be solved immediately. The chamois rollers now and then left innumerable very tiny circular spots of moisture on the base side which were very hard to polish off and which were very hard to discover before the duplicate negative was made. During one of his visits Mr. J. G. Capstaff of the Eastman Kodak Company mentioned a very satisfactory air squeegee he had designed. After the drawings arrived from Kodak Park we could readily see that some changes were necessary to suit the conditions in our laboratory. From our point of view the main difficulty was the necessity of taking the whole squeegee apart for inspection and cleaning. While retaining the main design of the squeegee, we split it in half to make the threading-up, cleaning,

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received May 5, 1941.

** Twentieth-Century Fox Film Corp., Hollywood, Calif.

and inspection a very simple matter. Fig. 1 shows the simple design. The air is supplied by a Nash Hythor compressor at eight pounds' pressure. After passing through two separators to take out water, the pressure is reduced by a Reliance regulator to two pounds for picture negative and to about two and one-half pounds for sound negative. No filters or screens are used in the airlines as we have never noticed any need for them. The air reaches the film through 0.038-inch apertures shown in the drawing. The results obtained are excellent.

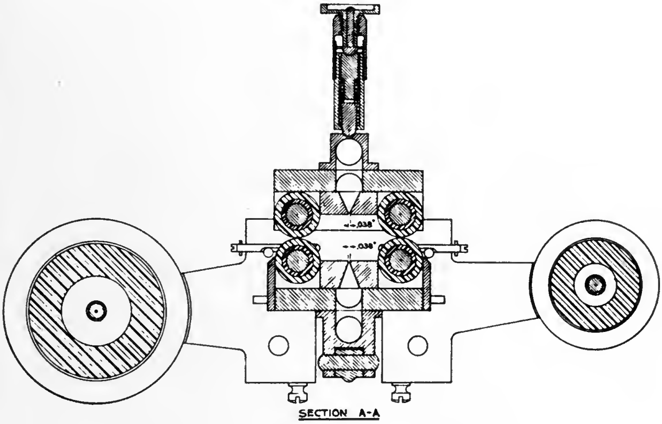

FIG. 1. Simple design of air squeegee.

With the introduction of this new air squeegee we were forced to look for a different method of splicing film for the developing machines due to the fact that the metal patches we had been using produced too big a disturbance in the rubber rollers of the squeegees, making the work unsatisfactory. We remembered seeing in the drawings of an Eastman Kodak developing machine mention of a waterproof tape splicer, which we proceeded to adopt for our needs. The first splicer built by us required too many manual operations, but as the work done by the splicer showed us that we were on the right track and that the waterproof tape was very satisfactory as a splicing medium, we proceeded to build an improved model. Fig. 2 is a photograph of the improved model, which has been in use now for a number of months in our laboratory. The number of operations has been decreased considerably and that is the reason for the complicated appearance of this piece of equipment.

It can be seen from the photograph that a splicer of this kind can not be produced very cheaply—ours cost a few hundred dollars. But when we say that during the first six months after installation of the waterproof tape splicer we used 39,000 feet less leader than during a corresponding period preceding the use of splices of this type, it will be seen that the money was very well spent. This saving may be surprising to some. Splices made with the metal patches took about eight inches of film. We inspected the leader and cut out every indication of damage every night before starting our night's work. Damaged portions were quite numerous, due to the prongs of the metal splices catching in the perforations of adjacent convolutions. The waterproof tape removed this difficulty, and we have leader with splices several months old that are just as good today as they were when they were made.

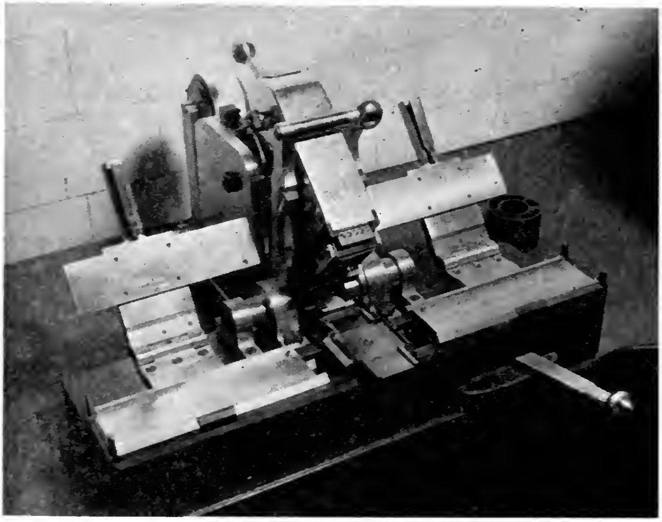

FIG. 2. Improved splicer.

The patcher is centrally located in the machine room on a bench or table, flanked on the left by a spindle bracket to hold the reel of leader to be inspected and on the right by a rewind on which the inspected and patched leader is wound. This rewinding is done by hand, any damaged or weakened portions being cut out and the ends joined on the patcher. All existing splices are examined and any that have deteriorated are replaced.

The splicer is mounted on a cast-iron base which is recessed so that shielded space is provided between the table top on which it is placed and the top of the casting, to accommodate the major part of the operating mechanism. A horizontal groove is provided through the length of the casting to receive two sliding plates. This groove is interrupted by a centrally located stationary anvil. The sliding plates are grooved for film width and each is provided with a single-perforation or index pin. The bed of the plates and that of the anvil are on a common plane. A lever projecting from the front of the base controls the reciprocating motion of these two plates.

The first operation in making a patch is to throw the two plates outward to a stop. The two leader ends to be joined are placed in the groove of the plates and over the perforation pins, with the film ends extending over the edges of the anvil. The plates are provided with hinged covers, which are lowered and spring-latched to lock the film ends in place. Two hinged and connected shearing cutters are now lowered manually. They straddle the anvil and shear the film ends, establishing a definite gap between the ends to be spliced. The operator now picks up the adhesive tape end, which is located centrally and back of the anvil, between thumb and forefinger, and operating a lever with the other hand, feeds the required length of tape over the anvil with the adhesive side up. The two film-holding plates are now moved inwardly toward the anvil by means of the same lever that located them for the shearing operation. The two film ends travelling toward each other are automatically raised to clear the tape. As the tables carrying the film ends approach their inward station, the film ends are dropped to the adhesive tape, leaving a gap of approximately $^1/_{16}$ inch.

A pedal-operated cutter parts the tape over the rear of the anvil. This operation includes pressing a rubber pad against the film, forcing air from between the tape and film, and the breaking of the tape around the film edges. The two tape ends are then folded manually to overlap. The pedal is again depressed, the rubber-padded head irons out the splice; and eight manually operated punches, spaced to match four perforations on each film end, strike the waterproof tape through the perforations to bring the adhesive back to back. The patch is now complete. The latched covers holding the leader are released and raised, and the leader is drawn from the index pins. The operations described are performed in approximately ten seconds.

M-G-M'S NEW CAMERA BOOM*

JOHN ARNOLD**

Summary.—*A new type of intermediate-size boom incorporating a number of very desirable features has been placed in serivice at the M-G-M Studio. The device is of the crane-arm, or boom, type, with a boom 9 feet in length carrying an underslung camera mounting. The camera may literally be laid upon the stage floor, or lifted to a maximum height of 16 feet. The entire boom-arm may be raised or lowered bodily by means of a motor-driven helical hoist.*

With the popularization of the modern moving-camera technic there has been an increasing trend toward the development of camera-supporting units capable of serving as virtually universal camera carriages for use not only in stationary but in most types of moving-camera shots. Obviously, questions of bulk and weight have consistently been limiting factors, as have those of operational facility.

Accordingly we have seen the evolution of two principal types. On the one hand, there is a variety of small, mobile camera carriages such as the "rotambulator" and the "velocilator." On the opposite extreme are the much larger crane or boom-type units capable of lifting a camera and its crew twenty or thirty feet into the air.

In some instances, intermediate-size cranes have been built; but, in general, various conditions of design and operation have limited their usefulness.

Nonetheless, it has been admitted generally that if some single device had been available, capable of fulfilling all the camera-carriage requirements of modern technic, with the exception of those few demanding the use of the largest cranes, production would have gained a valuable tool.

A new type of intermediate-size boom, apparently incorporating most of these desirable features, has been placed in service at the Metro-Goldwyn-Mayer studio. It features not only unusual versatility, but in many respects it differs radically from all accepted practice.

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* Presented at the 1940 Fall Meeting at Hollywood, Calif.

** Metro-Goldwyn-Mayer Studios, Culver City, Calif.

The device is of the crane-arm or boom type, with a boom 9 feet in length carrying an underslung camera mounting. The camera may literally be laid on the stage floor, or lifted to a maximum height of 16 feet. The entire boom arm may be raised or lowered bodily, by means of a motor-driven, helical hoist.

The boom arm rotates freely through a full 360-degree horizontal circle, while, in addition, the camera-head may, by an independent, extra quick-action pan movement, be panned through a full 360-degree circle. The tilt-head likewise operates through a 360-degree vertical circle. The device is considerably lighter, and may be operated much easier than any comparable unit.

FIG. 1. The new M-G-M camera boom.

Radically new principles of construction have been employed throughout, and full use has been made of the modern, lightweight, high-tensile alloys and stainless steels.

The chassis is of unusually simple tubular construction. Instead of the usual channel sections conventionally employed for this purpose, the main frame consists of a single tube of high-tensile steel.

Welded to this, at right-angles, are two smaller tubes forming the axles. No springs are employed, as these devices invariably are used on special plank or metal tracks, and it has long since been found that any form of springing introduces an undesirable unsteadiness, especially with the camera at the end of a long boom.

All four wheels are mounted in conventional steering knuckles. The rear wheels, however, are at present locked in a non-steerable position, though the design makes provision for rendering them steerable if any future need should arise.

The front wheels are steerable, being controlled from an automobile-type steering wheel mounted before an underslung seat on the left side. The design is such that the steering wheels may be turned almost parallel to their axle, for sharp maneuvering.

A fifth wheel is provided at the rear of the tubular main frame. This may be dropped down to raise the rear end from the rear wheels, so that the device can be turned in its own length, or moved sidewise into position. All four service wheels are ball-bearing equipped.

Extending upward from this tubular frame is a tubular vertical member. Upon this is mounted a power-driven helical hoist strikingly similar to that employed in the "rotambulator."

The mounting of the crane arm slides up and down this main shaft in a friction mount. It is propelled upward or downward by a suitably proportioned screw paralleling the main shaft.

This screw or helix is rotated by a $^3/_4$-hp motor controlled through a d-c reversing circuit and controller. Automatic stop switches limit the upward and downward travel of this unit.

This hoist is not intended primarily for changing the height of the camera during a scene, but instead for more accurate positioning, after which the boom arm raises or lowers the camera. The drive, therefore, while quiet, is not noiseless. In addition, it is low-geared, to simplify construction.

The crane arm itself embodies a type of construction not hitherto applied to this type of studio equipment. Instead of the conventional girder or box-truss construction, this arm employs a stressed-skin or "monococque" construction combining unusual rigidity with extremely light weight.

The arm is constructed of four 10-gauge sheets of high-tensile steel, welded together to form a long, tapering box girder. This boxlike construction is reinforced at approximately 6-inch intervals with transverse bulkheads of the same alloy, welded into place.

The result is a boom of unusually light weight, yet of remarkable strength. From an engineering viewpoint it is strikingly similar to the monocoque fuselages of the most modern transport and racing airplanes, in which the bulk and weight of longitudinal girders are eliminated by a skin strong enough to withstand the stresses normally taken by longitudinal beams, and reinforced with stiffening transverse bulkheads.

The outer end of the boom arm curves upward to afford increased clearance. At this end is the camera mount, which is of the underslung type.

In this the camera is slung beneath the panning mechanism, though of course the pan and tilt controls are in their usual places, beside and slightly under the camera. Each gives the camera a full 360-degree rotation in its plane; the crank-wheel controls favored at M-G-M are used.

The panoramic movement is geared to unusually high speed: only 14 revolutions of the control wheel are required to revolve the camera through a full 360-degree circle.

A single, well-upholstered seat, of tubular metal construction, is provided for the operative cameraman. This seat is quickly removable when not needed. Ordinarily no seat is needed for the assistant, as the camera is focused by an adaptation of a new d-c remote-control method.

Provision is made for mounting a second camera above the crane arm. This has a conventional M-G-M type pan-and-tilt head, and pans and tilts wholly independently of the lower camera.

A source of constant irritation, and in some cases even of danger, in conventional crane designs is the system of counterbalancing the weight of camera and crew, which is usually done by means of removable lead weights placed in a box at the opposite end of the arm.

The counterbalance is built permanently into the arm. Compensation for the varying weights of equipment and crew is made by turning a large control wheel at the inner end of the arm. This moves the counterweight toward or away from the fulcrum, accordingly decreasing or increasing its leverage.

By this means it is possible to counterbalance the boom so accurately that it may literally be raised or lowered with one finger. A set-screw type of friction lock, operating on a quadrant, permits locking the arm in any position. A similar lock is provided to limit the boom's horizontal rotation, and brakes of the automotive type are provided on the rear wheels.

A full circular catwalk is provided for the boom-operator. This is made in four sections, all of which are demountable. At the front end are two telescopic tubular members, either or both of which can be extended—one on either side—for the stage crew to use in pushing the crane for dolly-shots.

A non-extensible, curved bumper is fixed at the rear for the same purpose, and also as a guard-rail. All these units—catwalk, pushing arms, and bumper—are instantly demountable.

The degree to which the unique construction employed saves weight may be judged by the fact that while booms of comparable size and of conventional construction have an average of over 7600 pounds, the new M-G-M boom weighs but 3100 pounds. Yet there appears to be no sacrifice in either strength or rigidity.

This new boom is as nearly as possible a completely universal camera carriage. Its rigidity is such that it can be employed, except in the most cramped quarters, as a stationary camera support in place of conventional tripods and the like.

In this service, the elevated crane arm and underslung camera mount give the camera crew more clear working space about the camera than any conventional type of tripod or boom. At the same time the crane arm, together with the power-driven hoist and free-rolling chassis, makes accurate positioning of the camera quicker and easier.

The suitability of the unit for the majority of moving-camera shots will of course be obvious. The precise controllability of the counterbalancing facilitates one-man operation in scenes where the camera must quickly follow an actor from a low position to a normal or high one, or the reverse.

In addition, the underslung camera mount will permit the boom arm to be extended completely over such a prop as a café table or even an automobile, and, with the boom extended to the side of the chassis, to dolly from or to such a position without interfering with the use of the prop in the wider angles of the same shot.

Altogether the unit appears unusually versatile and represents a distinct forward step in the evolution of mobile camera platforms. The application of advanced materials and engineering principles to its construction are also noteworthy.

AN IMPROVED MIXER POTENTIOMETER*

K. B. LAMBERT**

Summary.—*A type of mixing control is described that permits unusual efficiency of operation. It is applicable to all types of mixing, particularly the complicated operations such as recording music, re-recording, and radio broadcasting.*

In re-recording, or in multiple-channel recording of original music, or in multiple-microphone set-ups in radio broadcasting, the conventional mixing potentiometer having a rotary motion has serious disadvantages. In 1930, M-G-M Studios adopted a potentiometer control for re-recording having a linear motion, to and from the operator, instead of rotary motion. The operating philosophies that prompted this move were important then and have become increasingly so since.

We believed that a certain amount of re-recording was inevitable and that more improvement than harm would result to the remainder of our product if it were completely re-recorded for release. We also believed that the control of the release quality should be concentrated largely in the re-recording operation, and that the group which did this operation should be as small as practicable, for ease in coordinating their operations to achieve a consistent product. Re-recording has become increasingly complex, but progressive experience has enabled our four re-recorders to continue to handle nearly all our work without other assistance. Even within this group, each man prefers to work alone on a reel when he can, for then he can concentrate upon his own concept of the work and not have to coördinate his concept with that of someone else assisting him. The writer believes that some studios make composite records of a number of effects when a sequence is very complex, to simplify the final re-recording operation. We have not found this practicable, as the use of any individual effect is influenced by each of the others. We therefore mix all component tracks together at the same time. For these

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* Presented at the 1940 Fall Meeting at Hollywood, Calif.; received October 1, 1940.

** Metro-Goldwyn-Mayer Pictures, Inc., Culver City, Calif.

reasons, it is desirable to make the mechanical handling of the controls as simple as possible.

With linear movement, several potentiometers can be operated simultaneously with each hand and the control of a number of channels becomes much easier. The early forms of these mixers were somewhat inconvenient to maintain and keep clean, but having them, we did not redesign them until they needed major repairs. Then a new design was produced jointly by M-G-M and Audio Products Co. engineers, which corrected the disadvantages of the earlier types to such a degree that we now recommend them to the industry's attention.

FIG. 1. Mixer table operated by one re-recorder.

As employed in re-recording at M-G-M, each mixer table contains ten similar potentiometers, eight of which are used for mixing, and two for extra controls that may be required, as for the simultaneous control of a group of tracks (Fig. 1).

The mixer potentiometers are connected to the channel through a group of coils, each of which has five windings. Each coil combines four circuits into one having the same impedance, with a loss of 6.5 db. If only four potentiometers are used, one coil is required. Our circuits are normally set up for eight potentiometers, which require three coils, as shown in Fig. 2. If four or eight additional potentiometers are required, they may be added by the addition of one or two coils as shown in dotted lines in Fig. 3. These are high-quality coils having very small losses and phase-shifts. The coil circuits are made to have a uniform resistance of 200 ohms in all circuit directions by 300-ohm terminating resistances, as shown in Fig. 2. These resistances are included in the 6.5-db loss mentioned. Each potentiometer is of approximately constant 200-ohm impedance in both circuit directions, and all equalizers are of this impedance. A truly constant impedance at all degrees of attenuation is not practicable because the potentiometers are not of the step-type but are continuously wire

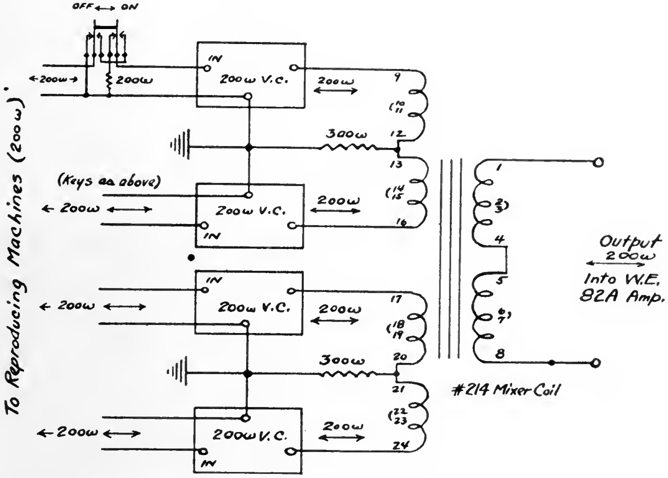

FIG. 2. Four positions of an M-G-M re-recording mixer.

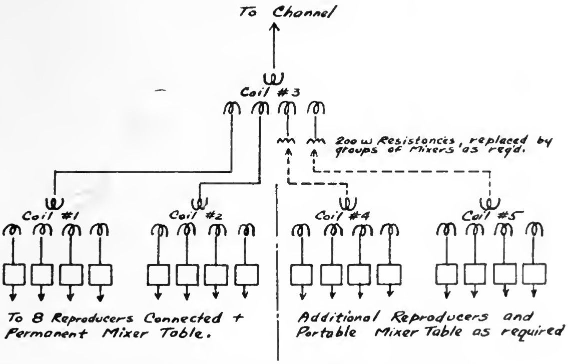

FIG. 3. M-C-M re-recording mixer tables.

wound. The large change of attenuation in one step of a conventional step-type potentiometer causes a click in the presence of loud signals. The change of attenuation in these potentiometers as the slider moves from wire to wire is about 0.1 db in the region where loud signals are mixed, and they therefore operate quietly. Quietness is apparently further aided by the use of graphite from a very soft lead-pencil as lubricant for the slider against the wires. This has also greatly reduced maintenance as compared to that required with the vaseline previously used. With the slider operating dry, or lubricated with vaseline, we averaged about one noisy potentiometer per day, with twenty in use; whereas with graphite we now have only about one per month. The minimum loss of each potentiometer is 6 db, and the minimum loss from the input of a potentiometer to the output of the 16-mixer coil is 19 db. The potentiometer is designed and wired to avoid internal cross-talk, having a maximum attenuation of 105 db at 1000 cps, and 90 at 7000 cps. This range appears to be sufficient in service. A key is provided for disconnecting and short-circuiting the reproducing machine and terminating the mixer with 200 ohms when it is not in use. The wiring of the table and jacks has cross-talk of less than 110 db. The mixers do not have a uniform linear rate of attenuation, as it has been found more desirable in operation to be able to change the attenuation rapidly at high degrees of attenuation where the signal is low, and more gradually at small attenuations where the signal is loud and the ear is more sensitive to

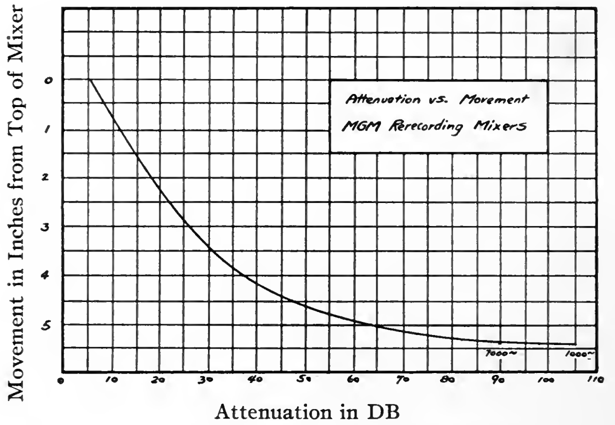

FIG. 4. Attenuation *vs.* movement, M-G-M re-recording mixers.

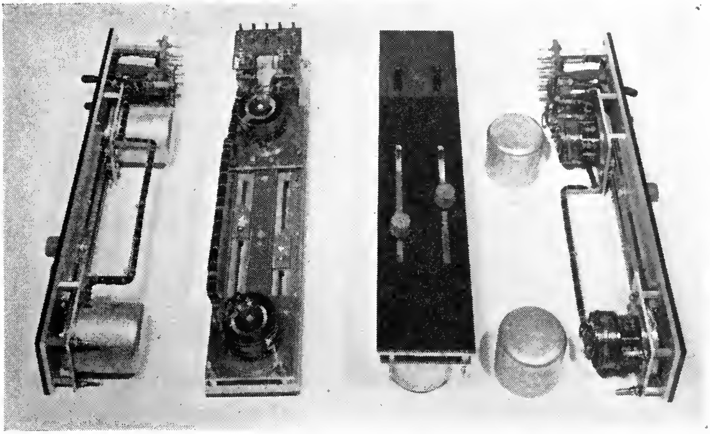

FIG. 5. Mixer construction.

FIG. 6. Mixer table open, showing jacks, *etc.*

small level changes. The curve of attenuation *vs.* movement is shown in Fig. 4.

The 10-position mixer table comprises five units of two mixer controls each, which can be inserted and removed similarly to a plug-in relay (Figs. 5 and 6). This facilitates maintenance, as a pair of mixers can be replaced with a spare with as little effort as a fuse. The potentiometers themselves have a rotary motion, and are controlled by a belt of cord, wrapped around a drum on the shaft. The sliding control knob runs in *V*-grooved tracks, set back from the slot in the panel so that dirt does not fall into the grooves. The mechanism is sufficiently free from friction that the mixer can be flipped from one extreme of its range of movement to the other. The knob itself has a depression for control by one finger, if this should be desirable.

FIG. 7. Two mixer tables set up for operation by two re-recorders.

Using this device, about 70 per cent of M-G-M's re-recording is done by the four individual re-recorders. With the exception of about $^1/_4$ per cent of the product, the remainder is done by teams of two as shown in Fig. 7. The exceptional reels may require a third man to operate equalizers.

DISCUSSION

Mr. Crabtree: It is still somewhat of a mystery to me as to how mixing is accomplished. What does the mixer do when he sits down at the mixing panel? When he gets the various sound-tracks, does he rehearse the picture with all of them and fiddle around with the keys until he thinks it is all right? Is the mixer responsible for the result, or does someone else listen in, and does the mixer remodify it to suit him? Suppose there is talking, with extraneous noises; does he first run through the speech record and adjust that, and then the noise record; or does he adjust the two simultaneously? It would seem that if he has eight fingers on eight keys he is attempting to integrate eight tracks simultaneously.

Mr. Hilliard: I can explain that as I would explain how I can drive nonchalantly downtown in Los Angeles through all the congestion of traffic, and yet pay attention while you are talking to me. Apparently, one does not think about what is happening, but adjusts himself automatically to the conditions.

As regards the lack of marks on the panel, the re-recording mixer indicates with a grease pencil how far he wishes to go in a given scene. Sometimes if the scene is very complicated he will break it down and run only the effects tracks, to get an idea of what has been given to him. In most cases, he has not previously seen the original material. In a temporary dubbing for previews a lot of material is given to him in a very short time, and he has to consult the log that is placed before him by the cutter, or by whoever is responsible for building up the effects to go along with the dialog and music. He looks at them and from previous experience knows roughly where they will be in the reel.

He breaks the material down and tells his operators on what types of machine to put it, if there is any preference in his mind. He might have higher-quality reproducers for dialog and music than for effects, so he utilizes the best machines for the work requiring the greatest precision.

By a cut and try process the mixer works the material up to a point where he feels he has the situation in hand. Someone may assist in advising him as to the relative values of the effects to be dubbed into the music, or as to the interpretation desired in the final released material. In a half hour or so the situation is sufficiently in hand for making the take. If the take is not satisfactory, the next day it is done again.

Mr. Crabtree: Does he first rehearse the individual tracks or does he start rehearsing with the entire six or seven?

Mr. Hilliard: That depends upon the complexity of the scene and upon the mixer's preference. Some would probably run the dialog track to find out what is in the sequence, and possibly add some music. Then later the effects would be brought in. That is one technic; there is no special way of doing it.

Mr. Crabtree: Having rehearsed it to his satisfaction, can the mixer reproduce the effect? He apparently has to remember how loud the various tracks were.

Mr. Hilliard: Volume indicators are his guides, and it is no effort for him to remember the scenes. He thinks in terms of the scenes themselves, of the action that is going on, in terms of a speed of 90 feet a minute. He knows he has to operate in a split second. You and I go into retrospect on what has happened and put it together at a later date.

Mr. Crabtree: Does one man do the entire mixing?

MR. HILLIARD: That depends upon the flexibility of the equipment and the policies of the various studios. In most studios one man handles the simple reels alone; when more than three or four tracks are involved, there may be two men, in other cases three.

MR. CRABTREE: What is the greatest number of tracks that one man can handle?

MR. HILLIARD: That varies with the equipment. In our case one can handle up to six or eight tracks; in fact he does so almost every day. It depends to some extent upon how fast the eight tracks may enter as they are distributed throughout the reel, or whether eight operations are demanded simultaneously. With this control he can handle a maximum of eight situations at once.

MR. LAMBERT:* Mixing is a little like playing the organ. Tremendous dexterity is demanded. Not only are all ten fingers busy on the keyboards, but they must operate the stops; and the feet are equally busy playing the pedals and the swells, *etc.* It seems beyond comprehension that one mind can simultaneously control so many different physical operations at the same time. The technic must be mastered so completely that when the eye sees a note on a sheet of music a hand or foot moves unconsciously to perform the operation it demands. In the case of re-recording, the picture on the screen is the sheet of music. On the re-recording log will be various comments, indicating that at a certain part of a reel an effect is to be found in a certain sound-track. These are similar to instructions on the music that a particular passage is to be played on the lower organ manual with the left hand, and then a few notes on another manual, which has been pre-set, while playing, to produce a desired effect. That is what occurs when a mixer, controlling several tracks with one hand, simultaneously changes equalizers, or throws various circuit keys with the other. The mixer is always guided by the picture. The action on the screen demands that certain sounds be produced that will agree well with the scene. The mixer frequently does not analyze these demands consciously, but satisfies many of them with an automatic reaction developed by experience, his conscious thought being left more free to concentrate upon some particular effect to be achieved. He will perhaps play a band parade "automatically," balancing all the street effects and the music to be realistic, but give very conscious attention to a line of dialog that must be made understandable, or a bass drum that must be sounded very loudly.

To be a capable re-recording mixer requires extensive experience and well developed judgment in:

(*a*) Dramatic presentation of situations.

(*b*) The conventionalities by which dramatic situations are developed in motion pictures.

(*c*) The technical limitations of presenting dramatic situations in theaters, and tact in reconciling a producer's wishes with these limitations.

(*d*) The mechanism, technics, and handling of the re-recording process itself, of which manual dexterity alone is but a small part.

(*e*) They must be able to coöperate with each other to produce a uniform product.

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* Communicated.

The best re-recording mixers must have experience that can be gained in no other way than by doing the work. Our mixers have been from four to ten years on this type of work, preceded by experience in other forms of motion picture work, and that again preceded by a technical or theatrical background of some kind. No matter what his previous experience, a re-recording mixer does not become a really efficient member of our re-recording organization until he has been at that specific work for at least six months.

Ordinarily we employ two men if the number of tracks exceeds six. There are cases where two are required for fewer than this number, and others where one man can control seven or eight. Each case is handled differently, and the mixer can save much time and effort by being able to analyze quickly how best to approach each problem.

REPORT ON THE ACTIVITIES OF THE INTER-SOCIETY COLOR COUNCIL*

Summary.—*A brief discussion of the activities, organization, and functions of the Inter-Society Color Council is given, followed by abstracts of twenty papers that have been jointly sponsored by the ISCC and its member bodies. The report concludes with a plea that members contact the delegates if there are matters that should be taken up with the Council.*

The Society of Motion Picture Engineers has, for the last year and a half, been a member of the Inter-Society Color Council. A brief description of this Council may be in order.

There has never been a National Society in the United States devoted exclusively to color as a general subject. The growing importance of color in all fields about ten years ago led to the feeling that such a Society might be successful. After some discussion among those interested in the project it was decided to follow a suggestion made by the late Irwin G. Priest. This proposal appeared in the form of a resolution from the Executive Committee of the Optical Society of America. In brief it proposed that a joint council be set up, formed of delegates officially appointed and sent to the council by societies interested in color as one part of their more general fields.

The Inter-Society Color Council was formed on this basis and consists of two types of members, the so-called member bodies and individual members. Member bodies must be national non-profit societies, and delegates from these member bodies control the policies of the Council as a whole. Individual members are those who do not represent national societies but who are individually sufficiently interested so that they are willing to pay the cost of being placed on the mailing list of the Council. The group of individual members is considered as a member body and sends three voting delegates to the Council meetings.

Each member body is also represented on the Council by three voting delegates, one of whom is designated as the chairman. The

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received May 5, 1941. Report prepared by R. M. Evans, Chairman of SMPE delegates to the ISCC.

member body may also, if it wishes, appoint up to seven other non-voting delegates.

The Council at the present time consists of thirteen member bodies and the group of individual members. The member bodies represent, respectively, the fields of Textiles; Ceramics; Psychology; Testing of Materials; Illuminating Engineering; Pharmacy; Optics; Pulp and Paper; The Textile Color Card; Art; Paint and Varnish; and, through our own Society, Motion Pictures. The individual members represent an even more diversified group of interests under their chairman who is an ophthalmologist. The delegates from the SMPE are Ralph M. Evans, *Chairman*, G. F. Rackett, F. T. Bowditch, and J. A. Ball.

The purpose of the Council is to act as a joint committee on color for all the societies and individuals represented. As a joint committee it is expected to consider problems referred to it and is free to appoint sub-committees from among the membership lists of all the societies involved. In this way the best talent in the whole field of color can be brought to bear on any problem of sufficient importance.

The separate delegations from each society, on the other hand, are charged with the responsibility both of forwarding problems and helpful information to the Council, and of reporting back to their societies the work of the Council so far as it is of interest to their fellow members.

The need for such a council and its mode of operation were discussed at some length in a very interesting paper presented by Dr. H. P. Gage at the Spring Meeting of the Society a year ago, and published in the October, 1940, issue of the JOURNAL.

This paper gives an illustration of how the Council can be of service to its member bodies. The U. S. Pharmacopoeia Revision Committee of the American Pharmaceutical Association requested the Council to investigate and recommend a list of color names which would be readily understandable and definite enough to use in the descriptions of all the material in the U. S. Pharmacopoeia. The Council undertook this problem with the following results. It obtained for this member body "the advice of the color experts of two other member bodies (the Optical Society of America and the American Psychological Association); it obtained for this member body the coöperation of the National Bureau of Standards, which had been previously sought and refused; and the Council served as an authoritative source of information unswayed by commercial considerations for deciding which of the various competing systems of material color standards was best suited to derivation of the color names. In all this work the allied interests of another member body (The Textile Color Card Association) were protected by the presence of its delegates at the Council Meetings." The outcome of this work, which involved a problem really too large for one society to handle successfully by itself, was a set of definite recommendations which have been accepted and will be used exclusively in the next edition of the U. S. Pharmacopoeia. This was published as a research paper of the U. S. Bureau of Standards, of which the following is an abstract.

METHOD OF DESIGNATING COLORS[1]

DEANE B. JUDD AND KENNETH L. KELLEY

In 1931 the first Chairman of the Inter-Society Color Council, E. N. Gathercoal, proposed on behalf of the United States Pharmacopoeial Revision Committee the problem of devising a system of color designations for drugs and chemicals. He said, "A means of designating colors in the United States Pharmacopoeia, in the National Formulary, and in general pharmaceutical literature is desired; such designation to be sufficiently standardized as to be acceptable and usable by science, sufficiently broad to be appreciated and used by science, art, and industry, and sufficiently commonplace to be understood, at least in a general way, by the whole public." With the assistance of the American Pharmaceutical Association, and following plans outlined in 1933 by the Inter-Society Color Council, there has been worked out a solution for this problem, which substantially fulfills the requirements laid down by Dr. Gathercoal.

Contents

(*I*) History
(*II*) Scope
(*III*) Logic of the designations
    (*1*) Surface-color solid
    (*2*) Basic plan of forming the designations
    (*3*) Divisions of the hue circle
    (*4*) Pink, orange, brown, and olive
    (*5*) Some unavoidable disadvantages
(*IV*) Definition of the color ranges
(*V*) Hue boundaries for various ranges of Munsell value and chroma
(*VI*) Color designations for opaque powders
    (*1*) Preparation of sample
    (*2*) Lighting and viewing conditions
    (*3*) Procedure
    (*4*) An example
(*VII*) Color designations for whole crude drugs
    (*1*) Comparison with Munsell color standards

    - (*2*) Lighting and viewing conditions
    - (*3*) Ways of using the color designations
- (*VIII*) Color designations for any object
    - (*1*) For opaque non-metallic materials
        - (*a*) With matte surfaces
        - (*b*) With glossy surfaces having no regular detailed structure
        - (*c*) With glossy surfaces made up of cylindrical elements
    - (*2*) For metallic surfaces
    - (*3*) For materials which transmit but do not scatter light
    - (*4*) For translucent materials
- (*IX*) Summary
- (*X*) References (4)

  How to use the color name Charts 1 to 34

The selection of a standardized set of color names was the particular problem that engaged the early attention of the Council. It is, however, not the only problem on which the Council is at present engaged. As listed in the last report of the Executive Committee they are as follows:

(*1*) Questions concerning the ICI standard observer
(*2*) Color names
(*3*) Color for poison label
(*4*) Designation of theatrical gelatins
(*5*) Who's who in color
(*6*) Survey of color terms in use by member bodies
(*7*) Survey of color specifications in use by member bodies
(*8*) Survey of color problems of member bodies
(*9*) Development of a color aptitude test

In addition to its fact-finding activities the Council has been very active in sponsoring joint meetings with member bodies at Conventions for general educational purposes in color. Several such joint meetings have been held. At each such meeting there has been a joint symposium of invited papers on a subject of particular importance to the member body. These papers have then been published in the regular journal of the member body and reprints bound together have been sent to all Council delegates.

In February, 1939, a joint meeting was held with the American Psychological Society. The topic of the symposium was "Color Tolerance." The following papers were presented and later published in the *American Journal of Psychology* in July, 1939.[2]

THE PSYCHOPHYSICS OF COLOR TOLERANCE[2]

EDWIN G. BORING

Any particular tolerance can and must be measured in terms of the physical units of the color-stimulus, since the stimulus-scale is an ultimate system of reference. One hopes, nevertheless, for some general statement of the limits of any particular kind of tolerance, and it would seem that such a generalization must be more likely to be expressible in the units of some psychological scale which is definitely but perhaps not linearly related to the physical scale of the stimulus.

Tolerance is a matter of perception and must therefore be related to discrimination. There must be as many kinds of tolerance as there are reasons for fixing the character of colors, and two colors that are not noticeably different would necessarily lie within the range of all tolerances, if they are really not discriminable. That sentence is, however, much too simple to express the whole truth. While many tolerances are supraliminal, certainly there are others which are subliminal. The difference limen is the average "jnd" (just noticeable difference), that is to say, it is the difference which is as often perceived as not. A difference that is perceived only forty per cent of the time is subliminal, yet it is perceived almost, though not quite, as often as not. Complete intolerance, a requirement that two colors should never be perceived as different, would specify a difference that is far below the limen.

There are three psychological scales, any one of which might be used for measuring tolerance. (*1*) The first is the DL difference limen. It can be chosen as the unit, and a tolerance specified as a permissible number of DL. (*2*) A more stable measure is (standard deviation) of the psychometric function. (*3*) The third measure is the sense-distance. Since these three measures are, unfortunately, almost the private property of the psychologists, their explanation is undertaken to show their natures and disadvantages. The thesis is, that for the measurement of tolerances, the DL has the most disadvantages, and the sense-distance the least. Unfortunately it is the DL that has been used most often by psychologists, whereas the sense-distance has hardly been used at all.

THE RATIO METHOD IN THE REVIEW OF THE MUNSELL COLORS[3]

SIDNEY M. NEWHALL

(*1*) The ratio method consists in the estimation by direct impression of the ratio of supraliminal sense magnitudes. The one magnitude or interval is taken as standard, and the ratio of the other to it is then estimated.

(*2*) The spacing problem is to detect and correct errors of allocation in surface color space of the 400 regular Munsell colors. The readjustments are being made for the samples as mounted on white, on gray, and on black (cardboard) grounds.

(*3*) The application of the ratio method to the spacing problem proves to be a complicated, meticulous, and lengthy process of choosing vectorial equivalents for sensory magnitudes. The principal attributes are evaluated separately under a flexible instruction.

(*4*) Observers are beset by the real and technical difficulties of the first chroma step, attributive abstraction, and separation of standard and sample. They do not use the ratio method in pure form, but resort to the methods of ranking and single stimuli in the effort to achieve results; and results are achieved.

(*5*) Preliminary results on the respacing of saturation tend to confirm the usefulness of the method and to suggest that many minor adjustments may prove desirable. Present data indicate that adjustments also will be necessary if the colors are to be corrected for gross variations in background reflectance.

COLOR TOLERANCES AS AFFECTED BY CHANGES IN COMPOSITION AND INTENSITY OF ILLUMINATION AND REFLECTANCE OF BACKGROUND[4]

HARRY HELSON

The hue, lightness, and saturation of any object depend upon a complex of conditions, chief of which are spectral reflectance of sample and background, spectral energy distribution of illuminant, and state of the visual mechanism as determined by its properties as a receptor and mode of functioning. Since color tolerance concerns the extent to which colors match, or if they do not match, in what respects they differ, any factors which affect the color of standard and variables have importance for the problem of tolerance. The problem as to how illuminant, background, contrast, adaptation, and so-called constancy operate in literally "coloring" objects seems to be nearing solution after recent work with strongly chromatic illuminants and backgrounds of high, medium, and low reflectance. The principles governing color changes which objects undergo in strongly chromatic illuminations throw light also on phenomena encountered in ordinary viewing situations. Hence consideration of the facts discovered under "abnormal" conditions of viewing is of value in bringing into sharp relief the principles operating in all visual functioning.

REPRESENTATION OF COLOR TOLERANCE ON THE CHROMATICITY DIAGRAM[5]

DAVID L. MacADAM

Actual practice in the establishment of color tolerances indicates that visual examination of a representative group of samples, and agreement between the manufacturers and representative users of the colored materials is more satisfactory to all parties concerned than any theoretical deduction of tolerances from abstract experiments. Tolerances established by such agreement can be represented just as clearly on the ICI chromaticity diagram as on any other chromaticity diagram. The ICI chromaticity diagram is recommended for such use because it has been standardized internationally and used extensively for many years, and because its use will not encourage any false simplifications of the color tolerance problem.

SPECIFICATION OF COLOR TOLERANCES AT THE NATIONAL BUREAU OF STANDARDS[6]

DEANE B. JUDD

The various parts of a color specification to be administered by working standards have required different methods for color-tolerance specification. Choice of method is also affected by the article whose color is specified and by the instruments used. Three chief methods are discussed: (*1*) the standard ICI coördinate system; (*2*) material standard and tolerance sample; and (*3*) the NBS unit of surface-color difference.

The ICI system applies aptly to color specifications not requiring account of the perceptibility of differences; it yields a precise and reproducible specification of color tolerance in fundamental terms. The use of a material standard and tolerance sample requires a sense-distance judgment, and within the limitations of precision of that judgment is perfectly adapted to insure tolerances of uniform perceptibility. The NBS unit of surface-color difference is intended to combine the precision and reproducibility of a fundamental system with the aptness of the sense-distance judgment by means of a tolerance sample. The formula for color difference defining this unit makes use of sensibility data obtained over a period of years by psychophysical methods, and, in effect, interpolates between the various series of stimuli for which color-difference sensibility is known. The NBS unit of surface-color difference suffers from two disadvantages: first, the psychophysical data on which it is based are so small a proportion of the total required for reliable evaluation of the complete surface-color solid that attempts to use the unit still reveal ways in which the interpolations yielded by the color-difference formula may be significantly improved; and, secondly, the unit varies with observing conditions so that the color-difference formula defining it is necessarily rather complicated. The NBS unit is already successful enough to justify its use in some standardization work, but our research continues to be directed toward its improvement. It should be emphasized, therefore, that changes in definition of the unit are to be expected, but it is believed that a practical unit of surface-color difference will result from our study, and that the definition of the unit will be no more complicated than the tentative form discussed here.

INDUSTRIAL COLOR TOLERANCES[7]

ISAY A. BALINKIN

The results of visual tests indicate that it is possible to establish a numerical scale for visual perception of magnitude in relation to color differences. A considerable amount of additional data will be required to provide the information for various spectral regions.

Although the degree of agreement between visual estimations of color differences and those computed from physical measurements are not satisfactory, their application to problems of consumers' acceptance and tolerance control proved of practical industrial value. The use of Hunter's reflectometer for these measurements gave fairly reproducible results within ±0.1 judd under most careful operational technic. Further improvements are needed, however, to achieve a better reproducibility of this instrument for routine industrial use under plant operating conditions. The reduction of color measurements to differences in terms of visual perception by the use of Judd's equation is still a very tedious and lengthy process requiring at least ten minutes for a pair of samples. The possibility of constructing a nomograph for such computations is now being investigated.

In February, 1940, at a joint meeting with the Technical Association of the Pulp and Paper Industry a symposium on Spectrophotometry in the Pulp and Paper Industries was sponsored. The papers were reprinted from *Technical Association Papers*, **23** (June, 1940), pp. 473–525; and were published in the TAPPI Section of the *Paper Trade Journal*, **111**, No. 10 *et seq.* (Sept.-Oct., 1940).

SURVEY OF SPECTROPHOTOMETERS[8]

KASSON S. GIBSON

Recent progress in spectrophotometry in the visible spectrum has been largely along photoelectric lines. Most of the new instruments, however, have been designed for transmission measurements only, and are of little direct interest to the pulp and paper industry. Reference is made to various previous surveys of spectrophotometry, and the present paper merely brings the subject up to date, with particular emphasis on reflection measurements.

Visual spectrophotometric measurements have proved inadequate for the accurate colorimetric specification of white and near-white materials. The colors of such materials are importantly affected by small changes or differences of spectral reflection, differences that are of the order of magnitude of the uncertainties inherent in visual spectrophotometry. The photoelectric cell, on the other hand, is ideally adapted to the determination of small differences, and in apparatus designed on sound electrical and optical principles is capable of yielding spectrophotometric measurements that are both precise and accurate.

All reflection spectrophotometers measure the apparent reflectance of a material relative to the apparent reflectance of a working standard, under certain fixed conditions of illumination and observation. The concept of apparent reflectance, the importance of considering the most desirable conditions of illumination and viewing, and the question of primary and secondary standards of apparent reflectance, are accourdingly briefly considered.

A SURVEY OF ABRIDGED SPECTROPHOTOMETERS[9]

J. A. VAN DEN AKKER

A survey has been made of abridged spectrophotometers, and a description and a discussion of the uses of these instruments are given.

TAPPI SURVEY OF COLOR INSTRUMENTS USED IN THE PULP AND PAPER INDUSTRIES[10]

The active interest of the pulp and paper industries in the use of instruments for the measurement and control of color is demonstrated by a survey of a number of mills in this country and Canada by the Technical Association of the Pulp and Paper Industry. Of the 43 inquiries mailed by TAPPI headquarters, 38 replies were received. The summarized answers are given to the questions comprising the inquiry. They indicate that properly designed instruments for the control and measurement of the color of pulp and paper are finding increased application by the industry. The fact that nearly 90 per cent of the replies showed their interest in the use of a more satisfactory instrument, if it could be found, demonstrates the trend of technical control and measurement in the manufacture of pulp and paper.

By control testing is understood the routine measurement of pulp, paper, and fillers, such as the determination of brightness. Color measurement usually involves a more thorough measurement of the color of the product for research, grading, reference standard, or other purposes, such as the determination of the spectral reflectance of the material.

THE MEASUREMENT OF COLOR OF PULPS[11]

R. S. HATCH

The problem of evaluating the color of pulps is one which involves the exact physical measurement of the color rather than the expression of color value in psychological terms. The best instrument and the instrument to which all physical measurements of color should be referred is an automatic recording spectrophotometer. Under certain conditions, where pulp is being produced from a single species, an abridged spectrophotometer may be used for general research purposes, and a properly designed brightness meter may be used for manufacturing control. Brightness meters should be so constructed that commercial samples of the pulp itself can be directly measured without resorting to the making of special color sheets from the sample in question.

CARD INDEX AND OTHER METHODS USED IN CONTROLLING THE COLOR OF BEATER FURNISHES[12]

R. N. GRIESHEIMER

Instrumental methods of controlling the color of beater furnishes are contrasted with the older method of visual control. Although the advantages of the instrumental methods are indisputable, neither method can be wholly successful in providing for color control of the finished sheet of paper unless account is taken of certain machine variables that affect sheet color by influencing dye retention, *etc.* Important variables are the *p*H and freenes (refining treatment) of the to-wire stock.

Instrumental methods are subdivided into empirical methods, and methods involving the absolute calculation of certain optical constants of the raw materials and finished sheet from either the Kubelka and Munk theory, or the theory of trichromatic coefficients. The latter methods are principally of academic interest and have not met wide-spread use in the industry. Two empirical methods are outlined, both depending on the ability of a technical man to associate various dyestuffs with the shapes of their spectrophotometric curves, and the displacements of these curves with changes in dye concentrations.

A particular instrumental method called the card index system is discussed in considerable detail. A program for indexing variations in reflectance at certain wavelengths (or variations in trichromatic coefficients) with weight of dye producing these changes for a given furnish is set up. It is then indicated how these data, considered with other data taken on the effect of important machine variables, can be used for predicting the color of the finished sheet. A double integrating sphere reflection meter and a time-saving wet pump sampling procedure are briefly described as tools found useful in applying the card index system.

In conclusion, general aspects of the problem are discussed including considerations of start-up losses due to off-color, color tolerances, and the selecting of method and instruments to fit a particular mill's requirements.

USE OF COLOR MEASURING INSTRUMENTS IN THE MANUFACTURE OF UNCOATED PAPER[13]

MYRL N. DAVIS

This discussion is limited to the use of spectrophotometers and colorimeters in the design and control of "white," uncoated papers. Experience has shown that a working estimate of the apparent "whiteness" of paper can be obtained by measurement of reflectance with light of 458 mmu wavelength. Instrumentation is available and widely used for making such single measurements on paper samples in controlling the uniformity of paper being manufactured. Hue of the paper is still controlled visually in all but a few paper mills.

It is possible, by use of the Guerivic, Kubelka-Munk, and Smith theories of the optical properties of diffusely reflecting materials, to determine scattering and absorption coefficients for the pulp and pigment, of which paper is manufactured, and by use of these coefficients to predict the reflectance and opacity of papers made from any proportions of these raw materials. Examples are given of such predictions for machine-made papers, the optical coefficients having been obtained from simple handmade papers.

The effect of supercalendering on opacity and color is discussed. Exact quantitative estimates of the effect of supercalendering are not yet possible.

SPECTROPHOTOMETRY ON COATED PAPERS[14]

WILLIAM J. FOOTE

By means of spectral reflectance curves, dyestuffs may be identified either in coated or uncoated papers and rough quantitative estimations made. In addition, spectral reflectance curves may be used to specify the color of standard grades, to act as a guide in color matching in general, and particularly in the case of matching the color of base sheet and coating of tinted whites and to indicate tolerances.

A more precise method of specifying standard colors and tolerances consists of using chromaticity diagrams based on the specification of color by the method proposed by the International Commission on Color (ICI) in 1931.

By the use of one additional measurement (either R_0 or $R_{0.88}$ at any chosen wavelength) and calculations involving the Kubelka and Munk relationship, valuable information is obtained on the fundamental optical coefficients (scattering and absorption) of coatings made up with various types of pigments. This permits a study of the effects of different raw materials and the successive steps in the process of manufacture on color, gloss, and opacity of the finished product.

The relation of the physical measurements, brightness and visual efficiency (Y), with visual "brightness" and "whiteness" and the possibility of there being an optimum color for white printing papers is briefly discussed.

SYSTEMATIC COLOR DESIGNATIONS FOR PAPER[15]

DEANE B. JUDD

The construction at the National Bureau of Standards of a system of color designations for drugs and chemicals in accord with recommendations by the Inter-Society Color Council raises the question whether a similar system, or the same system, would be worth while for description of paper color. The ISCC-NBS color designations are combinations of the simplest and most widely used color names: red, orange, brown, yellow, olive, green, blue, purple, pink, black, gray, and white; with such common and easily understood modifiers as light, medium, dark, weak, moderate, strong, vivid, pale, and deep. There are slightly more than 300 such designations, each one applying to a defined range of color, and, taken together, covering all colors.

As an aid to the initiation of coöperative study embracing all branches of the paper industry, the ISCC-NBS method of designating colors is described in detail. These designations have been found for about one-fifth of the colors given in the Blue-Book Manual issued in 1936 by the Trading Committee of the Groundwood Paper Manufacturers Association, and they have also been found for samples of bond paper supplied by 4 companies and known by 15 traditional paper-color names. These results serve to illustrate the descriptive qaulity of the ISCC-NBS color designations, and they also indicate how closely the traditional color names are followed for bond paper, and how wide the color departures may be between bond-paper terms and groundwood-paper terms.

THE PSYCHOLOGY OF COLOR[16]

I. H. GODLOVE AND E. R. LAUGHLIN

The psychological or subjective aspect of color problems must always be considered along with the physical or objective phases, sometimes in a subordinate or supplementary role, but often in a dominant one. The growing use of color and the role of psychological facts in the scientific and judicious use of color is discussed.

After citing some color idioms which illustrate the pervasiveness of color associations, as red and orange with warmth, the relation of the psychology of color to its physics and physiology is shown. The difficulty of explaining many color phenomena by means of the "pure physics" of color is pointed out; and in this connection recent work of the psychologists on the phenomena of "color constancy" is stressed. What is meant by the "true color" of an object is described, and alternative explanations are given. In this connection work on the process of adaptation of the eye to changes in the intensity and the spectral character of the illumination is cited. The legibility of colors on various backgrounds is discussed on the basis of this work and in relation to our knowledge of the fact of chromatic aberration in the eye. Rules for the application of the known data to the selection of colors for stock or backgrounds, rulings, initial lettering, letterheads, decorations, and the best relations of these to each other are given.

The extant data on the preferences of men and women for single colors and for color combinations; on the attention-attracting values of colors; on the subject of color harmony (including the utility of contrasts, complementaries, and color sequences); on the appropriateness of colors and combinations which may be considered in relation to their use in advertising, in packaging, and in commodities.

In September, 1940, at a joint meeting with the Illuminating Engineering Society a general symposium on color was sponsored. The four papers were published in *Illuminating Engineering*.

THE BASES OF COLOR VISION[17]

LEGRAND H. HARDY

A brief discussion of the physical, anatomical, physiological, and psychological bases upon which color vision is dependent. Light, its nature, origin, location in the electromagnetic spectrum, components, and sources are briefly discussed. The gross anatomy and physiological data concerning the photoreceptors and some considerations regarding the action of light upon these receptors are given in summary. A final short note on some psychological factors involved in color vision is presented.

COLOR DETERMINATION[18]

PARRY MOON

A general discussion is given of methods for the measurement of color stimuli. These measurements may be divided into two classes: measurements of the spectral-distribution curve, from which are computed the trichromatic coefficients; and direct measurements by means of colorimeters and (in certain special cases) color-temperature meters.

The spectroradiometric method is of fundamental importance in every branch of illuminating engineering, since the complete spectroradiometric curve gives information on color, luminous output, and heating effect. Perhaps the most important problem of illuminating engineering today is the development of a spectroradiometer for accurate and rapid absolute measurements. Such an instrument has not yet been produced, though satisfactory *comparison* instruments (spectrophotometers) are available.

If the spectroradiometric curve is known, the color stimulus can be *computed* and can be expressed in terms of:

The tristimulus values X, Y, Z.

The trichromatic coefficients x, y.

Dominant wavelength and purity, λ_d and p.

Color temperature T_c (only applicable if unknown can be approximately matched by a Planckian distribution).

Color can also be measured directly by means of various colorimeters. Results obtained with these instruments are generally less accurate than those obtained by the spectrophotometric method, and the data are of much less generality. Nevertheless, colorimeters and color-temperature meters may be of distinct value in industry where the routine comparison of large numbers of very similar lamps or materials is encountered.

COLOR SYSTEMS AND THEIR INTER-RELATION[19]

DEANE B. JUDD

By color system is meant a system of specifying color; that is, a system in which the color to be specified is matched with that produced by one member of a system of objects or lights. The specification consists of giving an identification of the member of the system producing the match.

Lights are combined to produce color systems in one of two ways: either three lights are added together to produce a tristimulus system, or a light of variable quality is added to one of fixed quality, the "monochromatic-plus-white" method. The tristimulus system recommended in 1931 by the International Commission on Illumination (ICI) is discussed and the method of transforming specifications from this standard system to other tristimulus systems is given. Seven other tristimulus systems used for color specifications are defined in terms of the ICI system; some of these were proposed because of simplicity in the computation of a color specification from the spectrophotometric curve, some to provide uniform chromaticity-scales, and others to quantify theories of color vision. Chromaticity is specified on the tristimulus system by trichromatic coefficients, two of which, plotted on coördinate axes, produce a Maxwell triangle; on the "monochromatic-plus-white" system, chromaticity is specified by an angle and a radius. Four methods of specifying the angle are described, and six methods of specifying the length.

Sets of material color standards may be made up of transparent media viewed by transmitted light or of opaque surfaces viewed by reflected or scattered light. The system of arrangement of standards made up of transparent media is that of subtractive combination; two such systems are described. Color systems based on collections of pigmented or dyed surfaces are described. These range from the Munsell color system, intended to conform as closely as possible to the surface-color solid, to color dictionaries whose system of arrangement is intended merely as an aid to discovery of the surface producing the match.

A description is also given of the ISCC-NBS method of designating colors together with the uses to which it is being put.

THE ILLUMINANT IN COLOR MATCHING AND DISCRIMINATION[20]

DOROTHY NICKERSON

A study of the part played by the illuminant in color discrimination may be divided into two broad sections. In one the chief concern is to find an illuminant under which color differences will surely be evident. The single illuminant most satisfactory for this purpose will depend upon the reflectance curve of the samples to be examined. In the other, the choice is limited to an illuminant under which an observer may see the colors with which he is concerned in the same relation to each other as he would if they were observed under an illuminant to which he has become previously accustomed, the most usual example being the selection of an artificial daylight in substitution for natural daylight. Results of studies made in the color-measurements laboratory of Agricultural Marketing Service regarding this latter choice are presented in charts and table form. They include studies of 18 illuminants, actual and theoretical, several pairs of samples expected to show large color differences under a change in illuminant, and 30 samples of cotton, the product with which this laboratory is chiefly concerned. The final results are summarized in a table which gives a relative rating of illuminants as substitutes for each other.

The Council also publishes a mimeographed News Letter to delegates. These News Letters give information regarding the operation of the council, the advance in the fields of color, dates of important meetings, and, finally, a rather extensive bibliography of magazine articles of interest to the member bodies. It is intended that notes from this News Letter may be reprinted in the journals of the member bodies.

In 1939 the Council issued a comparative list of color terms in which was given the definitions of a large number of color terms as supplied by several member bodies. At the time this booklet was compiled, the Society of Motion Picture Engineers was not represented. The delegates have proposed a set of terms and their definitions, derived from our existing Glossary of Color Names. This has been submitted to the Council for inclusion in their list. It is expected that the Council's final list will cover all words of definite meaning relating to color, with definitions as given by the users in all fields.

A test for color aptitude has been under consideration for some time by a very active sub-committee of the Council. This work is beginning to give results and it is expected that in the not-too-distant future a test will be available which it is hoped will test directly the inherent ability of a person to detect small color differences. The usefulness of such a test is apparent.

The Society has not, to date, taken advantage of the opportunity offered by our membership, to submit problems for consideration. No such problems are at present known to your delegates, and if any member has suggestions to offer, the chairman or the other delegates would greatly appreciate hearing about them. The problem, of course, must be of broad enough nature to interest experts outside our own field since all the Council activities are done by voluntary coöperation of members of other societies.

It is also to be hoped that at some time in the near future a joint meeting with the Council can be arranged for one of our Conventions. Suggestions are wanted as to the most desirable subject matter for invited papers for such a meeting.

REFERENCES

[1] *J. of Research, Nat. Bur. Stand.*, **23** (Sept., 1939), *RP 1239.*

[2] *Amer. J. Psychology*, **LII** (July, 1939), pp. 384–394.

[3] *Ibid.*, pp. 395–405.

[4] *Ibid.*, pp. 406–412.

[5] *Ibid.*, pp. 412–418.

[6] *Ibid.*, pp. 418–428.

[7] *Ibid.*, pp. 428–448.

[8] *Tech. Assoc. Pulp and Paper Industry* (TAPPI), **23** (June, 1940); *Paper Trade J.*, **III** (Sept.-Oct., 1940), pp. 475–479.

[9] *Ibid.*, pp. 480–489.

[10] *Ibid.*, pp. 489–490.

[11] *Ibid.*, pp. 491–493.

[12] *Ibid.*, pp. 494–499.

[13] *Ibid.*, pp. 500–505.

[14] *Ibid.*, pp. 506–512.

[15] *Ibid.*, pp. 512–518.

[16] *Ibid.*, pp. 518–525.

[17] *Illum. Eng.*, **XXXVI** (March, 1941), pp. 295–312.

[18] *Ibid.*, pp. 313–335.

[19] *Ibid.*, pp. 336–372.

[20] *Ibid.*, pp. 373–399.

AIR-CONDITIONING SAFETY DEVICE FOR THEATERS*

E. R. MORIN**

***Summary.**—A new fire damper release and method of preventing smoke from being recirculated or pumped into a theater auditorium through the air-conditioning system in the absence of heat or flame has just been developed by the Motion Picture Division of the Connecticut State Police and is here described.*

The Motion Picture Division of the Connecticut State Police is continually spending time and money in investigating existing safety devices and adapting them to practical uses for the theaters, as well as developing new items. It also takes into consideration the necessity of speeding up the action of such devices to prevent the spreading of fire and panic. At the same time it is further realized that the ultimate cost of these devices to the theater owner must be kept at a minimum. It is also our aim to localize smoke and flame at its origin so that there will be no cause for unnecessary alarm.

Like everything else, the theater is being modernized and brought up to date. One of the noticeable changes being brought about by this modernization program is the increasing number of air-conditioning equipment installations. This has presented us with a new problem, since at the present time the only safety devices being installed are those operating in the event of heat or flame: namely, a fuse switch by the dampers for the blower motor, and a fuse link holding the damper.

On March 8, 1936, at 7:40 P. M., the Bridgeport Fire Department received an alarm that brought their apparatus to the Cameo Fur Store on State Street, Bridgeport. The Cameo Theater is adjacent to this store and the dense black smoke caused by the furs burning came pouring out of the front of the store. It so happened that the fresh-air intake of the Cameo Theater's air-conditioning system was located at the front of the theater building, thus allowing a large quantity of smoke to be pumped into the theater auditorium, result-

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received May 5, 1941.

** Connecticut State Police, Hartford, Conn.

ing in a slight panic. At this particular time, very few of our theaters were equipped with air-conditioning systems and there was no known device to cope with this situation. Since this fire two or three other similar occurrences have been brought to our attention. These were caused by burning incinerators or rubbish on adjacent property, and in one instance a fire in the immediate neighborhood of the theater.

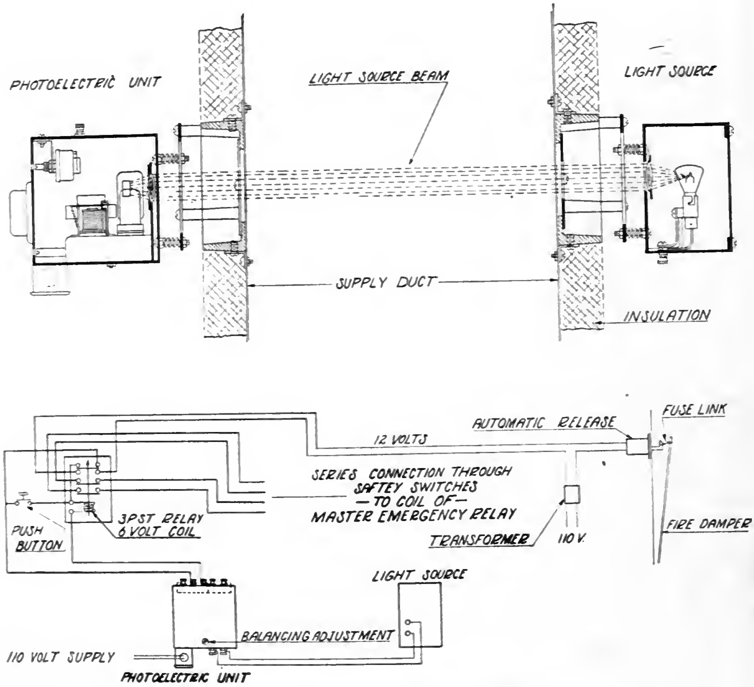

Fig. 1. Smoke cut-off unit and wiring diagram.

We have been constantly on the lookout for some method or device to guard against this panic hazard. During our search it was suggested that we use an existing smoke alarm or detector that rang a bell and flashed lights. We are very much opposed to alarming the patrons by the use of bells or buzzers, or by using anything which would depend wholly upon the human element for shutting off the air-conditioning equipment. Therefore, this did not appear to be the answer to our problem, as it would result in a lapse of time and cause smoke to be pumped into the theater.

We then asked a manufacturer to submit a smoke cut-off device for experimental purposes, suggesting that the alarm portion of this device be replaced by an added relay switch. On receipt of this device, consisting of a photoelectric cell with an exciter lamp and two relay switches, we conducted numerous experiments and found this to be a very practical method of shutting off the blower when smoke was in the vicinity. However, the minute the smoke cleared, the blower automatically started up again. We felt this to be an objectionable feature since if there were sufficient smoke in the vicinity to cause the blower to be shut down, it warranted investigation before starting the blower up again. We then incorporated a momentary contact switch located in the vicinity of the smoke cut-off device so that when the system was shut down by smoke it would require going to that location in order to start the system, and if desired, a signal light could be installed in such a location as to attract the attention of one of the employees. The experiments proved this to be a worthy and inexpensive addition. The complete device was presented to the theater owners and is now being installed in theaters in Connecticut as a smoke cut-off device and not as a smoke alarm as originally designed.

This solved only half our problem. As in the past, it has been our custom to approach these difficulties step by step, so we then gave consideration to the remainder of the problem which was the closing of the fire damper by the smoke detector.

The only automatic damper we could locate that could be released with the smoke detector was one of the motorized type. However, this was not equipped with a fuse link so that the damper might close in the event of failure of the electric current, and there would also be a lapse of time from the moment the current was applied until the damper was completely closed. We felt that this action should be speeded up to be momentary, and that the damper should be equipped with a fuse link as an added protection. This motorized damper was also quite costly to install in existing systems inasmuch as it was necessary to remove the present dampers and redesign the duct in that location to accommodate the new one, or else have two dampers. This excessive expense would, of course, be objectionable to the theater owners.

We then went in search of some simple and inexpensive device that would not require any alteration of the present damper or method of fastening the fuse link and would be instantaneous. We could not find any manufacturer who was interested in developing such a device. We, therefore, took it upon ourselves to construct such a re-

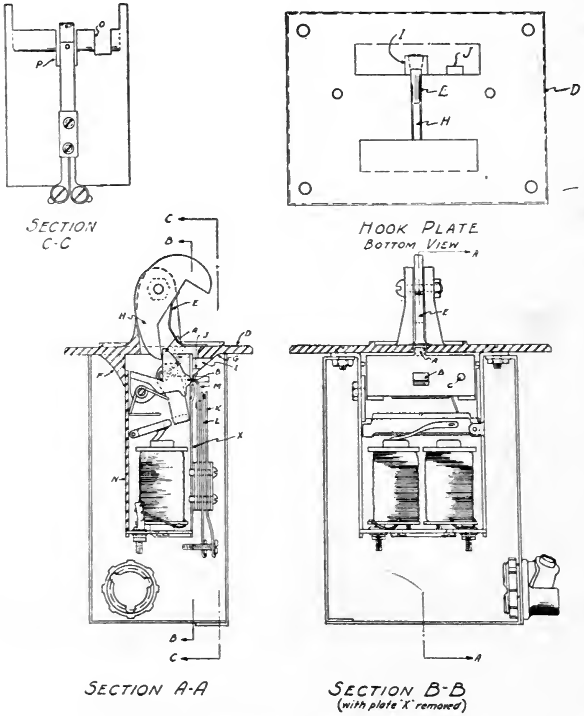

FIG. 2. Magnetic safety release.

(*A*) Small catch to fit up into hook plate opening
(*B*) Short nub on rotating member to cause electrical contact between *K* and *L*
(*C*) Projecting pin
(*D*) Flush hook plate with trip hook attached
(*E*) Spring dust closure attached to hook *H*
(*F*) Shoulder on hook plate to align box *N*
(*G*) Shoulder on hook plate with slots *J* and *I* to allow space for pin *C* and hub *B*
(*H*) Trip hook rotating when *A* is released
(*I*) Slot in hook plate
(*J*) Slot in hook plate
(*K*) Spring contact as shown
(*L*) Spring contact as shown
(*M*) Fiber and metal contact actuater
(*N*) Mechanism box
(*O*) Slot for pin *C*
(*P*) Cut-out for *M*

lease whereby only the catch protruded into the duct, replacing the eye-bolt now holding a chain or fuse link. We experimented with several types, such as using a magnet from a holding-type switch;

an electrical furnace with a thermostat cut-off for melting an added fuse link; a latch held with a fuse wire, which is the short-circuit method; and several others. The one which has proved most practicable has as its basic principle an electrical door-lock operating on 12 volts a-c or d-c and releasing the large, heavy dampers with the least amount of electrical energy. This had one serious objection. A loud buzzing sound was transmitted through the system that would naturally tend to alarm the patrons. By incorporating a specially designed switch using contact springs from a telephone jack-switch which opens the circuit as soon as the catch is released, this difficulty was eliminated.

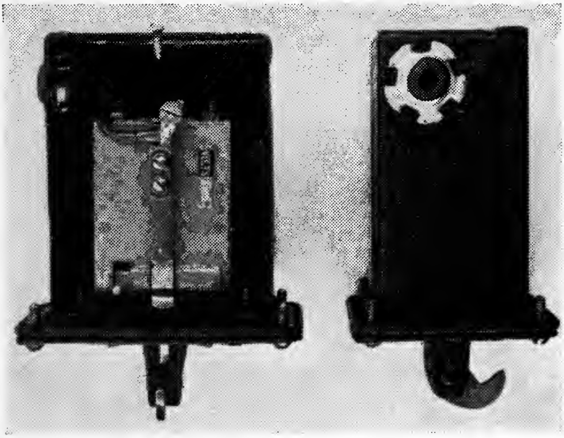

FIG. 3. Photograph of safety release, which is held mechanically, released electrically, and re-set manually.

Then we felt that there was still one more thing that should be done. Some of the large dampers made a considerable noise when released. We found that a $^1/_2$-inch asbestos wicking with a piece of asbestos cloth around it clamped into a metal frame would act as a cushion and gasket and practically eliminate the noise of the damper closing.

Since the completion of this electrical release, which can be operated from a remote station or stations, we have found it to be adaptable to other uses, such as the releasing of fire doors and asbestos curtains. In Connecticut, all asbestos curtains are equipped with a safety cord running from one side of the proscenium arch to the other with a fuse link in the center of the cord. On the operating side of the curtain is a ball with a half-hitch. On the other side is a screw-eye in the floor, and the cord is tied to this screw-eye. On the wall close by is hung a suitable knife and a sign which reads, "Cut This Cord in Case of Fire." This new device could replace the screw-eye in the floor by fastening a ring in the end of the cord and hooking it to the catch of the device. A switch could be installed in the switchboard where a man is on duty, and another switch could be installed just outside the stage door, thus making it possible to release the curtain off stage as well as on. By so doing, the stagehand's safety would not be jeopardized in trying to cut the cord to release the curtain and it would not be necessary to wait until such time as the flame had melted the fuse link, which might cause a delay in closing the curtain. In reference to fire doors, this could be manually operated, or operated from a sprinkler alarm system or fire alarm system.

NEW MOTION PICTURE APPARATUS

During the Conventions of the Society, symposiums on new motion picture apparatus are held in which various manufacturers of equipment describe and demonstrate their new products and developments. Some of this equipment is described in the following pages; the remainder will be published in subsequent issues of the Journal.

FIVE NEW MODELS OF 16-MM SOUND KODASCOPE*

W. E. MERRIMAN AND H. C. WELLMAN**

A new line of Eastman 16-mm sound projectors, identified by the model designations, *F, FB, FB-25, FS-10,* and *FB-40,* has been recently introduced to the public (Fig. 1). All these projectors are designed to be the ultimate in simplicity and rugged dependability, with the in-built precision so necessary to reproduce faithfully the finest existing 16-mm records.

There has been no compromise in the quality of the sound-reproducing systems or film-handling mechanism of these projectors from the lowest-priced to the most expensive. The same high accuracy of sprockets, aperture plates, film-gate, sound-drum, and film-guides is common to all models.

On all models the points at which film contact, and subsequent wear, take place, the surfaces are the same high quality. Buff chrome and stainless steel are used exclusively along the film's path through the projectors.

The basic picture projection mechanism used in the five models was developed several years ago and has since been subjected to continual refinement until we now find it capable of many hundreds of hours of good service. Technical advances in methods of hardening and toughening the film contact surfaces has added many hours to the life of the projectors. Precision cam grinders as well as sprocket and gear generators now produce mechanism parts with dimensional tolerances which were considered unattainable only a year or two ago. Tolerances of 0.0001 to 0.0005 inch are common among the sprockets, shafts, and pull-down mechanism parts.

The sound-head for these projectors is of simple, though effective design. The short, easily threaded, film path through the sound-head may be seen in Fig. 2. An easily threaded, well defined path for the film through the picture and sound-head provides positive synchronism of picture and sound.

The film need not be threaded through the sound-head when it is desired to project silent pictures. Fig. 3 shows the short film path for silent projection.

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*Presented at the 1941 Spring Meeting at Rochester, N. Y.; received May 5, 1941.

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

Simplicity of threading of the film on the projectors has been considered very carefully. It is believed that the new Sound Kodascope models offer something new in their straightforward threading.

The first three projectors mentioned previously are designed to operate on a d-c or a-c supply voltage of 100–125 volts. Universal operation of the amplifiers in these models is accomplished through the use of a conventional ballast resistance unit, suitably connected to allow series operation of the tube heaters from the supply lines. The use of a ballast device in the heater supply circuit provides essentially constant voltage on the various tube heaters in the operating range of 100–125 volts, a-c or d-c. Standard radio receiver type tubes of the metal shell or *GT* type with glass shells are used on all models.

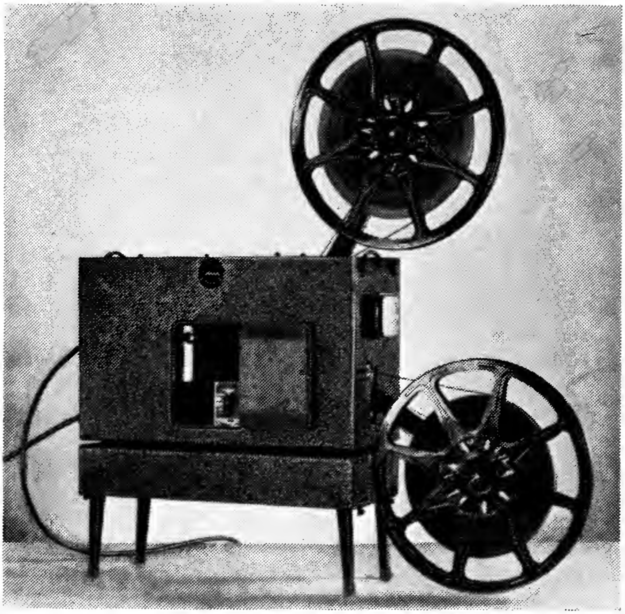

FIG. 1. Operating position for models *FB*, *FB-25*, and *FB-40* Sound Kodascopes.

A unique feature of the universal models is the method used in supplying plate or anode voltage for the amplifier tubes. High tube efficiency and output are obtained through the use of a combination single-unit motor-generator. By means of this device, power is provided to drive the projector mechanism, and it also provides, from the generator, a high d-c potential for the anode of the photocell and amplifier tubes. Governor control of the motor-generator unit assures constant output voltage and mechanism speed so essentail for high-quality sound and picture projection.

The last two projectors, *i. e.*, the *FS-10* and *FB-40*, are designed to operate on 50–60-cycle, 100–125-volt supply lines. Universal motors are used to drive these projectors and conventional a-c transformer-rectifier power supplies are used to supply the high d-c potential necessary for photocell and tube anodes.

Many features, such as ease of threading provided by "latchback" gates; resilient mounting of amplifier and motor units, providing freedom from microphonics; self-lubricating bearings on mechanisms and motors, assuring a minimum of attention and maximum life; double-claw pull-down; aperture plate framing; and provision for the use of crystal microphone or phonograph pick-up are common to all models. Also, all projector controls are grouped in the same plane on the operator's side of the projector.

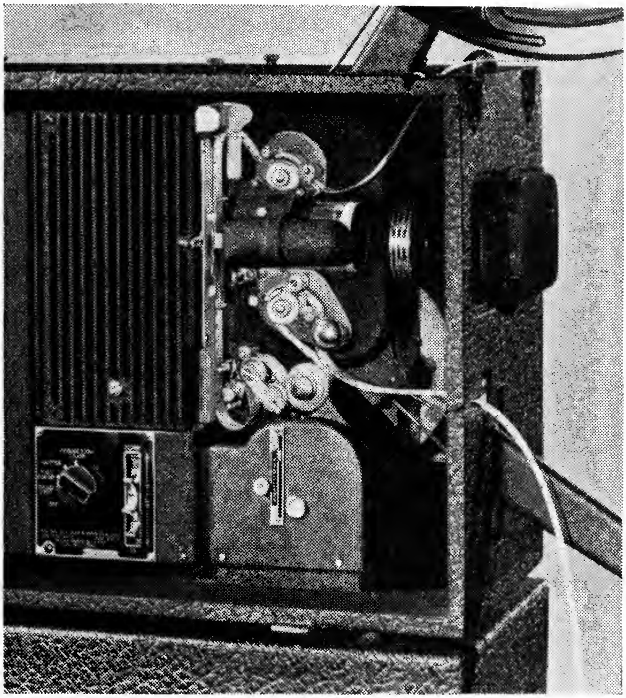

FIG. 2. Projector threaded for projection of sound-film.

In order to reduce the mechanism noise to a minimum, models *FB*, *FB-25*, and *FB-40* have been equipped with a "blimp," or noise-reducing cover.

Provision for the reproduction of either reversal or dupe prints has been made on three models, *i. e.*, the *FS-10*, the *FB-25*, and the *FB-40*. In order to accommodate both types of film, it is necessary to shift the focus of the scanning beam from one surface of the film to the other. A carefully machined cam, guides, and lever system have been assembled so that the movement of the lever (Fig. 4) easily shifts the focus of the scanning beam from one side of the film to the other. The scanning system is of the slitless or so-called apertureless type on all models and is characterized by greater freedom from microphonics. A standard 4-volt, 0.75-ampere, prefocus-base exciter lamp is used on all models.

Cost, accessibility, and freedom from microphonics dictated that the photocell be mounted on the main amplifier chassis for all models. A unique method of light transfer from the film to the photocell is used; it consists of a slightly bent glass rod approximately $5^1/_2$ inches long, silvered its entire length. Light, modulated by the film, falls on the end of the rod and is then transmitted through the rod to the photocell located on the other side of the sound-head. This method of light transfer permits all photocell wiring to be of minimum length. The consequent reduction of hum and stray modulation is well known to all designers and engineers responsible for sound-on-film photocell pick-up circuits.

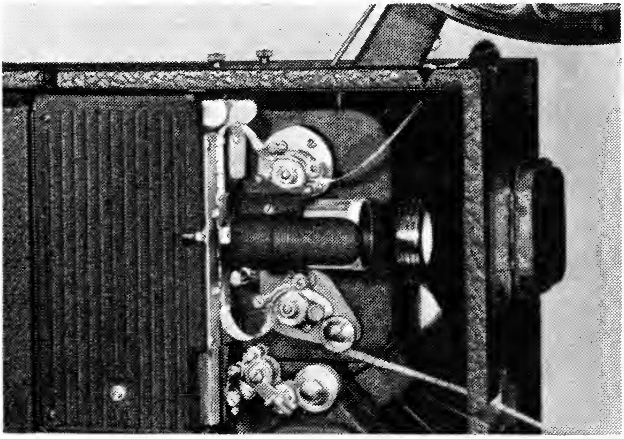

FIG. 3. Projector threaded for projection of silent film.

Fig. 5 shows the entire mechanism removed from the "blimp" case or housing. It is apparent in Fig. 5 that all mechanism parts, including the flywheel, amplifier, and motor-generator, are made accessible when the "blimp" housing is removed.

On all models, a governor of the electrical, vibrating-reed type maintains constant sound speed of 24 frames per second; in addition to this, a rheostat is provided to enable the user to obtain any desired speed below 24 frames per second.

All models except the *FS-10* have a thread-lite conveniently located and controlled automatically by the main control switch. Turning off the projection lamp turns on the thread-lite.

Model *FS-10* is a single-case unit in which the speaker case acts as a carrying case for the projector when not in use. Also, the back section of the speaker case is provided with folding legs and acts as a platform for the projector when a table is not available.

Fast rewind for all sizes of reels up to and including the 1600-ft is provided on all models through the use of a clutch, rewind lever, and main drive motor. The rewind mechanism on all models has been so designed that film damage can not occur. This feature has been accomplished by placing the rewind clutch lever in such a location that with film threaded onto the projector it is impossible to actuate the rewind lever. Also, accessory reel arms may be obtained for 2000-ft reels if desired.

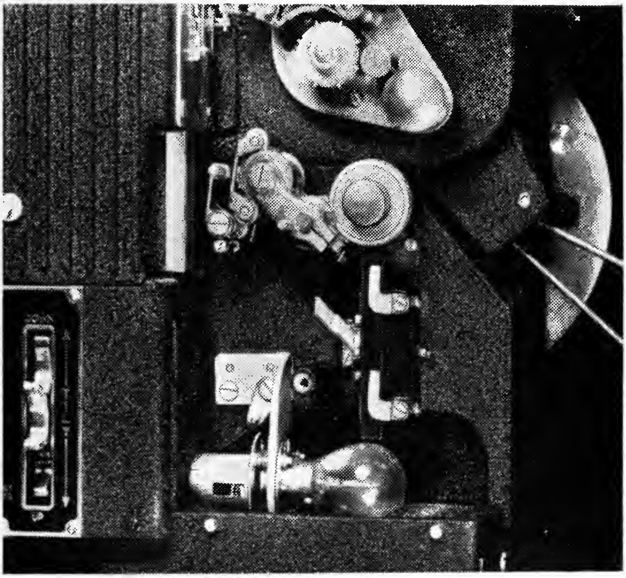

FIG. 4. Sound-head showing focusing optics and focusing lever.

Another feature common to all projectors is the use of a specially designed, oil-damped, film-driven flywheel. Uniform speed of the film at the scanning point is therefore assured.

Models *F*, *FB*, and *FS-10* provide ten watts of undistorted power output ample for most home and classroom service. Models *FB-25* (25-watt output) and *FB-40* (40-watt output) have been designed to cover large audiences. The use of twin speakers with these projectors provides good sound coverage for such assemblies. Twelve-inch permanent magnet speakers with 4.6-pound magnets are used in the twin-speaker assembly.

Model *FB-40* is provided with two jacks for inputs from phonograph and microphone plus an exciter-lamp dimmer and separate volume controls for phonograph and microphone. Complete mixing of film, phonograph, and microphone is, therefore, possible with the input channels and controls provided.

There are six lenses available for each of the five Sound Kodascopes. They are the 1-inch, *f*/2.5; the $1^1/_2$-inch, *f*/2.5; the 2-inch lenses, *f*/1.6 and *f*/2.5; the 3-inch, *f*/2.0; and the 4-inch, *f*/2.5 lenses.

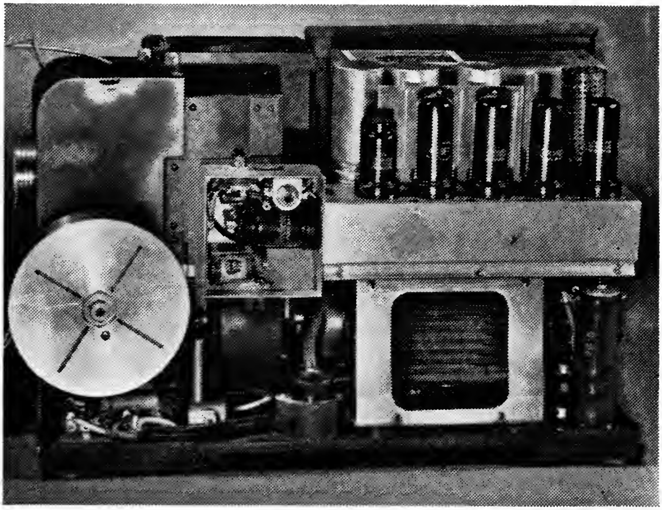

FIG. 5. Mechanism removed from "blimp."

Projection lamps of standard, medium prefocus base, construction are used, and range in wattage from 300 up to and including the 750-watt lamp recommended for large screens.

The five new projectors described fulfill a wide range of requirements in a field which demands equipment that must be reliable and economical. The design anticipates their use by many operators who have little or no experience.

HIGH-FIDELITY HEADPHONES *

L. J. ANDERSON**

Although the headphone is by no means of recent origin, the high-fidelity headphones and the general analysis of the problem were probably first presented as late as 1932.[1] Since that time, considerable work has been done, particularly with regard to improvement in response, sensitivity, and mechanical design, though the method of analysis remains unchanged.

The desired characteristic of a high-fidelity headphone is to produce a constant distortionless sound pressure in the ear when constant voltage is applied to the unit. The usual method of accomplishing this is to couple to a simple moving coil and diaphragm system a network as indicated in Fig. 1. Proper choice of constants will produce phone units that will deliver sound of surprisingly good fidelity. If the ear could be considered a small compliance, then the problem of obtaining a satisfactory response would be considerably simplified, since it would be necessary merely to move the diaphragm with constant amplitude throughout the desired frequency range. The ear, however, presents a more complex picture, which is approximately simulated by the simple circuit shown in Fig. 1. Here the compliance C_E represents the volume of the ear, and the values R_L and M_L result from the inevitable leakage between the ear-cap of the receiver and the ear. Actually, there are more elements to the circuit, and especially so at the higher frequencies, where the dimensions of the ear become appreciable in terms of the wavelength of the sound in question.

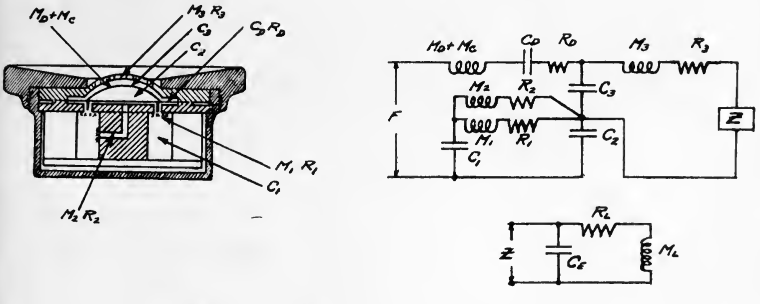

FIG. 1. Cross-section of phone unit and equivalent circuit.

The problem of providing adequate low-frequency response may be attacked

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received June 12, 1941.

** RCA Manufacturing Co., Indianapolis, Ind.

from two points: the seal between the unit and the ear may be improved by using specially designed ear-caps, or the acoustic circuit may be proportioned so that the low-frequency response will be relatively flat, in spite of the leakage. In the case of the phones in question, it was found desirable to resort to a combination of the two methods. Various ear-caps were checked by placing a dummy receiver case and the ear-cap in question on the ear and blowing smoke into the case. It was thus possible to observe the extent and points of leakage around the ear. By this means, it was found that a soft sponge-rubber-faced cap, about $2^3/_4$ inches in

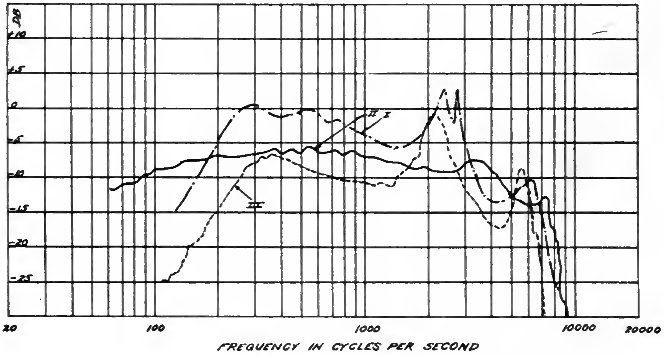

FIG. 2. Curve (*I*) Response of final unit on artificial ear.
(*II*) Response of an experimental unit operating into a sealed cavity.
(*III*) Response of experimental unit operating into artificial ear.

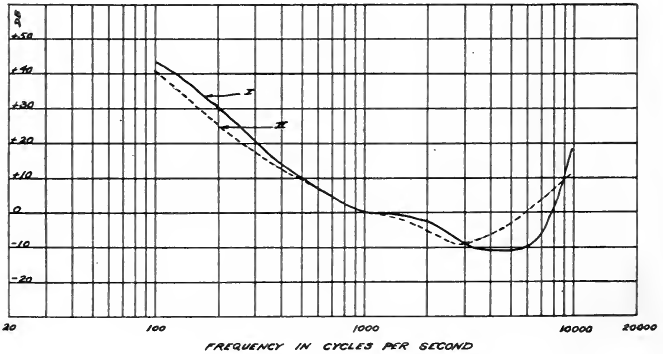

FIG. 3. (*I*) Threshold curve obtained with phones.
(*II*) Normal threshold curve

diameter, gave a good seal consistent with a moderate amount of pressure. In this connection, it is well to note that the phones will be far from high fidelity if they are not worn so that they fit snugly on the ears. Incidentally, the ear was well plugged before this smoke experiment, in order to prevent the entry of smoke into the ear. The effect of the leakage path M_L and R_L will obviously become more and more effective in reducing the response as the frequency of the signal decreases. In order to compensate for this effect, the velocity of the diaphragm below 300 cycles must be made very nearly inversely proportional to the frequency.[2] This is accomplished by introducing into the circuit the path M_2 and R_2, in which M_2 is very large and R_2 very small. As the frequency decreases, the impedance of this path decreases rapidly and allows the diaphragm velocity to increase as desired. Between 300 and 500 cycles, the velocity should be independent of frequency. The principal reason for attempting to improve the low-frequency response by providing a better seal to the ear was to reduce the necessary amplitude of the diaphragm as much as possible, and so avoid distortion due to non-linearity of the edge compliance. A number of headphones with poor sealing appeared to have quite good low-frequency response, which proved on analysis to be mostly harmonic.

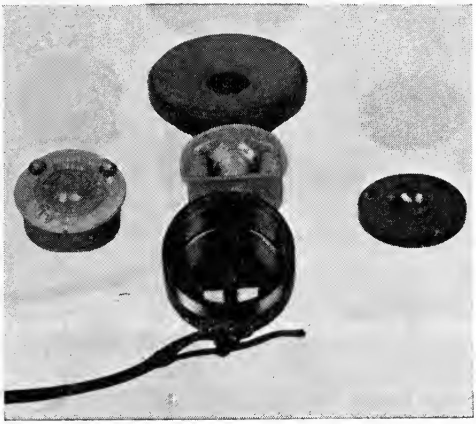

FIG. 4. Headphone unassembled.

In the actual design of the unit, the choice of circuit constants is to a great extent limited by the physical size the phones may have. The unit values of M_D and C_D are chosen so that their resonance occurs at about 800 cycles. The compliance C_2 back of the diaphragm is then made small enough to produce a resonance peak at the highest frequency desired. C_3 and M_3 are then selected to resonate in combination with Z at approximately the same frequency, thereby producing a double peak at the high-frequency end. The value of R_1 is then adjusted to give the desired ratio between high and low-frequency response. The path through M_2R_2 is predominantly inductive, as previously noted, and serves to short-circuit M_1R_1 at low frequencies, thereby boosting the low-frequency response.

In practice, it is possible to set up the electrical equivalent of the circuit and make the adjustments in terms of electrical units, and thus save a great deal of time. Most of the circuit elements come out a feasible size, and, if not, a proportional circuit may easily be set up.

The mechanical considerations of the design are comparable in importance to the electroacoustic performance. In addition to high sensitivity, low distortion, and good frequency response, the phones must be comfortable and readily serviced. Comfort for the wearer involves several factors, among the most important of which are weight, pressure on the ears, and material in the ear-cap. It was found that weights in excess of 1.25 pounds complete were undesirable when the phones had to be worn for long periods. Service requirements dictate that the cords may be changed without disturbing the units, and that the phone motors may be exchanged without tools.

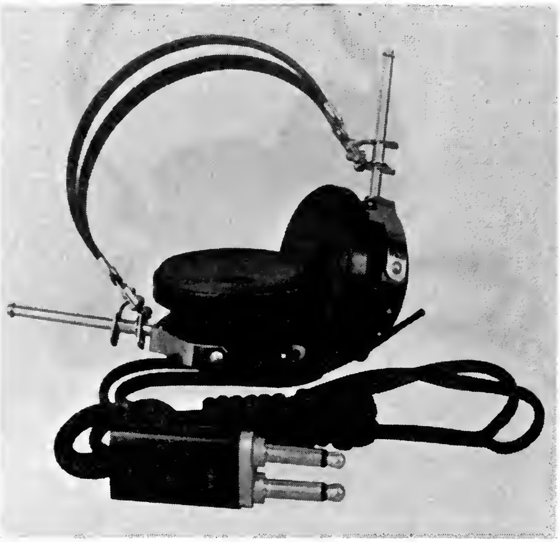

FIG. 5. Complete headphone set.

Since the final criterion of a good phone unit is the opinion of the listener, the measurement of the performance of the phone units is of special interest. The initial measurements were made using an artificial ear,[3, 4] but after making a few listening tests, it became apparent that the leakage path afforded was too large. This was probably due to the fact that the leak in question was designed to represent the leakage normally occurring between the hard cap of a telephone receiver and the ear. The leakage between the ear and the soft rubber cap proved to be considerably less. This was clearly evident in the fact that more comparable results between listening tests and measurements were secured by the simple expedient of completely closing the leak in the artificial ear. The results of these measurements are shown in Fig. 2. Here Curve *III* shows the response of a preliminary model operating into the artificial ear, and Curve *II* the response obtained with the leak completely closed. The actual performance of the phone unit no doubt lies between these two extremes. Two other methods, both subjective in nature, were used for further checks. The first of these might be called the threshold curve of the listener, and curve *I* was determined by the following method: a constant voltage was applied to the phone circuit through an attenuator, and the attenuation between the supply voltage and the phones increased until the listener could no longer hear the signal. The values of attenuation were then plotted against frequency, as shown. Had the two curves coincided, the indication would have been that the preliminary phones were flat in response; however, variations from this ideal are to be noted, especially at the higher frequencies. As a final check, a direct listening test was made between the phones and a high-fidelity speaker channel, with results that fairly well substantiated the frequency response variations indicated by the threshold method. The extent to which it was adjudged desirable to alter the frequency response in the final unit in order to obtain the flat response required for high-fidelity performance under actual listening conditions is indicated by a comparison between curves *I* and *III* of Fig. 2.

REFERENCES

[1] WENTE, E. C., AND THURAS, A. L.: "Moving-Coil Telephone Receivers and Microphones," *J. Acoust. Soc. Amer.*, III (July, 1931), p. 44.

[2] OLSON, H. F.: "Elements of Acoustical Engineering," *D. Van Nostrand Co.* (*New York*), p. 232 (1940).

[3] *Ibid.*, p. 270.

[4] INGLIS, A. H., GRAY, G. H. G., AND JENKINS, R. T.: "A Voice and Ear for Telephone Measurements," *Bell Syst. Tech. J.*, II (April, 1932), p. 293.

FIFTIETH SEMI-ANNUAL CONVENTION

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Hotel Reservations and Rates

Reservations.—Early in September, room-reservation cards will be mailed to members of the Society. These cards should be returned as promptly as possible in order to be assured of satisfactory accommodations. Reservations are subject to cancellation if it is later found impossible to attend the Convention.

Hotel Rates.—Special *per diem* rates have been guaranteed by the Hotel Pennsylvania to SMPE delegates and their guests. These rates, European plan, will be as follows:

Room for one person	\$3.50 to \$8.00
Room for two persons, double bed	\$5.00 to \$8.00
Room for two persons, twin beds	\$6.00 to \$10.00
Parlor suites: living room, bedroom, and bath for one or two persons	\$12.00, \$14.00, and \$15.00

Parking.—Parking accommodations will be available to those motoring to the Convention at the Hotel fireproof garage, at the rate of $1.25 for 24 hours, and $1.00 for 12 hours, including pick-up and delivery at the door of the Hotel.

Convention Registration.—The registration desk will be located on the 18th floor of the Hotel at the entrance of the *Salle Moderne* where the technical sessions will be held. All members and guests attending the Convention are expected to register and receive their badges and identification cards required for admission to all the sessions of the Convention, as well as to several *de luxe* motion picture theaters in the vicinity of the Hotel.

Technical Sessions

The technical sessions of the Convention will be held in the *Salle Moderne* on the 18th floor of the Hotel Pennsylvania. The Papers Committee plans to have a very attractive program of papers and presentations, the details of which will be published in a later issue of the JOURNAL.

Fiftieth Semi-Annual Banquet and Informal Get-Together Luncheon

The usual Informal Get-Together Luncheon of the Convention will be held in the Roof Garden of the Hotel on Monday, October 20th.

On Wednesday evening, October 22nd, will be held the Silver Anniversary Jubilee and Fiftieth Semi-Annual Banquet at the Hotel Pennsylvania. The annual presentations of the SMPE Progress Medal and the SMPE Journal Award will be made and officers-elect for 1942 will be introduced. The proceedings will conclude with entertainment and dancing.

Entertainment

Motion Pictures.—At the time of registering, passes will be issued to the delegates of the Convention admitting them to several *de luxe* motion picture theaters in the vicinity of the Hotel. The names of the theaters will be announced later.

Golf.—Golfing privileges at country clubs in the New York area may be arranged at the Convention headquarters. In the Lobby of the Hotel Pennsylvania will be a General Information Desk where information may be obtained regarding transportation to various points of interest.

Miscellaneous.—Many entertainment attractions are available in New York to the out-of-town visitor, information concerning which may be obtained at the General Information Desk in the Lobby of the Hotel. Other details of the entertainment program of the Convention will be announced in a later issue of the JOURNAL.

Ladies' Program

A specially attractive program for the ladies attending the Convention is being arranged by Mrs. O. F. Neu and Mrs. R. O. Strock, *Hostesses*, and the Ladies' Committee. A suite will be provided in the Hotel where the ladies will register and meet for the various events upon their program. Further details will be published in a succeeding issue of the JOURNAL.

PROGRAM

Monday, October 20th

9:00 a. m. *Hotel Roof;* Registration.

10:00 a. m. *Salle Moderne;* Technical session.

12:30 p. m. *Roof Garden;* Informal Get-Together Luncheon for members, their families, and guests. Brief addresses by prominent members of the industry.

2:00 p. m. *Salle Moderne;* Technical session.

8:00 p. m. *Salle Moderne;* Technical session.

Tuesday, October 21st

9:00 a. m. *Hotel Roof;* Registration.

9:30 a. m. *Salle Moderne;* Technical session.

2:00 p. m. *Salle Moderne;* Technical session.
Open evening.

Wednesday, October 22nd

9:00 a. m. *Hotel Roof;* Registration.

9:30 a. m. *Salle Moderne;* Technical and Business session.
Open afternoon.

8:30 p. m. Fiftieth Semi-Annual Banquet and Dance.
Introduction of officers-elect for 1942.
Presentation of the SMPE Progress Medal.
Presentation of the SMPE Journal Award.
Entertainment and dancing.

Thursday, October 23rd

10:00 a. m. *Salle Moderne;*—Technical session.

2:00 p. m. *Salle Moderne;* Technical and business session.
Adjournment

W. C. KUNZMANN,
Convention Vice-President

SOCIETY ANNOUNCEMENTS

1941 FALL CONVENTION

NEW YORK, N. Y.

OCTOBER 20TH–23RD, INCLUSIVE

The 1941 Fall Convention will be held at New York, N. Y., with headquarters at the Hotel Pennsylvania.

Members are urged to make every effort to attend the Convention, as a very interesting program of papers and presentations is being arranged.

Details of the Convention will be found elsewhere in this issue of the JOURNAL.

ADMISSIONS COMMITTEE

At a recent meeting of the Admissions Committee, the following applicants for membership were admitted into the Society in the Associate Grade:

ABBOTT, H.
1311 South Wabash Ave.,
Chicago, Ill.

ALBERSHEIM, W. J.
Electrical Research Products, Inc.,
20 Vandam St.,
New York, N. Y.

ANDERS, GUS
Droll Theater Supply Co.,
351 E. Ohio St.,
Chicago, Ill.

BAILEY, E. L.
Box 815N,
1421 Arch St.,
Philadelphia, Pa.

BINGHAM, E. H.
5 East 39th St., South,
Salt Lake City, Utah

BURTON, C. C.
Paramount Pictures, Inc.,
1501 Broadway,
New York, N. Y.

GATES, J. R.
629 N. 15th,
Lincoln, Neb.

GAW, E. D.
26 Drake Court,
Omaha, Neb.

GELLERUP, D. W.
Milwaukee Journal,
333 West State St.,
Milwaukee, Wis.

GOLDMAN, A. I.
Box 51,
Assinippi, Mass.

JOHNSON, E. O.
533 East 32nd St.,
Indianapolis, Ind.

MAUTHNER, E. I.
4649 Beacon St.,
Chicago, Ill.

MCLEAN, J. F.
Miller Broadcasting System, Inc.,
113 West 57th St.,
New York, N. Y.

SACHTLEBEN, L. T.
RCA Manufacturing Co., Inc.,
501 N. LaSalle St.,
Indianapolis, Ind.

SWEN, MING-CHING
Dept. of Educational Cinematography,
University of Nanking,
Chengtu, China

THOMAS, P. E.
501 West Mills St.,
Creston, Ia.

WAGLE, M. M.
17 Mathew Road,
Bombay 4, India

WYSOTZKY, M. Z.
Bolshoi
Gnezdnikovsky Pereulok dom 10 kvartira 724,
Moscow, U.S.S.R.

In addition, the following applicants have been admitted to the Active Grade:

BARNETT, H.
30 Jefferson St.,
Garden City, L. I., N. Y.

LEBEL, C. J.
370 Riverside Drive,
New York, N. Y.

Society of Motion Picture Engineers

HOTEL PENNSYLVANIA
NEW YORK, N. Y.

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APPLICANT'S RECORD

Name...Age............

Mailing Address..

Present Occupation..

Employer..

A complete account of the applicant's qualifications and accomplishments is required before an application may be submitted to the Board of Governors. The applicant should describe any inventions and improvements he has made in the art, as these are considered of more importance than a mere record of experience or the names of positions the applicant has filled.

Education..

....

Record of Accomplishments..

....

Motion Picture Experience..

....

Grade Applied For..
(Active or Associate)

REFERENCES

1. .... 3. ....

....

2. .... 4. ....

....

The undersigned certifies that the above statements are correct, and agrees, if elected to membership, that he will be governed by the Society's Constitution and By-Laws so long as his connection with the Society continues.

Date................19... *Signed*.......................................

(*Use a separate sheet of paper for complete record of accomplishments*)

JOURNAL
OF THE SOCIETY OF
MOTION PICTURE ENGINEERS

Volume XXXVII **October, 1941**

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**Term expires December 31, 1942.

THE STEREOPHONIC SOUND-FILM SYSTEM—GENERAL THEORY*

HARVEY FLETCHER**

***Summary.**—The general requirements are discussed for an ideal recording-reproducing system as determined by the characteristics of hearing of a typical group of persons listening in a typical concert hall or theater. Quantitative values are set down as ideal objectives. Although microphones, loud speakers, and amplifiers which had been developed for the stereophonic transmission system were available for meeting these objectives, no recording medium was known which would record the wide dynamic range of intensity levels which the objectives indicated was necessary. However, this wide intensity range objective was met by using a compandor in the electrical system. A general discussion is given of the reasons for choosing the particular compandor used, for using variable-area rather than variable-density on the recorded film, for using three instead of a greater or lesser number of channels. A general description of the stereophonic sound-film system is given, including the enhancement feature. This feature makes it possible to re-record from the original recording, at the same time making any desirable changes in the dynamic range or frequency response in each of the three channels.*

In 1934 a series of papers[1] on auditory perspective was presented before the A. I. E. E. describing a transmission system which was later called a stereophonic transmission system. It consisted essentially of three complete channels working together, each comprising a microphone, a high-gain amplifier, a predistorting and corrective network, a transmission line, an amplifier, a restoring and corrective network, a variable distorting network and attenuator, a power amplifier, and a loud speaker, as shown in Fig. 1. It was shown that by means of this system symphonic music and other sounds could be picked up in a hall in Philadelphia, transmitted to a hall in Washington, D. C., and there reproduced without the introduction of apparent distortion or noise.

This system not only made possible the production of a facsimile of the original music, but it also had what is called an enhancement

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received May 27, 1941.

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

feature. The part of the equipment used for this enhancement is labeled "control box" in Fig. 1. By means of these controls the director of the orchestra, while listening to the reproduced music, raised and lowered at will the intensity level of each channel by means of dials attached to the attenuators. By means of appropriate switches, he could increase or decrease the level of the bass, or make the music less or more shrill by throwing in or out networks having a sloping frequency loss characteristic. These networks were designed to produce changes in the frequency response characteristics of the system, as indicated in Fig. 2. There were also auxiliary control circuits used for giving signals to the orchestra, governing the tempo, and giving instructions to the leader of the orchestra.

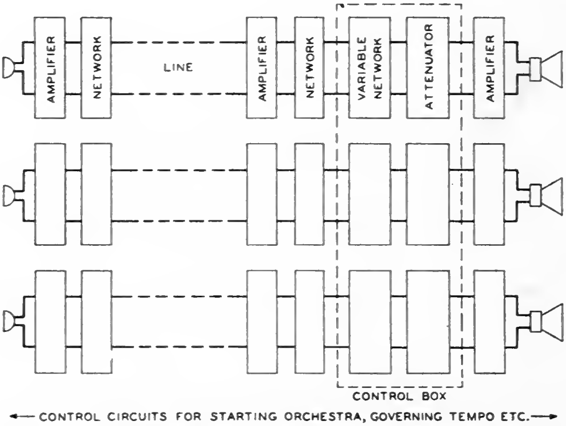


FIG. 1. Philadelphia-Washington stereophonic-transmission system.

In the development of the stereophonic sound-film system (SSFS) nearly all the features of the stereophonic transmission system described above were retained. The loud speakers, power amplifiers, and microphones are the same and the attenuating and equalizing networks are similar. The fundamental requirements upon which the design of both the transmission system and the recording-reproducing system are based are the same and will be reviewed here.

It is well known that when an orchestra plays, vibrations continually changing in form and intensity are set up in the air of the hall where the recording is made. An ideal system is one which will make a record of these vibrations and at any desired later time reproduce them so as to produce at every position in the hall the same time sequences of wave motion as were produced during the recording. To accomplish this for a sound source which is spread out, for example, the sound coming into a concert hall from the orchestra on the stage, requires more than one channel.

Suppose there were interposed between the orchestra and the audience a sound-transparent curtain on which were mounted small microphones for picking up the sound going through the curtain; and suppose to each microphone there is connected an ideal recording system. Records made with such an ideal system would have stored on them a complete history of the sound changes at every position on the curtain. Now if small ideal loud speakers were placed at the positions occupied by the microphones and connected to ideal machines reproducing the records, then a sheet of sound would be reproduced having all the characteristics of the original sound. Theoretically, there should be an infinite number of such recorder-reproducer sets. Practically, however, only a few such channels are needed. On a large stage it has been found that three channels are sufficient to give a good illusion of the sounds coming from all parts of the stage. We developed a three-channel system not only because it gave better representation of movements on a large stage, but also because of the possibility of using the center channel for solo work while still retaining the stereophonic features of the orchestra on the two side channels. If one wished as much flexibility up and down as

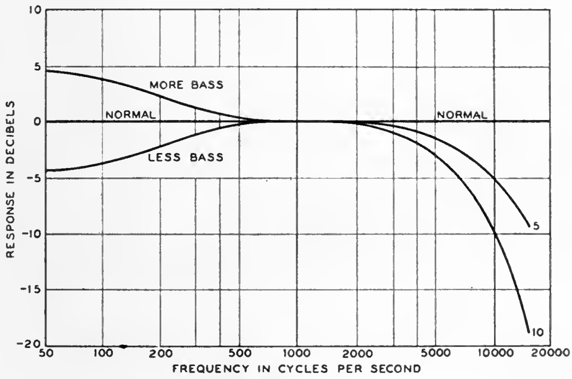


FIG. 2. Variable network characteristics.

the present system gives sidewise, then the channels would have to be increased from three to nine.

It is important to recognize the difference between this stereophonic system and a binaural system. The latter requires only two channels for a perfect reproduction but requires that head receivers be held tightly against the ears, while the former can use loud speakers but for perfect reproduction requires an infinite number of channels. If we design the system to handle any kind of sounds that the ear can hear and tolerate, then the limits of frequency and intensity are set by the hearing characteristics of a typical group of listeners. It was this ambitious objective that was set for the SSFS.

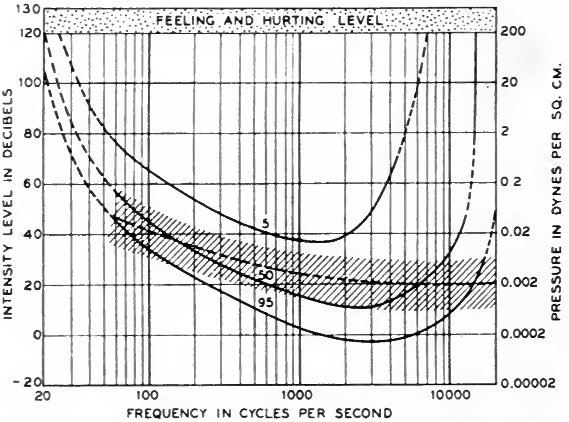


FIG. 3. Threshold hearing level curves for quiet and noisy rooms.

During the past two years a survey of the hearing capabilities of persons in a typical population has been made by the Bell Telephone Laboratories. This was done in connection with the exhibits at the World's Fairs at San Francisco and New York City, sponsored by the Bell Telephone companies. At these exhibits records of the hearing of more than one-half million persons were analyzed. The record expressed the hearing acuity as a relative hearing loss or gain with respect to an arbitrary reference. Measurements at the Laboratories on this reference have made it possible to express these data on an absolute scale. The results were published in a paper entitled "Results of the World's Fair Hearing Tests," by Steinberg, Montgomery, and Gardner.[2] Fig. 3 has been constructed from data taken from this paper. The lower curve labeled 95 indicates that 95 out of 100 persons in a typical group can not hear pure tones whose frequency and intensity levels lie below this curve. The top curve indicates that 5 out of 100 can not hear these tones until they exceed the intensity levels indicated by this curve. The middle curve indicates the levels where one-half the group can hear and the other half can not hear. The dashed portions of the curves indicate regions where no measurements have been made. Feeling and hurting levels lie somewhere above 120 db as indicated by the field of dots at the top of the chart. Our experience with reproduced music has taught us that it is undesirable and probably unsafe to reproduce sounds for a general audience that have greater intensity levels than 120 db.

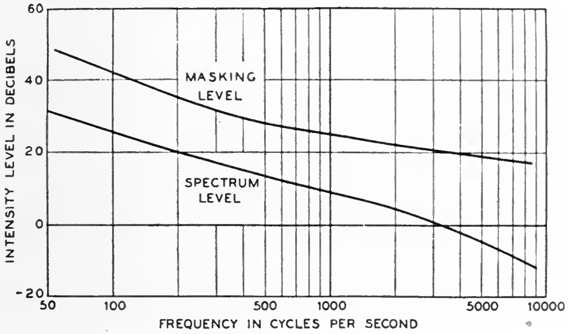


FIG. 4. Masking and spectrum levels for average room noise.

If the listener is in a quiet place, these curves set the limits for the ideal transmission system. This ideal of no noise is seldom if ever realized by listeners. Measurements of room noise have been made by the Bell Telephone Laboratories and from these measurements the average noise spectrum can be deduced. In a paper by Seacord[3] it was found that 43 db was the average sound level in residences not having radios playing. The standard deviation of levels in different residences from this figure was 5.5 db. The distribution about this average value indicated that about one-half the residences have noise levels between 39 and 47 db, and 90 per cent are in the range between 33 and 52 db.

Hoth[4] found that the form of the noise spectrum was about the same for all types of rooms. This is shown for a room noise having a total level of 43 db in Fig. 4, lower curve. In a paper entitled "Relation between Loudness and Masking"[5] it was shown that the masking level could be obtained directly from the spectrum level. Using this relation the curve shown in Fig. 4 labeled *Masking Level* was obtained. This curve then gives the level of pure tones which can just be perceived in the presence of average room noise by a reference observer. This masking curve is shown in Fig. 3 as a cross-hatched band. It shows the range of the masking levels for about 90 per cent of the residences in a typical group. The dotted curve gives the average. These figures refer to residences. Measurement of noise levels by Mueller[6] in quiet motion picture theaters gave an average level of 25 db, but with an audience present the average was 42 db, which is just 1 db below the average room noise given above. Consequently, the curve given in Fig. 4 will apply to this case. It will probably generally apply also to concert halls, although in this case for the very quiet listening periods the lower part of this hatched portion more nearly represents the noise conditions. It is interesting to note that the threshold hearing levels vary about 20 db due to noise conditions in residences, theaters, and concert halls, whereas it varies nearly twice this amount due to differences in acuity of hearing by different persons considering only the middle 90 per cent of the cases.

If these deductions are correct, then it is seen that the lowest levels that can be heard by the average person in a group are determined by the hearing mechanism when the frequencies are below 200 or above 6000 cycles, but by room noise when they are between 200 and 6000 cycles. For example, the fundamental of a 60-cycle hum should be kept below a 57-db level, whereas any components of this hum around 1000 cycles should be kept below a 25-db intensity level. It is seen that for the 5 per cent of the rooms which are quietest the limit is set entirely by the hearing acuity curve. This condition is nearly reached in some of the quietest periods in the very best concert halls. From Fig. 3 one can also set the frequency limits if all sounds that can be heard by the average listener are to be recorded. This range is from 20 cycles per second to 15,000 cycles per second for the highest possible levels, and for any lower levels this frequency range is smaller, as indicated.

Fig. 3 also gives the maximum levels such an ideal system might be called upon to transmit. This maximum level is taken as 120 db and the same for all frequencies. To reproduce this high level in a large concert hall requires about $^1/_2$ kw of sound power. In a small room, however, this level can be attained with about 3 watts of sound power.

A summary of the limitations set by average hearing is shown in Fig. 5. The lower curve may be anywhere in the hatched area, depending upon the noise conditions of the room. This figure then sets the design objectives for frequency and intensity determined by the characteristics of average hearing and average noise conditions in listening rooms.

As stated above, most of the features of the stereophonic transmission system were carried over to the SSFS. The transmission line of the former is replaced by a long period delay or storage system in the latter. The amplified microphone current, instead of flowing into a transmission line, is translated into a record in a form which can at a later date be retranslated into a facsimile of the original recording current. While problems of noise, non-linearity, and attenuation distortion are met both in the transmission and storage systems, their source and character are such that solutions of quite a different nature are demanded.

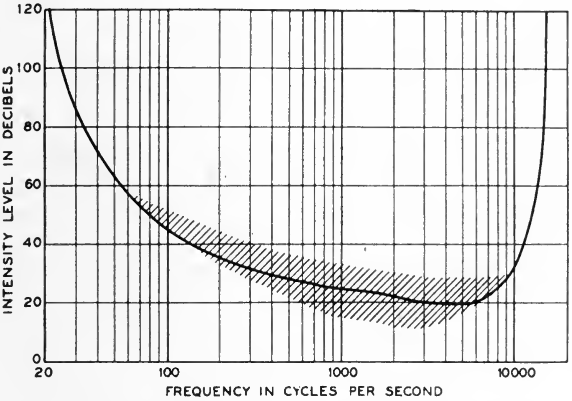
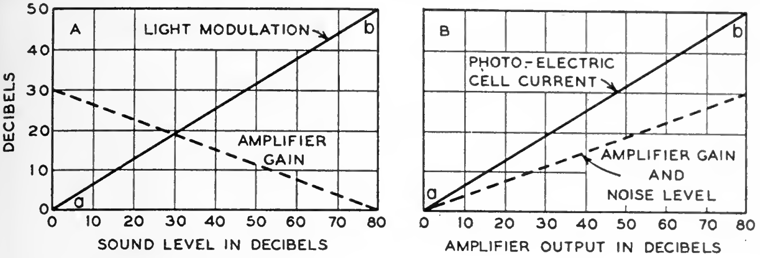


FIG. 5. Hearing limits for pure tones of a typical listener in a room having typical residential room noise.

Since current in three signal channels must be recorded simultaneously and subsequently reproduced in synchronism, a linear type of phonograph carrier presents itself as probably the most suitable recording medium. In this class, the photographic sound-film is farthest advanced in its development and was therefore adopted for the stereophonic system.

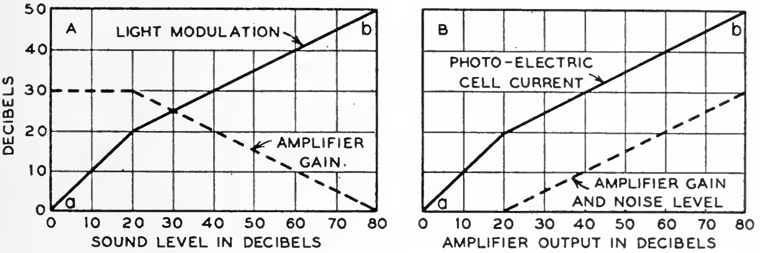
Two types of sound-film records are now in wide commercial use, variable-area and variable-density, each having advantages which we shall not discuss in detail. We shall merely point out the chief reasons for adopting the variable-area method in this particular project. With a sharply defined boundary between the light and dark areas, and with clean handling of film, the variable-area record has initially the advantage of greater volume range, which is soon lost in successive playings. The rate of loss in volume range can be kept down by careful film handling. In the design of the stereophonic equipment, special thought was given to obviating conditions that result in surface abrasions of the film, which was here made easier by the fact that the film does not have to pass through a picture projector. A second advantage possessed by the variable-area record is that the level of the photoelectric cell current in reproduction is about 6 db higher, which is of some importance in dealing with signals of low intensity over a broad band system. One of the principal disadvantages of the variable-area method is that improper film processing will result in the introduction of high intermodulation components, even at low signal levels, whereas in variable-density recordings, while bad processing will result in a signal distortion, the distortion falls off rapidly with the signal level. Lately better methods of measuring and controlling this distortion have been developed, so that, where the choice of positive print stock is unhampered by picture considerations, the non-linear distortion of the variable-area record can be held to a low value. Special requirements that the variable-area method demands in the reproducing system, such as the uniformity of the illumination per unit length in the scanning line of light, it was felt, could be taken care of by extra precautions in the design and construction of the apparatus.

The range of maximum signal to noise in a film record 80 mils wide is of the order of 50 db. It is more or less dependent upon circumstance and exact definition of the term. Measurements made with a high-speed automatic level recorder showed a volume range for a large symphony orchestra of 78 db. The range of signal intensity level that is to be recorded and reproduced when recording music is then of the order of 80 db. For purposes of discussion, we shall use simply these rounded figures of 50 and 80 db. The 80-db signal must, therefore, in some manner be compressed at least 30 db and if dynamic range is to be preserved, it must be expanded the corresponding amount in the reproduction. In the sound *versus* light



(*a*) (*b*)

FIG. 6. Amplifier gain and noise relationships with compandor operating linearly and continuously over the whole sound level range. (*a*) recording; (*b*) reproducing.



(*a*) (*b*)

FIG. 7. Amplifier gain and noise relationships with compandor operating linearly and continuously over the upper 60-db level of the sound signal. (*a*) recording; (*b*) reproducing.

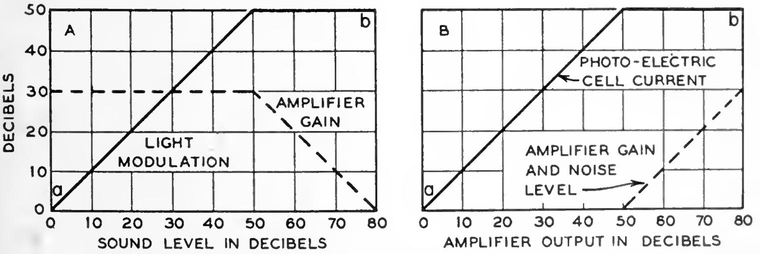


FIG. 8. Amplifier gain and noise relationships with compandor settings fixed for the lower 50-db range of sound signal level.

modulation coördinate diagram, two points, labeled *a* and *b*, respectively, in Fig. 6(*a*) are fixed, if the capabilities of the film are to be used to full advantage. One of these points is defined by the maximum sound level and complete light modulation, and the other, by a sound level 80 db and a modulation level 50 db lower. In between, the relationship may be of any desired kind so long as it can be represented by a single-valued line connecting these two points, and provided that for every change in the gain of the recording amplifier an equal amount of attenuation is subsequently introduced in the reproducing amplifier at a corresponding point of the record, provided further that there is no signal distortion between these two parts of the circuit.

The departure of the slope of the line connecting *a* and *b* from unity gives the rate of change of amplification of the recording amplifier with sound level. If, for instance, the characteristic of a recording system is represented by a straight line connecting *a* and *b*, then for each db increase in sound level, there is a decrease in amplification of $^3/_8$ db. The gain in this case therefore changes continually with the signal level. If now a record so made is reproduced with an amplifier the gain of which increases $^3/_8$ of a db for every $^5/_8$ db increase in the photoelectric cell current, or, which is equivalent, for every db increase in amplifier output, the dynamics of the original sound will be recovered in the output current of the reproducing amplifier. These conditions are graphically represented in Fig. 6. Fig. 6(*a*) shows the recording and Fig. 6(*b*) the reproducing conditions. In Fig. 6(*a*) the solid line gives the relation between sound level and the modulation of the recording light. The dashed line gives the relation between sound level and amplifier gain. In Fig. 6(*b*) the solid line represents the relation between amplifier output and photoelectric cell current, while the dashed line gives the relation between amplifier gain and amplifier output level. Similar designations hold for Figs. 7 and 8, which are to be discussed presently. The amplifier gain curve in Fig. 6(*b*) also represents the level of the film noise that accompanies the output signal. If the gain of the amplifier is set so that at the minimum signal (80 db below maximum) the noise is at or above the threshold under the particular listening conditions, then the signal will be accompanied by "hush-hush," a term used to designate the audible rising and falling of noise with the signal. If, for minimum signal, the signal and noise are both at threshold, then as the signal is raised 8 db the noise will be only 5 db below the signal, even though at maximum level the noise is 50 db below the signal. One further disadvantage of this type of compression and expansion is that distortion which may be introduced by the process will enter throughout the whole signal level range.

In the case illustrated in Fig. 7(*a*) the compressor system is so arranged that the signal is recorded in a normal way over the lower 20-db range after which there is a reduction of $^1/_2$ db in the amplification for every db gain in input signal. The corresponding signal *versus* noise relationships in reproduction when the dynamics of the signal are restored are shown in Fig. 7(*b*). There will be no hush-hush until the signal reaches a level of 20 db above the minimum. After that, for every db rise in signal, there is $^1/_2$-db rise in noise level. In comparing this system with that represented by Fig. 6, we note from 7(*b*) that when the output signal has a level of 40 db, the noise level is 10 db, whereas in the system of Fig. 6, the corresponding noise level is 15 db. At higher levels this difference in the two systems becomes less until at the highest level, the noise is down 50 db in either case, the volume range of the film.

Fig. 7 is of particular interest, as the noise relationships shown in *b* are virtually those which would obtain for a 30-db noise-reduction system of the usual form. An inherent weakness in the ordinary noise-reduction scheme is that only for the maximum signal is the full track width utilized. For example, in a system with 10 db of noise reduction, signals more than 20 db below the maximum are reproduced from a record which is one-tenth as wide as a record occupying the full width of the track and which consequently has 10 db less volume range. It is evident that as the characteristic of the compandor (compressor-expandor) is changed so that the upper part of the line *ab* becomes more nearly horizontal, the hush-hush becomes less.

The ideal type of system is the one represented by Fig. 8. In this system no change is made in amplifier gain over the lower 50-db range of sound level, *i. e.*, not until the sound-track is fully modulated, after which the recording amplifier gain is reduced by 1 db for each db increase in signal level. In other words, the recording level remains constant. In reproducing, there is then no possibility of hush-hush, and the quality of the signal can not in any way be impaired by the action of the automatic gain control system over the lower 50-db range. For the most part sound sequences of the kind ordinarily recorded will therefore be entirely free from hush-hush and from distortion in excess of that introduced by a normal system. The masking of one sound by another increases rapidly with the level of the masking sound. As all noise-reduction schemes depend for their success upon the masking of the noise by the signal, it is of great advantage to restrict noise reduction to the higher signal level range as is done to the greatest extent possible in the system of Fig. 8. The objective in the design of the stereophonic system was to approach the ideal of Fig. 8 as closely as possible.

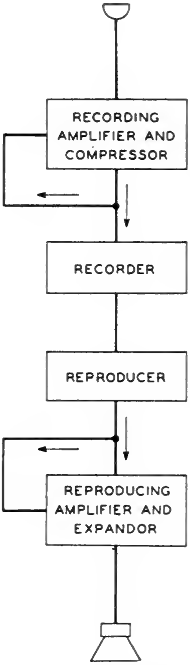


FIG. 9. Recording-reproducing system with compression and expansion controlled directly by the signal.

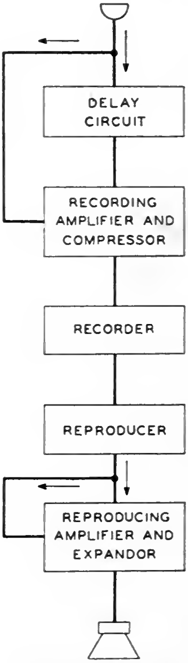


FIG. 10. Recording-reproducing system with compression and expansion controlled directly by the signal and time-delay network in signal channel.

The operations involved in a compression-expansion, or a so-called compandor system, can be carried out in one or the other of two general ways. The compression and expansion operations may be controlled directly by the signal, or they can be placed under the control of a separate channel which may be called a pilot channel.

In Fig. 9 is shown a recording-reproducing system in which the signal itself is used to control the amplifier gains in recording as well as in reproducing. In this particular arrangement, if there were no distortion in the recording and reproducing processes, it would be possible to reproduce the sound without distortion, since both amplifiers are controlled virtually by the same dynamically distorted signal. If the control system is so constructed that the gain adjustments follow the signal very rapidly, the operation and frequency-range requirements for the recording-reproducing system become severe. If the adjustments follow the signal slowly, then noticeable clipping may result, *i. e.*, when the signal tends to rise suddenly the recording system may be overloaded before the proper gain adjustment has been effected.

This difficulty can be overcome in the system of Fig. 10. In this arrangement, the gain of the recording amplifier is controlled by the microphone instead of the recording amplifier output current. By the insertion of a time delay at the part of the circuit indicated, it is possible to have even a slowly operating control circuit reduce the gain to the proper value before a sudden increase in signal level can make itself manifest at the input of the recording amplifier. Clipping is thus avoided. It will be noticed that in this system, in contradistinction to that represented in Fig. 9, the recording and reproducing amplifiers are not controlled by current of the same dynamic characteristics, so that there is a greater likelihood of introducing waveform distortion in the current finally delivered to the loud speaker.

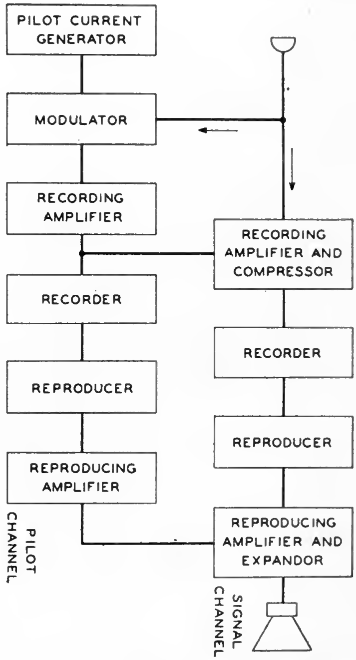


FIG. 11. Recording-reproducing system with compression and expansion controlled through a pilot channel.

Since the sound in a room reaches its maximum value in a relatively short time after its inception, but decays from the maximum to threshold rather slowly, it has been customary in all noise-reduction systems to have the controls operate rapidly when the signal level increases and slowly when the signal decreases. This arrangement greatly reduces the operating requirements of the recording-reproducing apparatus, particularly as regards phase distortion at low frequencies.

Neither of the above systems can operate in the way that is represented by Fig. 8—set up as the ideal—for in the level region where gain adjustment must be made the signal current coming from the reproducing machine is of constant level and so does not contain the requisite information for the gain adjustments. These systems operate best under the condition shown in Fig. 6, *i. e.*, where the slope of the curve relating light modulation and current is large.

In the system shown in Fig. 11 a pilot track, for carrying information about the required gain adjustment in the reproducing amplifier, is made along with the signal record. This system is not subject to the limitations mentioned in the last paragraph.

Current from an oscillator is recorded on a separate track. The level of this current is modulated by the signal coming from the microphone. This modulated current controls the gain of the recording as well as that of the reproducing amplifier—in the latter case, of course, after having been recorded and reproduced. A given change in the current-level of the pilot channel should produce an equal but opposite change in gain in the two amplifiers. By a proper design of the modulator, the system can theoretically be made to operate with any desired relationship of sound level and recording current, including that of Fig. 8. No matter what this adjustment may have been for any particular record, it can always be reproduced with the proper dynamics without special adjustment of the modulator controlling the gain of the reproducing amplifier. The introduction of a time delay in the signal behind the control current presents no basic difficulties in this system. In subsequent re-recording, the dynamics may be altered at will by a manual adjustment of the pilot current. The stereophonic system operates with a pilot track in essentially the manner indicated.

We should like to point out that in any of the above-described systems, if the gain-control circuits are properly balanced, the control current manifests itself in the signal channel only in the desired modulation of the signal. When the signal current is zero, variations in the control current are theoretically not detectable in the signal channel. Except for greater ease in the elimination of distortions introduced by the photographic process, there is here not the advantage in the push-pull track that there is in an ordinary noise-reduction system, where the light-modulator biasing current is recorded directly on the sound-track. The extra complications of a push-pull recording system were therefore avoided.

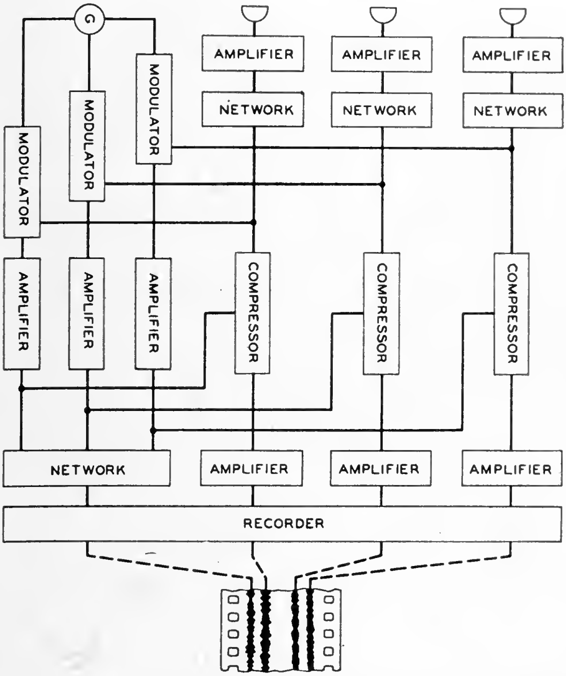


FIG. 12. Schematic diagram of stereophonic recording circuits.

Some further gain in noise reduction could be effected if, in addition, use were made of the ordinary noise-reduction method having preferably very slow operating speeds, and used only when there are longer intervals of quiet passages. However, this arrangement can have an advantage only where the limit of automatic adjustment of the reproducing amplifier has been reached. As the major difficulties in a compandor system are not in respect to noise at low signal levels, but rather to hush-hush effects, the extra complication of the addition of this kind of noise reduction did not seem warranted.

The general features of the recording part of the three-channel stereophonic sound-film system are shown in Fig. 12. It will be seen that there are three signal channels and three control channels. The three frequencies come from the generator and pass through the modulators and amplifiers, and are combined in the combining network and recorded as the pilot track on the film. If there is no signal in the signal channels, these three frequencies are recorded with equal amplitudes. Their phases are controlled at the generator *G* so that their combined amplitude is a minimum. A more detailed schematic drawing of one channel is shown in Fig. 13. As the signal current appears in the signal channel a small part of it is tapped off and sent through the amplifier *2* and the rectifier *I* into the modulator. The rectifier is designed so that a constant direct current leaves it and enters the modulator. As long as the signal current remains below a critical value, this critical level is controlled by the bias current in the rectifier. Above this level the direct current fed into the modulator is proportional to the signal current. The critical value can be easily changed by changing the gain of the amplifier *2* preceding the rectifier.

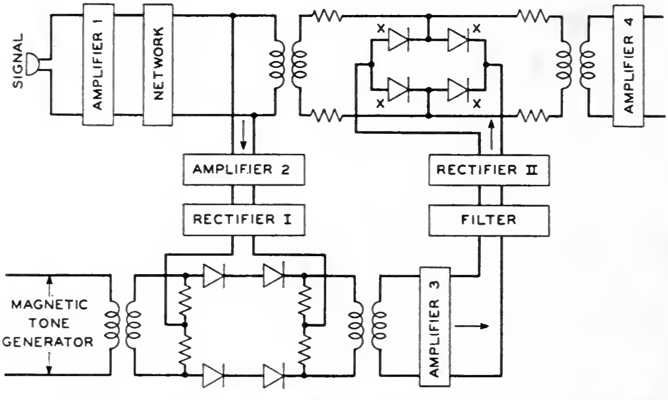


FIG. 13. Schematic diagram of one channel of the recording circuit.

The modulator is designed so that the amplitude of a single frequency leaving it and going to amplifier *3* is proportional to the direct current entering it from the rectifier. So it is seen that the amplitude on the pilot track is constant until the critical level in the signal channel is reached. Above this level the amplitude of the pilot track is proportional to the rms amplitude in the signal. At the same time that this modulated frequency is recording on the pilot track it is also sent back through the filter and the rectifier *II*, to the compressor. The compressor is designed so that the change in loss introduced by it into its signal channel is equal to the change in level of the rectified current coming into it. Consequently, the signal levels beyond the compressor never exceed the critical value and remain constant for all levels coming into the compressor above the critical one. In other words, as the signal level rises and falls on the input side of the compressor, the loss and gain in the compressor are automatically regulated by just the right amount to keep the output level constant, and the amount of this regulation is recorded on the

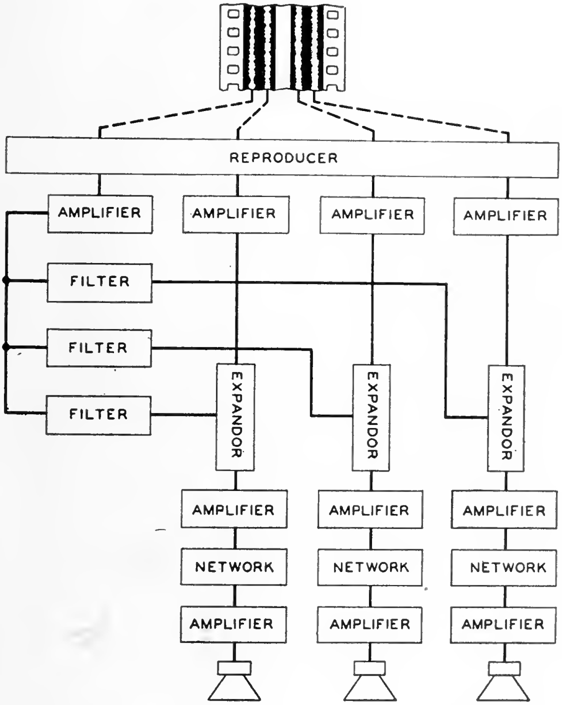


FIG. 14. Schematic diagram of the stereophonic reproducing circuits.

pilot track. This corresponds to the case discussed above and shown in Fig. 8.

The general features of the reproducing circuits are shown in Fig. 14. Three signals coming from the three tracks enter the upper three channels as indicated. The combined three modulated frequencies from the pilot track enter the lower channel where they are amplified the proper amount and separated by three filters. Each frequency is sent through a linear rectifier to the appropriate expandor. A more detailed diagram of one channel is shown in Fig. 15. The rectifier must be linear through a much wider range than the corresponding one in the recording system. By "linear" is meant that the rectified direct current be proportional to the alternating input current. The reason for this wider range is to take care of the enhancement feature, which will be explained later. Each expandor is designed so that its gain is directly equal to the change in level of the rectified current entering the expandor. In other words, if the rectified current is increased tenfold, the signal current leaving the expandor is also increased tenfold. Consequently, it will be seen that whenever a loss is introduced during recording there will be an equal gain introduced during reproducing so that the signal will be restored to its normal relative values. For the same reason that was given for the rectifier, the expandor must be linear for a much wider range than the compressor. Since the signal before recording must be compressed 30 db, the objective in the design of the compressor was to obtain a linear relationship over this range.

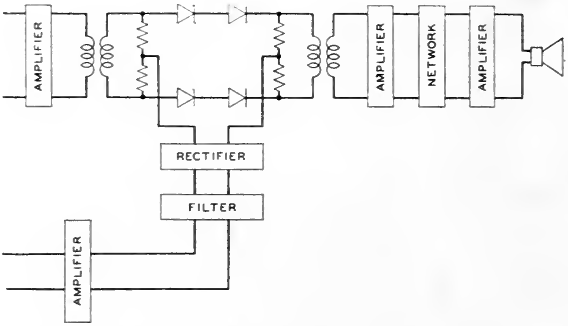


FIG. 15. Schematic diagram of one channel of the reproducing circuit.

It was considered desirable to include in the design of the system the enhancement feature so that the music could be re-recorded and additional interpretations added by the director of the orchestra as desired. In order to give the director as much freedom as possible, the maximum level should be limited only by the ear, that is, at 120-db intensity level. It has been found that the maximum peak intensity level for a large orchestra sometimes reaches 110 db. For this reason the system was designed so that the maximum levels of the original orchestra could be raised 10 db if desired. The control box is designed so that level changes can be made over a range of 30 db, from 10 db higher to 20 db lower than the normal signal levels. The 10-db increase and 5 of the 20-db decrease were produced by changing the level of the pilot channel. The other 15-db decrease

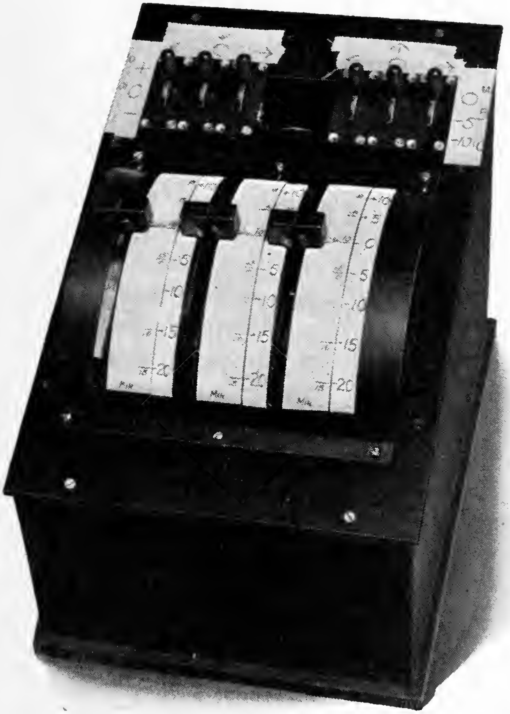


FIG. 16. Control box for enhancement and quality control.

was introduced directly in the signal channel. If a signal near the film noise level is decreased 5 db by the pilot channel and the maximum signal level is increased 10 db, the enhanced music will have an intensity level range of 95 db. The maximum intensity of an orchestra occurs at frequencies between 400 and 800 cycles. So it is seen from Fig. 5 that this range is all that the ear can hear and tolerate.

The networks which change the frequency response of the system were introduced directly into the signal channel before the recorder. Except for changes made by these networks, the re-recorded signal track was the same as the recorded signal track. It will be seen then from these figures that the expandor must operate at levels 5 db lower and 10 db higher than for the compressor, or through a range of 45 db.

In Fig. 16 is shown a picture of the control box which the director uses for this enhancement feature. It is evident that this enhancement can be done at the first recording, rather than on re-recording. This procedure would save any inherent distortions due to the re-recording process. In this case, however, the director must have an associate, either operating the control box or directing the orchestra.

It has been pointed out that although the film noise is at the same level as the orchestra noise at its "silent" period in the unexpanded music coming from the film, this is not true when the music is expanded to normal or enhanced, because in this case the film noise is also raised, being at most 50 db below the signal. In general, for orchestral music such noise is masked. However, for intense low-pitched tones the film noise, being principally in the high frequencies, is audible and may be heard as a hissing sound varying in intensity as the tone increases and decreases in level. To provide as large a margin as possible against this, a predistorting network is introduced into the system which makes it possible to record the higher frequencies at greater amplitudes on the track than normal. This is possible without increasing the track width because these higher frequencies come from the orchestra at considerably lower intensity levels. When the signal is reproduced, a restoring network cuts down the intensity of these high frequencies by the same amounts that they were raised during recording, and at the same time lowers the film noise in these high-frequency regions.

The frequency characteristic of the pre-equalizer used in the SSFS is shown in Fig. 17. The philosophy back of choosing this particular characteristic is rather involved and will be dealt with in the paper by

Dr. Steinberg.* It is sufficient to say here that this effective reduction of noise is possible only because music has a different sound spectrum from that due to noise. In recording orchestral music, this gives an effective reduction of noise of about 10 db. In other words, for such recorded music using these pre-equalizers and restorers, the film noise is effectively 60 db below the signal. This additional reduction in noise also provides a margin in case the director, who is doing the enhancing, raises the level of the soft passages in the rerecording process.

It has already been mentioned that, because of the time required for the compressing system to operate, a signal of suddenly increased intensity may overload the light modulator initially and thus undergo "clipping," the audible effect of which is a low-frequency thud. It was also suggested that this difficulty could be overcome by the introduction of a delay in the signal channel. The required amount of delay depends upon the speed of operation of the compressor. Unfortunately, delay equipment had not been incorporated in the circuits that were used in making the orchestral records which will be demonstrated at the end of this paper. The effect of the introduction of delay for various impulsive sounds was subsequently studied by using two microphones—one for the signal, and the other for the control circuit. The delay time was easily varied by altering the relative distances of the two microphones from the source. It was found that the method eliminates the "clipping" thud and otherwise operates entirely satisfactorily.

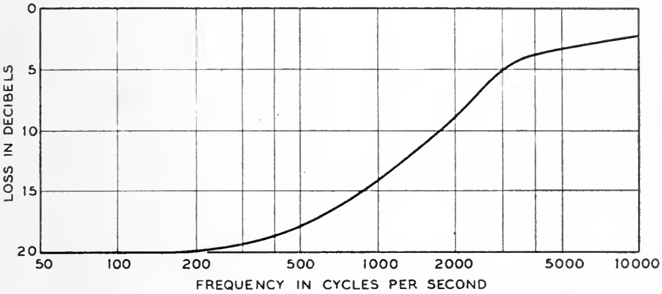


FIG. 17. Transmission-frequency characteristic of predistorting network.

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The object in the development of the recording and reproducing machines was to provide a means of putting into and taking out of storage the compressed signal wave. The frequency range to be covered was set at 20 to 14,000 cps without the introduction of any audible amount of distortion.

The various mechanical and optical features of the recording-reproducing equipment are described in some of the other related papers.* It will here be sufficient to say that the four records to be demonstrated are made on one standard 35-mm strip of film by four special light-valves, one for each track, and that in reproducing, a separate optical system and a separate photoelectric cell are used with each track. Except for the optical features, the same machines are used for reproducing that were used in the making of the records.

REFERENCES

[1] A symposium of six papers on "Auditory Perpsective," *Electrical Engineering*, **LIII** (Jan., 1934), p. 9; *Bell Syst. Tech. J.*, **XIII** (April, 1934), p. 239.

[2] STEINBERG, J. C., MONTGOMERY, H. C., AND GARDNER, M. B.: "Results of the World's Fair Hearing Tests," *J. Acoust. Soc. Amer.*, **XII** (Oct., 1940), p. 291; *Bell Syst. Tech. J.*, **XIX** (Oct., 1940), p. 533.

[3] SEACORD, D. F.: "Room Noise at Subscribers' Telephone Locations," *J. Acoust. Soc. Amer.*, **XII** (July, 1940), p. 183.

[4] HOTH, DANIEL F.: "Room Noise Spectra at Subscribers' Telephone Locations," *J. Acoust. Soc. Amer.*, **XII** (April, 1941), p. 499.

[5] FLETCHER, HARVEY, AND MUNSON, W. A.: "Relation between Loudness and Masking," *J. Acoust. Soc. Amer.*, **IX** (July, 1937), p. 9.

[6] MUELLER, W. A.: "Audience Noise as a Limitation to the Permissible Volume Range of Dialog in Sound Motion Pictures," *J. Soc. Mot. Pict. Eng.*, **XXXV** (July, 1940), p. 48.

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* Published in this issue of the JOURNAL.

MECHANICAL AND OPTICAL EQUIPMENT FOR THE STEREOPHONIC SOUND-FILM SYSTEM*

E. C. WENTE, R. BIDDULPH, L. A. ELMER, AND A. B. ANDERSON**

Summary.—*The same mechanism is employed for propelling the film in both recording and reproducing. To permit recording the longer orchestral selections without interruption, the machines are designed to handle film in 2000-ft lengths. Special features of the film-propulsion system for obtaining great uniformity of speed at the translation points are described. The three signal-currents and one control-channel current are recorded by means of light-valves of identical construction. All four tracks are exposed while the film is passing over a free-running supporting roller, mounted on the same shaft with a new type of internally damped roller. In reproduction, each track is exposed through an objective of high aperture to light from an incandescent source. After passing through the film, the light from each track is carried by a glass rod to a photoelectric cell.*

The primary function of the mechanical part of the recording machine of the stereophonic system is to move film from one magazine to another and intermediately pass it at a uniform speed over a support that will hold the film in accurate focus at four translation points simultaneously. The reproducing machine must perform essentially the same function with film reels substituted for the magazines. Aside from the optical systems, the same machines have, therefore, been used both for recording and reproducing. In order that long orchestral selections may be recorded without interruption, the machines must be capable of handling film successfully in 2000-ft lengths.

The optical system for each of the channels in the recorder must transmit light from the modulator in sufficient quantity for exposing the film adequately in a sharply defined image. The width of the image in the direction of film travel should be as small as the resolving power of the photographic emulsion warrants. When the recording is of the variable-area type, the ends of the image must also be sharply defined so that the boundary line between the light and dark

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received May 1, 1941.

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

areas in the record will be clear cut. A border of high contrast will permit the fullest modulation of the sound-track area and keep the noise from this part of the record to the lowest value.

The reproducing optical system for each channel must form an image on the film slightly longer than the width of the track, and, in the direction of film travel, the image must be narrow or have a narrow intense region, but does not need to be so sharply defined as the image in the recording system, since the scanning losses, if they are not too large, can here be equalized in the electrical circuit.

FILM PROPELLING MECHANISM

The apparatus as set up for recording is shown diagrammatically in Fig. 1. The passage of film is from left to right and is controlled by the two 24-tooth sprockets S_1 and S_2, which are driven through spiral gears from a transverse shaft directly connected to the motor. Between the two sprockets, the film passes over a series of rollers having various functions. They are all mounted on ball bearings. Rollers *1, 2, 11,* and *12* are pad rollers for the sprockets; *3* and *10* are guide rollers which lead the film around a shield placed over the photoelectric cells when the machine is used as a reproducer; *3* and *5* are flanged rollers limiting the weave of the film; *7* is the main sound or scanning roller, which is depended upon to keep the film in focus at all four tracks and moving at a uniform speed; *6* is a steel pressure

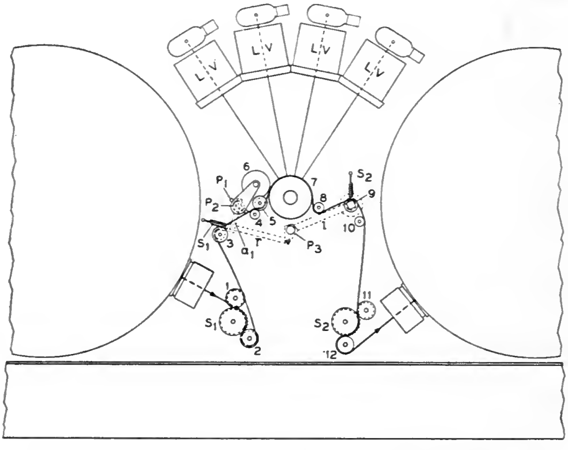

FIG. 1. Diagrammatic view of recording machine.

roller which presses the film against the sound roller with sufficient force to prevent film slippage. This roller bears only on a narrow portion of the film along its center line. It is mounted in a fork which is pivoted at p_1 so that the roller can seek a position in which it will not exert sidewise thrust on the film. The axis of this pivot is rigidly connected to the lever arm a_1, which in turn is pivoted on the horizontal axis p_2. The pressure roller tension is controlled by adjustment of the spring s_1 connected to the lower end of the lever arm a_1. The purpose of *8* is to give the film a relatively large angle of wrap around the sound roller, thus providing good seating for the film at the translation points and greater insurance against slippage. A damping roller is rigidly mounted on the sound roller shaft.

While the power needed to drive the sound roller under steady-state conditions is small, the driving torque must be increased considerably when the roller is being brought up to speed from rest because of the relatively high moment of inertia of the damping roller. During this time, the roller *6* must be pressed against the film with increased force if film slippage is to be prevented. The linkage, shown by the dashed lines in the figure, is provided for this purpose. The lever l of this linkage is pivoted at p_3. A loose-fitting rod r connects the arm a_1 to the lower arm of the lever l. The upper end of the lever l carries the supporting shaft of the flanged roller *9*. The spring s_2 forces this shaft against a stop so that, in normal operation, the axis of roller *9* is virtually fixed. When the sound roller is being accelerated, the tension of the film between it and the leading sprocket will increase, the upper arm of the lever l will be pulled down from its stop, the slack in the bearings of the rod r will be taken up, and pressure of roller *6* on the film will be increased until the sound roller is up to speed, when the film tension will become normal and the shaft of roller *9* will again be pulled back against the stop. With this arrangement, the sound roller is brought up to speed in about four seconds.

Flanged reels may be used in reproducing, but in recording the film must be wound in a light-tight magazine. It is practically impossible to avoid a certain amount of rubbing of the film against the side walls by the time most of the film has passed into the magazine. Consequently, a greater torque must be applied to the take-up shaft when the magazine is nearly full than would be necessary for a flanged reel holding the same amount of film. If the take-up shaft were driven by a slipping clutch, the torque would be the same for the empty as for the full magazine. If the clutch were set so that it would turn the shaft of the full magazine without risk of failure, the film tension would be so high at the beginning as to expose the film to serious injury. This condition is greatly aggravated in going to 2000 instead of the usual 1000-ft lengths of film. In place of the friction clutch, a spring belt type of drive was, therefore, substituted. This drive was so designed that the troque delivered by it increases with the diameter of the film spiral up to a certain point, and from there on remains constant. The belts and pulleys are so proportioned that the spring material never becomes strained beyond the endurance limit. Danger of breakage is, therefore, small. To avoid serious trouble if there should be such breakage, two belts are used in parallel. The belts run in *V*-grooved fiber pulleys. The driving pulley is driven from the leading sprocket shaft through a pair of spur gears.

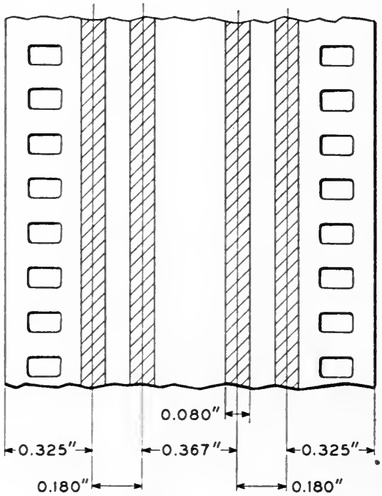

FIG. 2. Location of sound-tracks on 35-mm film strip.

The light-valves *LV*, shown above the sound roller, are held in exact position by brackets provided with suitable guide surfaces. They are clamped down with spring clips so that they can be readily replaced. All valves are assembled and adjusted on one fixture so as to render them completely interchangeable. No further adjustments need be made after they have been attached to the brackets. They are so located along the axis of the sound roller that the four sound-tracks are generated at the positions on the film shown in Fig. 2. The outer tracks are sufficiently far from the sprocket-holes to avoid sprocket-hole flutter resulting from processing variations around the sprocket-holes.

Fig. 3 is a skeleton side view of the frame. Above to the left is the sound roller with the damping roller to the right, carried by the same shaft. This damping roller consists of a casing having an annular channel carrying a liquid which is coupled to the casing by a porous partition. This roller is described in more detail in a separate paper.[1] Below is shown the sprocket shaft, carrying the leading sprocket at the left. Toward the right, the spiral gears through which the shaft is driven by the motor may be seen. The gear in the middle is one that meshes with another gear attached to the driving pulley of the spring belt drive for the take-up reel shaft.

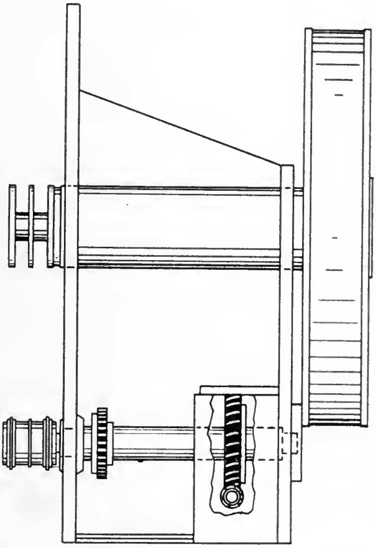

FIG. 3. Skeleton side view of film-propelling mechanism.

A 3000-cycle record was made with one of these machines and the frequency modulation in this record measured for us by Electrical Research Products, Inc., on one of their flutter meters. While the stereophonic records were made on acetate base, this particular record was made on a nitrate base to reduce the modulation caused by uneven film shrinkage. Measurements were made on a number of sections taken at random along the record. The results of these measurements are given in Table I.

TABLE I

Frequency of Flutter (Cps)	Observed Speed Variations (Per Cent)	Minimum Perceptible Speed Variations (Per Cent)
96	0.02–0.085	0.05
9	0.055–0.09	0.0045
1.2	0–0.038	0.0055
Drift	0–0.018	

The first column gives the frequencies of flutter, and the second, corresponding magnitudes in per cent. The upper and lower figures given in the second column for each frequency region represent the extreme values that were found in the entire set of measurements. Zero percentage, of course, means no more than that the flutter meter was not sensitive enough to indicate the flutter actually present. The value given for drift was said to be not in excess of that which normal unevenness of shrinkage could produce. The source of the flutter at the various frequencies is easily accounted for except that at 9 cycles. It was later reported that at least some, if not all, of the indicated flutter at this frequency was assignable to a fault in the particular meter used in these measurements. The maximum values of flutter are in excess of those which the ear can detect under the most favorable listening and frequency conditions on an *A*-*B* comparison test. These values, taken from an unpublished memorandum by W. A. MacNair, are given in the third column of the table. While these values are considerably lower than the higher figures of column *2*, it is known that, for the complex tones ordinarily recorded when reproduced in a moderately dead room, the values of column 3 can be exceeded without detection.

RECORDING OPTICAL SYSTEM

Fig. 4 shows the optical system used with each one of the four light-valves on the recording machine. The light-valve itself is described in detail in another paper.[2] *A* and *B* are two views in sections passing through the axis of the valve, the former at right angles and the latter parallel to the axis of the sound roller. The filament of an exciter lamp is brought to a focus by means of a single-element condenser on the ribbons of the light-valve. In the bottom pole-piece of the light-valve is mounted a commercial ten-power apochromatic microscope objective having a numerical aperture of 0.3. With this, the inner edges of the two light-valve ribbons are imaged on the film, at a magnification of 10:1. L_2 is a cylindrical lens which forms a reduced image of the edges of a fixed slit S in the film plane. The slit and the cylindrical lens together define the height of the image in the direction of film travel, while the microscope objective and the slit formed by the light-valve ribbons define the length of the image. The lens L_2 consists of a round circular rod provided with a stop limiting the image angle to about 20 degrees. The clearance between this lens and the film surface is about $^1/_{32}$ inch. The cylindrical lenses for all four channels are mounted in a single block, which can be removed from the machine as a unit. This block has embossed ridges on its undersurface, running parallel to the film travel, which prevent accidental contact between the film and the lens surfaces. In this arrangement, no trouble has been experienced from particles

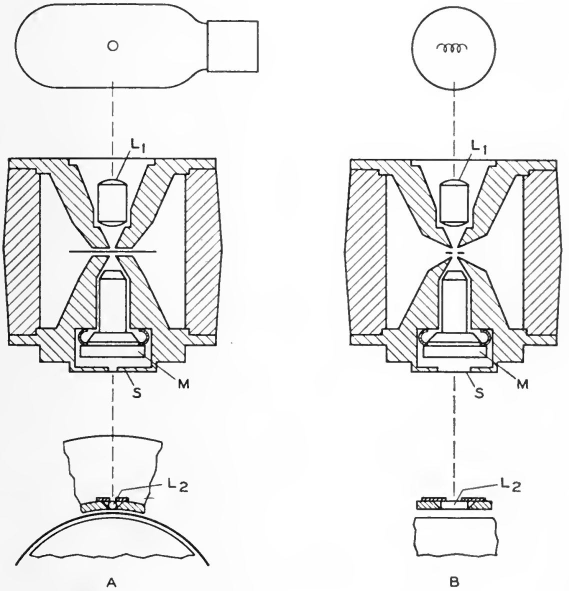

FIG. 4. Recording optical system.

becoming attached to the glass surfaces of sufficient size to impair image quality.

The slit *S* acts as a stop on the system, as seen in view *A*. In this plane, therefore, the aperture, and consequently the image aberration of the condensing lens, is small. Hence, in the narrow direction, the image of the lamp coil is sharply defined at the valve ribbons. In the plane of Fig. 4(*B*), the optical system operates at the full aperture of the microscope objective, and the single-piece condenser has, therefore, a relatively large amount of spherical aberration. Here, this is no disadvantage since a lamp may be chosen having a coil length such that the image formed by the lens has a central uniformly bright portion long enough for amply covering the operating area at the light-valve ribbons. At the same time, the aberration prevents sharp focusing of the individual turns of the lamp coil, which would result in a recording image of uneven brightness along its length.

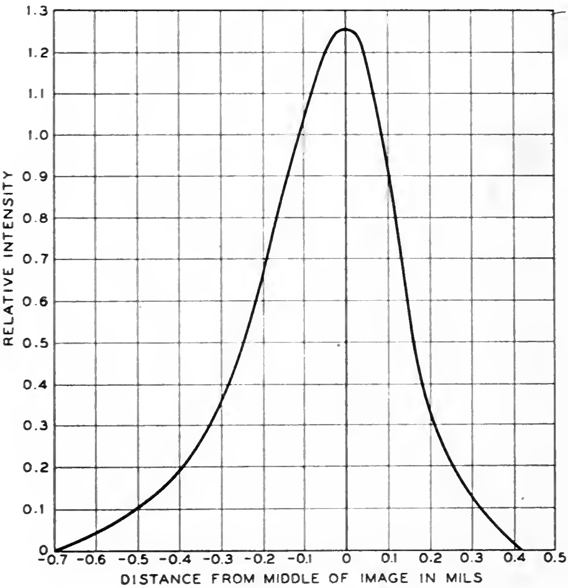

FIG. 5. Light distribution in scanning image of microdensitometer.

An exact determination of the frequency characteristic of a sound record free from effects introduced by the optics of the measuring system presents some difficulty. Such a characteristic could be obtained theoretically by scanning the record with a line of light of infinitesimal width and observing the transmitted light. While this procedure is impracticable, a pretty good estimate of what the results of such measurements would be can be gained from scanning data obtained with a narrow, but finite, line image in which the distribution of the light is known. Such measurements were carried out on records made at a number of discrete frequencies in the range from 1000 to 16,000 cycles with the light-valve modulation maintained at 50 per cent. The light distribution in the scanning image used in these measurements is shown in Fig. 5. The nominal width of the image was between 0.25 and 0.3 mil. This curve was obtained from measurements on the variation of the light passing over a knife-edge, set and held accurately parallel while it was moved in measured steps across the image. The fact that the curve is unsymmetrical is probably due to some imperfections in alignment. The frequency records were scanned very slowly with this image, while the transmitted light was measured with a microdensitometer. The amplitudes of the microdensitometer records for the various frequencies were measured. The value so obtained, when translated into decibel losses, are plotted as *A* of Fig. 6. Next, the scanning *vs.* frequency characteristics of an image having the light distribution shown in Fig. 5, when used to scan sine-wave records of constant amplitude,

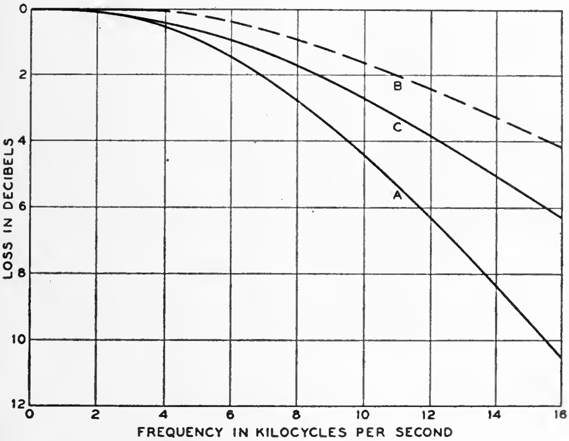

FIG. 6. Relative modulation in negative sound record.

were computed. The values so obtained are shown by the dashed curve B in Fig. 6. The ordinates of this curve were then subtracted from the corresponding ordinates of curve A. From these values, C was plotted. This curve shows a loss of 6 db at 16,000 cycles, but it must be considered in the light of the method whereby it was obtained. It does not represent the true state of affairs accurately. The correction for the image was made on the assumption that sine-wave records were scanned—which is here not the case, certainly not at the higher frequencies. Prints of these sound records, ideally made with proper exposure and processing, should show less high-frequency loss than the negatives which were here explored. Practically, the high-frequency losses are likely to be higher as the result of failure in meeting the ideal conditions. While thus there remains some doubt regarding the frequency characteristic of the records as made for reproduction in the stereophonic system, it is likely that curve C does give at least the order of magnitude of the part of the total overall transition loss of the recording-reproducing system that is attributable to the photographic processes involved in making the records.

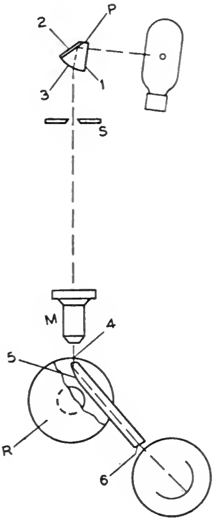

FIG. 7. Reproducing optical system.

THE REPRODUCING OPTICAL SYSTEM

The objective in the planning of the reproducing optical system was to get a large quantity of light from an exciter lamp into a reasonably small scanning line, so that a high signal current might be generated in the photoelectric cell. The optical arrangement had to be such that the light transmitted by the film could be brought conveniently from each record to a photoelectric cell.

Fig. 7 shows the arrangement of the optical system used for each one of the four channels. The lamp coil is parallel to the axis of the sound roller. M is a commercial ten-power achromatic microscope objective with a numerical aperture of 0.3. It forms an image on the film of the illuminated slit S. This slit is adjusted to give an image normally equal to 0.5 × 85 mils. Actually, because of lens aberrations, the width is greater, but no measurements have been made on the light distribution within the image. The slit S has the length of about 0.85 inch. The condensing system between the lamp and this slit must provide uniform illumination of this slit and it must fill completely the microscope objective if the advantage of the large aperture of the latter is not to be sacrificed. The condenser used is a one-piece combination prism, lens, and reflector shown at *P*. All its surfaces are either plane or cylindrical: *1* is a plane surface approximately normal to the center line of the light beam; *2* is a cylindrical surface with its center line of curvature in a plane that is perpendicular to the roller axis and passes through the center line of the light beam; *3* is also a cylindrical surface with its center line of curvature parallel to the roller axis and lying between the center line of the objective and the lamp. The prism surface *2* reflects the light internally through the slit *S* and brings it to a focus in the direction of the roller axis at the objective *M*. Light from the different coils of the lamp is, therefore, completely diffused along the length of the slit and the slit is otherwise illuminated with great uniformity along its length. The surface *3* forms an image of the lamp coil on the slit *S* in the transverse direction. The illumination angle is small—only one-tenth of that which obtains at the image on the film. Spherical aberration is, therefore, not a serious problem.

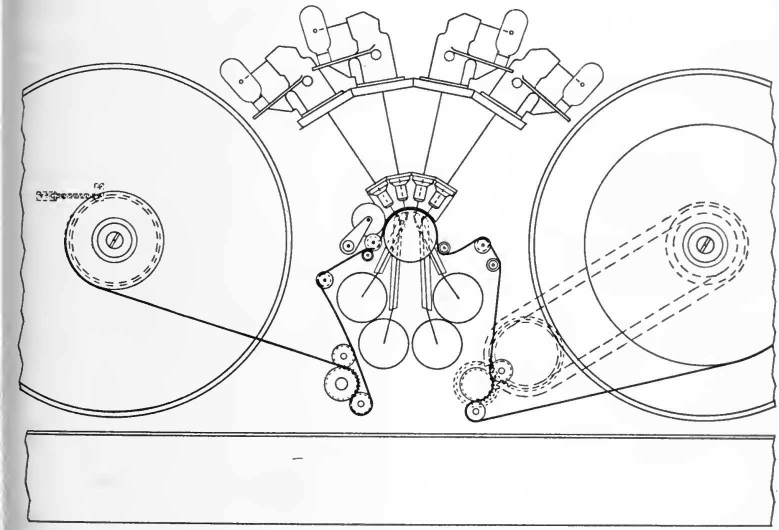

FIG. 8. Diagrammatic view of reproducing machine.

After the light has traversed the film, it enters a glass rod through which the light is deflected around a roller shaft to the photoelectric cell. The plane surface through which light enters the rod is approximately perpendicular to the light-beam. After it has passed this surface, the light is reflected internally by the cylindrical surface *4*. The curvature and orientation of this surface are such that the light is reflected along the axis of the rod with minimum spread. The surface *6* is cut at a slight angle to the rod so as to refract the beam to the middle of the photoelectric cell cathode. This rod serves not only to lead the light from the film to the photoelectric cell, but it also acts as a diffuser so that light coming from various parts of the line image on the record is spread over approximately the same surface area of the cathode. The introduction of wave-form distortion by any non-uniformity of sensitivity of the cathode surface is thus avoided.

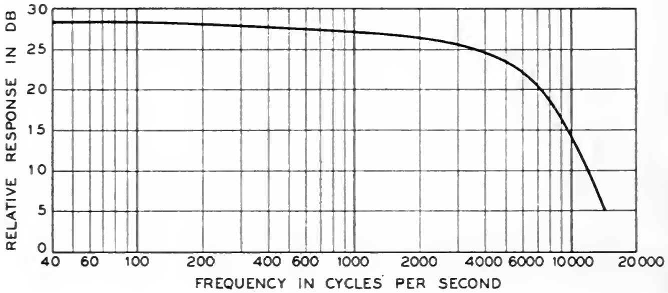

FIG. 9. Insertion loss of recording-reproducing system.

The arrangement of the various optical parts on the machine when set up for reproducing is shown in Fig. 8, which shows also the gear and pulley arrangement of the spring belt drive. The condensing prism and lamp for each channel are mounted in one casing, which is fastened to a bracket that holds a light-value in recording.

No measurements have been made on the scanning efficiency as a function of frequency of this optical system. The variation of the insertion loss of the recording-reproducing system is shown in Fig. 9. In this loss are included those due to scanning in recording and reproducing, processing and printing, and photoelectric cell and photoelectric cell amplifier losses.

In conclusion, we wish to point out that all records and prints used in the measurements here reported, as well as those used in the demonstration of orchestral music, were made with white light and the surfaces of none of the lenses were coated for reduction in reflectivity.

REFERENCES

[1] WENTE, E. C., AND MÜLLER, A. H.: "Internally Damped Rollers," *J. Soc. Mot. Pict. Eng.*, **XXXVII,** (Oct., 1941), p. 406.

[2] WENTE, E. C., AND BIDDULPH, R.: "Light-Value for the Stereophonic Sound-Film System," *J. Soc. Mot. Pict. Eng.*, **XXXVII,** (Oct., 1941), p. 397.

THE STEREOPHONIC SOUND-FILM SYSTEM—PRE- AND POST-EQUALIZATION OF COMPANDOR SYSTEMS*

JOHN C. STEINBERG**

Summary.—*In order best to fit the volume range of the program material into the volume range available in sound-film, it is generally advantageous to pre-equalize the program material before recording, and to compensate for the equalization by means of a complementary post-equalizer on reproduction. The type and amount of pre-equalization depends upon the properties of hearing and on the characteristics of the program material and the film noise. This paper discusses the relations between these quantities for systems using compandors, where the film noise varies up and down in level as the compandor gains vary. Ideally, different types of pre-equalization are needed for different types of program material, and a compromise must be made if a single type is to be used. The considerations leading to the choice of the pre-equalization used in the stereophonic recording and reproducing system are discussed.*

The purpose of introducing pre- and post-equalizers and compandors into a recording and reproducing system is to bring about a better fit than would be obtained otherwise, of the intensity range of the program material into the intensity range afforded by the system. The form that such elements take and the good that is accomplished by their use depend upon the type of program material, the properties of hearing, and the particular characteristics of the system. It is the purpose of this paper to discuss the ways in which these factors enter into the problem, which are general in character, and then to describe the pre- and post-equalization used in the stereophonic sound-film system (*SSFS*).

It will serve our present purpose to take as our program material the sounds produced in a concert hall by a large symphony orchestra, and to take as our system one involving sound-film recording and reproduction. The intensity range afforded by the sound-film is determined by the difference between the intensity levels which cause objectionable overloading in recording, and those intensity levels which

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received May 1, 1941.

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

are just audible in the background of film noise. The maximum orchestral intensity levels can be recorded so as to just avoid overloading, and then, on reproduction, they can be amplified to their original maximum values. Under these conditions, the intensity range of the reproduced sounds is limited by the reproduced film noise, and the amount that the film noise must be attenuated in order that it be just inaudible in the presence of the background of audience noise is a measure of the amount of the original intensity range that has been lost in reproduction. The reduction in the reproduced film noise that is afforded by the use of equalizers and compandors gives a measure of the increase in the intensity range of the recording and reproducing system due to the use of such elements.

From measurements reported by Sivian, Dunn, and White,[1] information is available on the maximum intensity levels produced by a large orchestra, and by individual instruments. The peak amplitudes occurring in alternate $^1/_8$-second intervals were measured for the whole spectrum, and for various frequency bands throughout the spectrum. In the case of the orchestra, the measurements were made at a point near the conductor's stand, on four different musical selections. The results may be expressed in the form of the instantaneous peak intensity levels (referred to hereafter as peak intensity levels) which are exceeded in given percentages of the intervals. The total or whole spectrum peak intensity levels that were exceeded in only one per cent of the intervals for the different selections are as follows: 109, 112, 108, and 111 db from 10^{-16} watts per sq-cm. A study of the data indicated that for a given selection the one per cent values were rarely exceeded by more than 2 db. It seems reasonable, therefore, to take 115 db as representative of the maximum peak intensity levels for an orchestra. Measurements made on the Philadelphia Orchestra at the Academy of Music by somewhat different methods indicate similar values.

Fig. 1 shows the peak intensity per cycle levels which are exceeded in one per cent of the intervals, for a whole spectrum peak intensity level of 115 db. The peak intensities per cycle were obtained by dividing the peak intensities measured in the different frequency bands by the band width in cycles.

For good recording and processing conditions, the total level of film noise in a 10,000-cycle band may be taken as 53 db below the peak sine wave level at which overloading occurs in recording. The noise intensity may be considered as distributed uniformly throughout the frequency band. Hence, the intensity per cycle level of the noise is 93 db below the peak sinusoidal intensity level at which overloading takes place.

Measurements have been made in which the maximum peak intensity levels of the orchestra were compared with sine-wave peak intensity levels when both were at the overload point. The results indicated that the peak intensity levels of the two classes of signals were nearly the same when overloading occurred, with perhaps a tendency for the maximum peaks of the orchestra to be slightly higher than the sine-wave peaks. If these levels be taken as equal, which is the conservative procedure for our present purpose, the film noise will be reproduced at an intensity per cycle level of 22 db above 10^{-16} watts per sq-cm, when the system is set to record and reproduce peak intensity levels of 115 db.

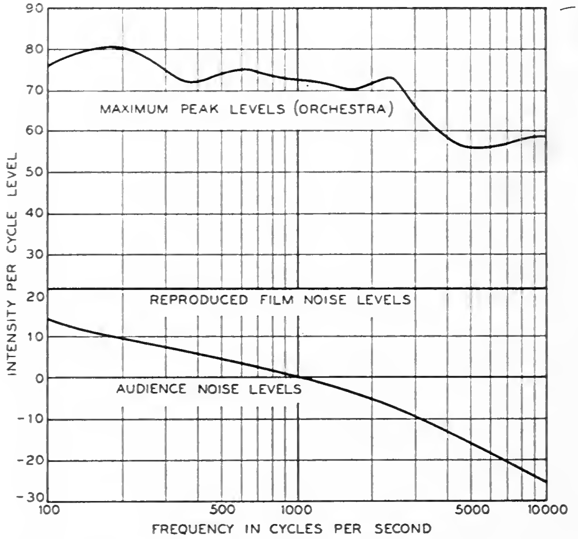

FIG. 1. Spectrograms of audience and film noise and orchestral sounds.

Measurements made with the sound level meter on the audience noise at the Philadelphia Academy of Music, and also at Constitution Hall in Washington, when filled with audiences, indicate minimum sound levels of 33 db, when measured with meters employing the so-called 40 db weighting. From auxiliary measurements, a spectrum of audience noise corresponding to a sound level of 33 db was obtained, and is shown in Fig. 1 along with the spectrum of the reproduced film noise.

The three curves of Fig. 1 represent quantities which must be considered in attempts to increase the intensity range of the recording and reproducing system. In order to provide the original intensity range, the system must be capable of reproducing the maximum orchestral levels, and the reproduced film noise must be masked by the audience noise, or by the sounds of the orchestra. The amount that the film noise must be reduced in order that it may be masked by the audience noise is best shown by the curves of Fig. 2.

In this figure, the film noise and audience noise are plotted in terms of the intensity level per critical frequency band. In sensing a random type of noise, such as film noise, the ear tends to integrate, over a small frequency interval, the intensity carried by each cycle of the noise.[2] This interval, called the critical frequency band, depends upon frequency, and has the property that a pure tone having the mid-band frequency and an intensity level equal to that of the noise in the critical band, will be just audible in the presence of the noise.

The lower curve in Fig. 2 shows the intensity levels of pure tones at the threshold of hearing for people having very good hearing and listening in a quiet place. The curves for film and audience noise show the threshold intensity levels for pure tones when heard in the presence of the respective noises. The audience noise and pure tone threshold curves set the lower limit of the original intensity range in the concert hall, and, to preserve this limit in reproduction, the film noise levels must be reduced, at least to the levels indicated by these two curves, the audience noise curve setting the limit for those frequencies at which it lies above the threshold curve. The required reduction is shown by the solid curve of Fig. 3.

As previously noted, the pure tone threshold curve of Fig. 2 indicates the threshold values for people having very good hearing. The results of the World's Fair hearing tests[3] indicate that less than five per cent of the people are able to hear such tones. If threshold levels which can be heard by at least 50 per cent of the people are used in obtaining the required film noise reduction, the dashed curve in Fig. 3 results.

The figure shows that a film noise reduction of some 42 db at frequencies near 7000 cycles is needed if the recording and reproducing system is to provide an intensity range equal to the original range in the concert hall. It should be noted that this amount of reduction is in the nature of a maximum. It is the reduction required for the reproduced film noise to be inaudible to a listener having very good hearing when located at a point near the conductor's stand in a concert hall similar to the original hall, and when the recording and reproducing system is set to reproduce the maximum peaks of the orchestra without noticeable overloading, using, in the process sound-film which has a peak signal to noise ratio of 53 db. For a listener located in the seating area of the concert hall, the reproduced film noise might be 5 to 10 db below audibility under these conditions.

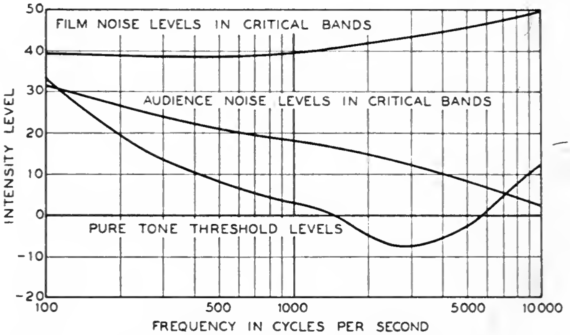

FIG. 2. Levels of film and audience noise in critical bands.

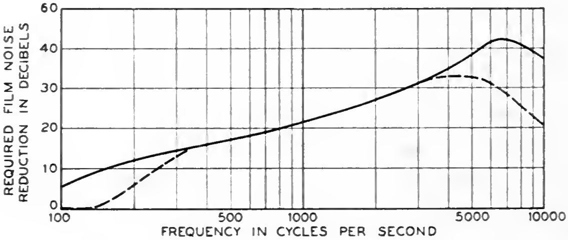

FIG. 3. Required film noise reduction.

For a given film technic, there are three ways in which the film noise may be reduced: (*1*) by the use of pre- and post-equalizers, (*2*) by the use of compandors, and (*3*) by the use of appropriate combinations of *1* and *2*.

Pre- and post-equalization makes use of the fact that the maximum peak intensity levels for the higher frequencies are generally smaller than the peak levels for the lower frequencies, as may be seen from Fig. 1. In reducing the noise by this method, the high frequencies are recorded at greater than normal levels, relative to the low frequencies, by using a pre-equalizer, and then on reproduction they are reduced back to their normal levels by means of a complementary post-equalizer. The penalty that is paid for reducing noise by this method is in the reduced capacity of the system for recording and reproducing high-frequency peak intensity levels. Although this does not limit the usefulness of the system for orchestral sounds, it may present difficulties for other types of sounds.

In order to show the amount of noise reduction that may be accomplished by the use of pre-equalizers, two different types will be considered, which will be designated as pre-equalizers No. *1* and No. *2*.

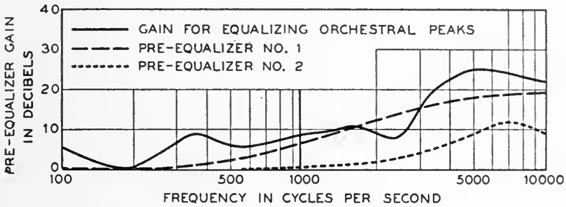

FIG. 4. Pre-equalizer characteristics.

With pre-equalizer No. *1*, the insertion gain is such as to produce at the recorder, equal maximum peak levels for the different frequencies in orchestral sounds. The solid curve in Fig. 4 shows the gain that is required to equalize the orchestral peak levels indicated in Fig. 1, and the dashed curve shows the gain characteristic of pre-equalizer No. *1*, which approximately meets this objective. The dotted curve shows the gain characteristic of pre-equalizer No. *2*, in which the increase in gain is confined principally to the frequency regions above 3000 cycles.

The use of such pre-equalizers produces an increase at the recorder, in the maximum whole spectrum peak levels of the orchestra. The increase may be obtained by integrating, over the frequency range, the peak intensity per cycle spectrum of the orchestra before and after pre-equalization, and taking the difference between the integrated values. The appropriate spectra may be obtained from the peak intensity per cycle level curve of Fig. 1 and the equalizer gain characteristics of Fig. 4. The calculations indicate that the whole spectrum peak levels for pre-equalizer No. *1* are 11.5 db higher than the corresponding levels for the unequalized orchestra. The corresponding figure for pre-equalizer No. *2* is 3.0 db.

If the same peak levels in different parts of the frequency range were equally effective in producing noticeable overloading, the whole spectrum peak levels should be a criterion of overloading. Hence, in order to avoid overloading, it would be necessary to reduce the gain ahead of the recorder by 11.5 and 3.0 db, respectively, when pre-equalizers Nos. *1* and *2* are used.

It is believed, however, that high-frequency peaks are not as effective as low-frequency peaks in producing noticeable overloading because of their relatively shorter durations, and also because of the greater tendency of the modulation products of high-frequency peaks to fall outside the audible band. In sensing sounds, the ear integrates peak amplitudes over a time interval of some $^1/_8$ to $^1/_4$ of a second. To determine the auditory characteristics of peak levels, it would be more appropriate to deal with the intensity levels integrated over $^1/_8$-second intervals than with the peak intensity levels occurring in such intervals. These two quantities differ by a peak factor which is larger for the high-frequency peaks than for the low-frequency ones. Unfortunately, quantitative measurements of such peak factors for orchestral sounds are not available, and it has been necessary to estimate, from rather fragmentary data, a set of weight factors for indicating the relative overloading effects of peak levels at different frequencies. The estimated values which are shown in Table I, should be subtracted from the peak intensity per cycle level curve of Fig. 1. The curve thus obtained is used for calculating the whole spectrum peak levels in the manner indicated above.

TABLE I

Factors for Weighting the Peak Levels of Orchestral Sounds

Frequency	100	200	500	850	1200	1800	3000	5000	10,000
Weight factor db	0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0

The calculations employing the weight factors indicate that, in order to avoid overloading, the gain ahead of the recorder must be reduced by 8.5 db for pre-equalizer No. *1*, and by 1.5 db for pre-equalizer No. *2*. It is believed that these values are more nearly correct than the corresponding values of 11.5 and 3.0 db calculated from the unweighted peak levels, and they will be used in the subsequent discussion.

When the sounds are reproduced, the post-equalizer introduces a loss equal to the gain introduced by the pre-equalizer, and thus reduces the reproduced film noise levels. Also, since the gain ahead of the recorder was reduced in order to avoid overloading, the gain following the reproducer must be increased by a corresponding amount in order to reproduce the sounds at their original levels. This increases the reproduced film noise level, and the net change in level is given by the difference between the post-equalizer loss and the overloading gain adjustment.

The effects achieved by the use of the equalizers may be seen from the curves of Fig. 5. The solid curve, which was replotted from Fig. 3, shows the film noise reduction that is required when a pre- and post-equalizer is not used, in order that the original intensity range in the concert hall be reproduced. The dashed curve shows the reduction that is required when pre-equalizer No. *1* is used. This pre-equalizer represents the maximum amount of pre-equalization that may be used advantageously. Any larger amount will increase the low-frequency noise levels without further affecting the high-frequency levels. If a smaller amount of pre-equalization were used, low-frequency noise levels would be diminished, but the intermediate and high-frequency levels would be increased as indicated by the dotted curve for pre-equalizer No. *2*. In either case, the high-frequency noise levels have been decreased by some 10 db only, and a further reduction of some 30 db is needed.

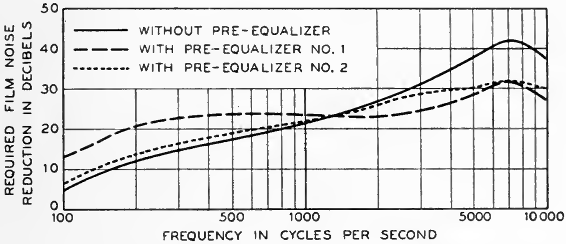

FIG. 5. Required reduction for equalized film noise.

A further reduction in the reproduced film noise may be achieved by the use of compandors. Such devices compress the signals before recording, and then expand them to their original values on reproduction. In the case of a 30-db compressor, for example, this is done by providing a gain increase of 30 db ahead of the recorder. During silent periods, this gain remains unchanged at the value of 30 db. As the signals increase in level, the gain decreases in accordance with the increase in signal level and becomes zero for the maximum signal levels. On reproduction, a 30-db loss is provided by the expandor during silent periods. As the signal levels increase, the loss diminishes in a manner which is complementary to the gain changes of the compressor and becomes zero for the maximum reproduced signal levels. Hence, during silent periods the reproduced film noise levels are 30 db below the values they would have if the compandor were not used. They increase and approach the latter values as the signal levels increase and approach their maxima. If during this period the film noise were masked by the signals, and if during the silent periods it were masked by the audience noise, then the recording and reproducing system would be capable of reproducing the original intensity range in the concert hall.

It will be recalled (Fig. 3) that a film noise reduction of 42 db is needed in order that it be masked by the audience noise. Hence, a 42-db compandor would be required if the film noise were to be inaudible during silent periods. Such a compandor is practicable and could be used, but generally it would be advantageous to achieve part of the reduction by the use of pre- and post-equalizers. The reduction achieved by their use is effective not only during silent intervals but during the intervals that the noise levels change in accordance with the signal levels. By the proper choice of equalizer characteristics, the noise may be more effectively masked by the signals than would be the case if the noise reduction were accomplished by the compandor alone. Also, in the case of the SSFS it was desired to combine a 15-db enhancement feature with the expandor, so that the reproduced signal levels could be increased by 10 or diminished by 5 db. This would require a 57-db expandor, which becomes somewhat impracticable. It was decided, therefore, to use an equalizer in combination with a 30-db compressor and a 45-db expandor. The pre- and post-equalizer No. *1*, which has been described, was chosen for this purpose. It provides a film noise reduction of 10 db (Fig. 5) and the combination affords a reduction of 40 db during silent intervals. The film noise levels thus obtained are shown on Fig. 6 in relation to the audience noise levels and pure tone threshold levels.

The reduction is sufficient to reduce the film noise below audibility during silent periods, and it remains now to investigate how effectively the film noise is masked by the signals during other than silent periods.

It may be noted in passing that equalizers may be combined with the compandors in such a way that the gains in different parts of the frequency range depend upon the signal levels in those parts. Such variable-equalizer compandors would probably be the most ideal way of fitting the program material into the intensity range afforded by sound-film, particularly for widely different program materials. Their use, however, presents a number of practical problems which seemed to outweigh their advantages for the present application.

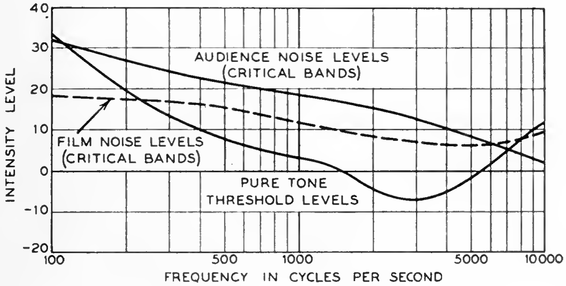

FIG. 6. Reproduced film noise during silent periods.

Many types of compandors have been used, involving different relationships between the change of compressor gain and signal level. In the type used in the SSFS, the compressor gain increases 1 db for each 1-db decrease of signal level in the range of signal levels beginning a few db below the maximum levels and extending to levels 30 db lower. For still lower signal levels, the compressor gain remains fixed at the 30-db value. The loss provided by the expandor changes in a similar fashion on reproduction. These changes are accomplished by means of a pilot or control current which is modulated by the signal levels. The pilot current operates the compressor on recording, and is also recorded. On reproduction, the reproduced pilot current operates the expandor. The considerations leading to the choice of this type of compandor for the SSFS are discussed in the paper by Dr. Fletcher.* One of the principal reasons for the

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* In this issue of the JOURNAL.

choice was that this type provides the greatest possible margin between signal levels and noise levels during other than silent periods.

The performance of the compandor is shown by the curves of Fig. 7. The upper solid curve shows how the output level of the compressor (*i. e.*, recorder input level) increases as the signal levels increase, then flattens off and finally increases again until the compressor (and also the recorder) overload level of 115 db is reached. The lower solid curve shows the reduction in the level of the reproduced film noise due to the complementary action of the expandor. The input signal level to the compressor is shown as equal to the acoustic peak intensity level input to the system provided a pre-equalizer is not used. To obtain the acoustic level when a pre-equalizer is inserted ahead of the compressor, the signal level shown in Fig. 7 must be corrected by the gain changes caused by its insertion.

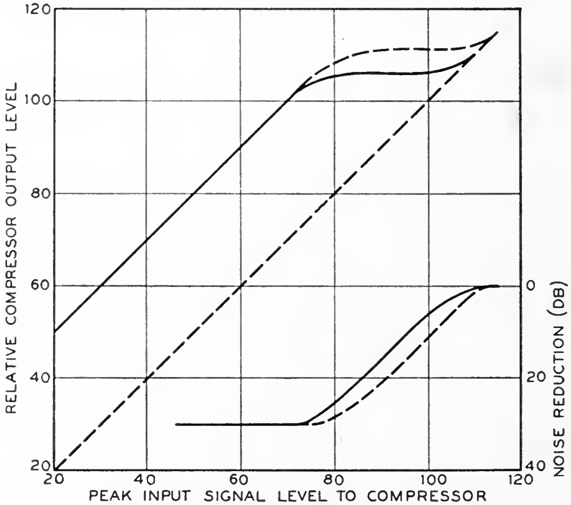

FIG. 7. Noise reduction afforded by compandor.

The control current operating the compressor must be set such that the output level will flatten off before overloading occurs. If the compressor acts infinitely fast, and if the compressed signals have no more tendency to overload than the uncompressed ones, the level for flattening off should be 115 db. In practice, it was found necessary to flatten off the compressor output at a level of 106 db, as shown by the solid curve of Fig. 7. When the signal levels reaching the compressor were delayed some two or three milliseconds with respect to those modulating the control current, so as to give the compressor time to act, it was found that the flattening off level could be raised 5 db. As shown by the dotted curves of Fig. 7, this reduces the reproduced film noise an additional 5 db during the period when the compressor acts. The records for the most part, however, were made in accordance with the solid curve of Fig. 7, as the technic for introducing delay was not well worked out at the time of recording.

The combination of equalizers and compandor affords sufficient film noise reduction that it will be inaudible during all silent periods and during all periods when the full orchestra is playing. The periods when the noise is most likely to be audible are when either low or high-frequency tones only are being produced by single instruments or small groups of similar instruments, as happens rather frequently in symphonic programs. To obtain a conservative estimate of the audibility of the noise under such conditions, the levels of the reproduced film noise have been determined when the system is called upon to record and reproduce either a 200 or a 4000-cycle pure tone. From the levels of the reproduced film noise, it was possible to determine, from the pure tone masking curves, the levels of the noise above threshold in the presence of the reproduced pure tones.

The curves in Fig. 8(*A*) show the levels above threshold of the reproduced film noise as heard in the presence of the reproduced pure tones of 4000 and 200 cycles, for the combination of equalizer No. *1* and the 30-db compandor. The tone levels are shown by the x-axis, and represent either the input or the reproduced tone levels, since they are equal. The frequency range of the noise that is audible in the presence of the 200-cycle tone extends from 5000 to 10,000 cycles. The range that is audible in the presence of the 4000-cycle tone extends from 100 to 3000 cycles. This noise, as it rises and falls with fluctuating tone levels, produces the so-called "hush-hush," which may be either low or high-frequency in character. As suggested by the dotted curves of Fig. 7, the hush-hush may be reduced 5 db below the values shown, by delaying the signals two or three milliseconds at the compressor input.

Fig. 8(*B*) shows similar curves for the equalizer No. *2* when combined with the 30-db compandor. They suggest that equalizer No. *2* would have been a better choice than No. *1*, as less low-frequency hush-hush is produced, *i. e.*, the hush-hush of the noise when heard in the presence of the high-frequency masking tone.

In an earlier paragraph it was noted that the use of a compandor alone, to accomplish the noise reduction required for silent periods, would not generally result in the most effective masking of the noise by the signal. This is illustrated by the curves of Fig. 8(*C*), which obtain for a 40-db compandor without an equalizer. Although such a compandor reduces the film noise to inaudibility during silent periods, the high-frequency hush-hush is considerably greater than obtained with an appropriate equalizer.

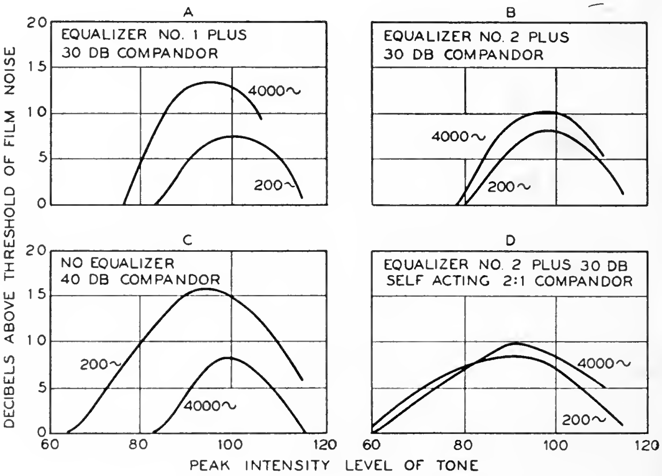

FIG. 8. Hush-hush effect from compandor action.

In the paper by Fletcher, it was pointed out that a self-acting compandor would not give as good a discrimination against noise as one of the type described here, involving the use of a pilot channel. The curves of Fig. 8(*D*) show the noise levels for a 30-db 2:1 self-acting compandor when combined with equalizer No. *2*. In this type of compandor, the compressor gain changes through a 30-db range at the rate of 1 db per 2-db change in signal level. Although the two types are equally satisfactory during silent periods, the self-acting type results in hush-hush over a wider range of signal levels than does the type used in the SSFS.

The foregoing discussion has been predicated on such a gain setting of the SSFS as to afford unity reproduction, *i. e.*, reproduced intensity levels equal to the original levels. The enhancement feature provides for a gain increase of 10 db above unity. Since the gain increase takes place on reproduction, it will cause a corresponding increase in the level of the reproduced film noise. Reference to Fig. 6 will show that the film noise during silent intervals is just about at the threshold, so that any increase in gain during these periods will result in audible noise. Gain increases made while the full orchestra is playing will not result in audible noise, as the full orchestra provides sufficient masking. When single instruments play at levels below the operating level of the compressor, *i. e.*, 60 to 70 db, a gain increase raises the film noise from the level which it has during silent intervals. Fig. 6 shows that at this level, the film noise below 3000 cycles is some 7 db below the audience noise. Hence, if the instruments are producing high-frequency tones, the gain may be increased 7 db without the noise becoming audible. When low tones are produced, however, a gain increase would produce audible high-frequency noise, as low-frequency tones at these levels would not mask the high-frequency noise. When single instruments play at levels high enough to operate the compressor, the increase in noise levels caused by a gain increase correspond, in the worst cases, to those shown in Fig. 8(*a*), as it is unlikely that any single instrument producing a relatively pure tone would ever produce a level within 10 db of the overload level of the compressor. Many instruments cover a wide enough frequency range to mask the film noise for any gain increase up to 10 db. Hence, the system makes some, although not complete, provision for inaudible noise levels during periods when the reproduced sounds are enhanced by gain increases.

REFERENCES

[1] SIVIAN, L. J., DUNN, H. K., AND WHITE, S. D.: "Absolute Amplitudes and Spectra of Certain Musical Instruments and Orchestras," *J. Acoust. Soc. Amer.*, II (Jan., 1931), p. 330.

[2] FLETCHER, H.: "Auditory Patterns," *Rev. Modern Phys.* (Jan., 1940), Fig. 16.

[3] STEINBERG, J. C., MONTGOMERY, H. C., AND GARDNER, M. B.: "Results of World's Fair Hearing Tests," *Bell Syst. Tech. J.*, **19** (Oct., 1940), p. 533 (Fig. 8).

ELECTRICAL EQUIPMENT FOR THE STEREOPHONIC SOUND-FILM SYSTEM*

W. B. SNOW AND A. R. SOFFEL**

Summary.—*An electrical system is described which permits the use of sound-film with its limited signal-to-noise ratio, as a recording medium for wide-range stereophonic reproduction of symphonic music. Noise reduction is accomplished both by pre-equalization, rising to 18 db above 8000 cycles, and by automatic signal compression and expansion of 30 db.*

To secure maximum suppression of noise and freedom from distortion, a pilot-operated, flat-top compandor system was selected. In each channel low-level signals are recorded on a separate track with constant gain 30 db above normal, which places them above the film noise. Higher-level signals cause automatic gain reductions and are recorded at substantially full modulation. These signals vary the intensity of a pilot tone, which in turn controls the compressor gain. There is a pilot frequency for each of the three channels, and the three are combined and recorded together on the fourth film track. During reproduction they are separated by filters, and operate expandors which restore the signals to their original forms but reduce the noise to inaudible levels.

The compressor and expandor gains are made proportional to pilot level in db, and the expandor range over which this relation holds is 45 db. Therefore a 15-db variation in average pilot level during reproduction causes a corresponding average level change but no distortion. This is used to allow expansion of the original signal intensity range during recording or re-recording by simple gain controls in the pilot circuits.

The paper describes the apparatus and circuits developed to accomplish these results, and discusses the frequency, load, distortion, noise, and dynamic characteristics of both constant and variable-gain elements. Also included are considerations of microphone and loud speaker arrangement and equalization to secure high fidelity of reproduction.

The general requirements for performance of the stereophonic sound-film system (SSFS) and the mode of operation of its principal parts have been described in other papers of this series,[1, 2, 3] and we shall attempt a minimum of repetition. This paper will deal with the actual apparatus used in making and playing the records and the characteristics of the parts and the system. Therefore, only a brief

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received May 26, 1941.

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review of the material from the other papers as it affects the electrical system will be given.

In order that the system may reproduce all sounds without deterioration of quality, the aim in its design has been to reproduce the entire range of frequencies and intensities to which a person of unimpaired hearing is sensitive under conditions existing in quiet auditoriums. This leads to the requirement that the complete system have an overall frequency response characteristic that is essentially uniform from 40 to 15,000 cycles per second. The acoustic output of the system should allow maximum sine-wave intensity levels of +120,* yet any noise generated within the system must be low enough so as not to be heard at any time. For the quietest auditoriums and auditors with acute hearing this means that the 60-cycle component of power hum which is often the most prominent must be at least 75 db below maximum signal, and the 120-cycle component should be at least 90 db below. Even if only average conditions are expected it is well to be strict on hum limits because standing-wave patterns can build up the steady hum in local spots where random noise of the same projected intensity would be inaudible. Thermal noise, usually generated in the microphone and first amplifier, will be about 95 db below the maximum signal with the more efficient of the microphones in use at present. In the critical bands around 4000 cycles this is somewhat above threshold in quiet rooms for acute hearing. The system should not add appreciably to this noise.

These requirements are determined by the characteristics of hearing rather than those of particular types of sounds or program. The acoustic intensity level ranges discussed are for single frequency signals, therefore, and should not be confused with the volume ranges of program material measured by volume indicator.

The electrical equipment, it will be recalled, is used in conjunction with a sound-film recorder and reproducer capable of handling three signal channels and one control channel. The ratio, in this recorder and reproducer, of maximum rms sine-wave to total band of film noise as measured by volume indicator is about 50 db. In order to meet the requirements set forth above, pre-equalization rising to 18 db above 8000 cycles and automatic compression and expansion of signals by 30 db are used to reduce the effects of this film noise. The effective level of the film noise is reduced approximately 10 db by pre-

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* Acoustic levels will be expressed in db from 10^{-16} watts per cm^2.

equalization and 30 db by compression for zero signal and it is thus about equal to the thermal noise during quiet periods. Provision is made for a manual manipulation of the expandor gain which allows sounds to be reproduced up to 10 db above and down to 5 db below unity ratio. These gain changes can be introduced either during recording or re-recording. In general, the frequency range and hum requirements are satisfied. Three-channel stereophonic reproduction, with quality comparable to the best direct transmission and reproduction, was accomplished with the use of this electrical system.

Fig. 1 is a block diagram of the recording system and Fig. 2 of the reproducing system. Of course, in the actual case there are three identical signal channels but to conserve space only one is shown completely. The three pilot tones are handled together in a fourth channel the details of which are given. The system consists of three main parts: the acoustic and fixed gain amplifying and equalizing portion; the compandor and recording and reproducing circuits; and the pilot system. We shall describe them in this order.

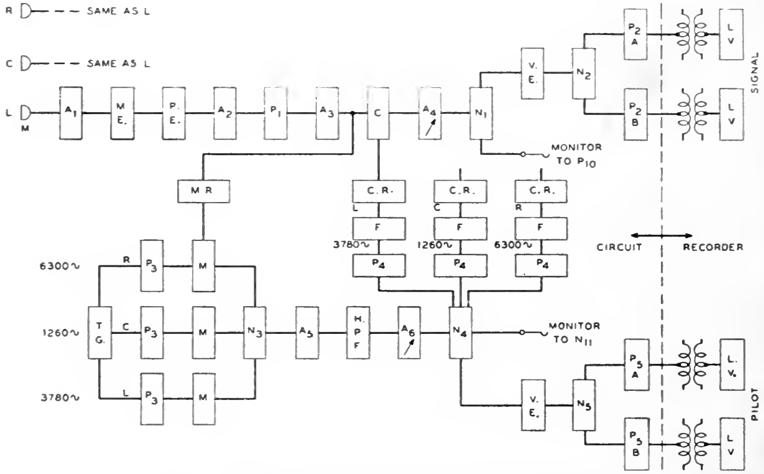

FIG. 1. Block diagram of the recording circuit.

ACOUSTIC AND AMPLIFYING SYSTEMS

To supply the large amplification necessary before the compressor and following the expandor the original amplifiers of the 1934 demonstrations were used with some rearrangement.[4] This includes amplifiers A_1 to A_3 of Fig. 1 and A_{12} to A_{14} of Fig. 2. The pair of power amplifiers A_{14} on each channel is rated at +52* maximum rms sine-wave, which is sufficient to produce the desired maximum acoustic intensity level +120. The total hum output is set by these amplifiers at 87 db below maximum, a close approach to the ideal. At higher frequencies the thermal noise of the microphone resistance sets the limit. All these amplifiers have satisfactory gain-frequency characteristics over the 40 to 15,000-cycle range desired.

The microphones *M* used for the records made in Philadelphia were the same ones used in the 1934 demonstration[5] which combine high efficiency with a smooth characteristic to 15,000 cycles. The cardioid *642A* microphone has since become available and has been used in Hollywood with excellent results. While the microphone characteristic was relatively smooth, it was not uniform and it was therefore necessary to equalize for it. In the direct transmission of 1934 the microphone equalization was included with the loud speaker equalization. However, when a record was to be made of the sound it was thought better to employ the separate microphone equalizer designated *ME*. Precisely, the equalizer is a constant-resistance network the loss-frequency characteristics of which is inverse to the field

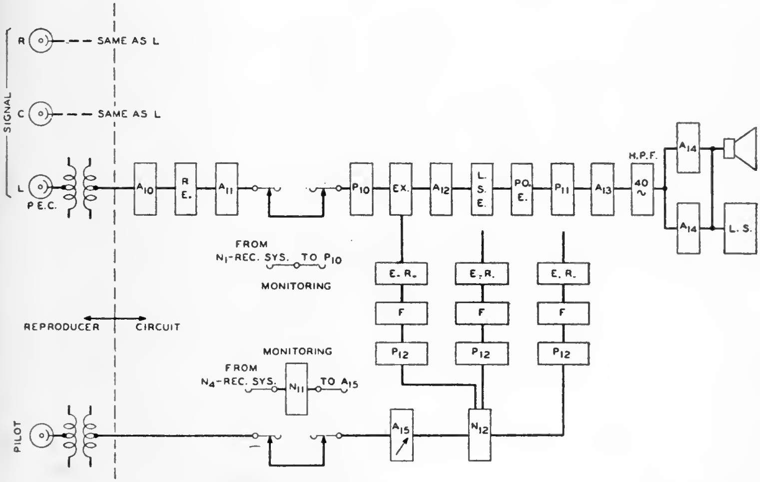

FIG. 2. Block diagram of the reproducing and monitoring circuit.

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* Throughout the paper electrical levels are expressed in db from 1 milliwatt.

calibration at normal incidence of the microphone. This calibration was chosen since the microphones were used close to the sound sources and received most of their sound directly and at approximately normal incidence. This procedure yields records which are a faithful copy of the sound and consequently can be reproduced on any flat loud speaker system.

Pre-equalization is thoroughly discussed in the other papers[1,3] of the series. The pre- and post-equaliers they describe are represented in our drawings as *Pr. E* and *Po. E.* P_1 is an attenuator which sets the recording gain.

The loud speaker equalizer designated *LSE* is also a constant-resistance network, with a loss-frequency characteristic inverse to the response characteristic of the loud speaker. These loud speakers are similar to those used in 1934.[5] The low-frequency units are identical, but for frequencies above 300 cycles standard W. E. *594A* units are used with a special coupling to the old 4 × 4 cell horns. This gives the advantages of the commercial unit combined with the 60 × 120-degree coverage of these horns. The horns are mounted behind the low-frequency ones far enough to reduce the delay between upper and lower frequency ranges to about 5 milliseconds.

The characteristic of the loud speaker was measured in a unique manner.* Two systems were set up, one consisting of an oscillator, an interrupter key, an attenuator, and amplifier, and the loud speaker. The other consisted of a microphone, an amplifier, and the film recorder used in the regular system. The loud speaker was placed at the front edge of the stage of the Academy of Music in Philadelphia and the microphone was hung out in the auditorium 18 feet from the loud speaker with its diaphragm parallel to the speaker mouth. Then, at a number of single frequencies, tones giving roughly equal outputs were abruptly started and stopped on the loud speaker. The output of the microphone was recorded on sound-film and the sound-tracks thus obtained were examined and measured under a microscope. On each spurt of tone there was recorded an initial few cycles of constant amplitude representing the direct wave from the loud speaker followed by transient waves and finally by a steady wave as determined by the acoustics of the hall. It was the first section that was measured and used for the calibration of the loud speaker. Since the electrical equipment, microphone, and recorder were of

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* Suggested by Mr. E. C. Wente.

known frequency characteristics the actual values of loud speaker output could be determined. This calibration was equivalent to a free space calibration since the effects of reverberation were eliminated.

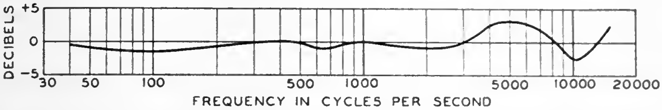

FIG. 3. Acoustic reproduction characteristic. The curve gives the ratio, expressed in db, of direct sound output of the loud speaker to field pressure at the microphone.

The compandor system is designed to have a uniform frequency characteristic. Consequently the equalizers described above determine the acoustic characteristic of the system. This is considered to be uniform when the direct sound output of the loud speaker is equal to the direct sound at normal incidence at the position of the microphone. It will be remembered that the microphones are placed close to the sound source. The argument is that by this means the sound is projected into the listening hall as if the original sound source were there and is acted upon normally from an acoustic standpoint. As little as possible of the acoustic effect of the originating auditorium is

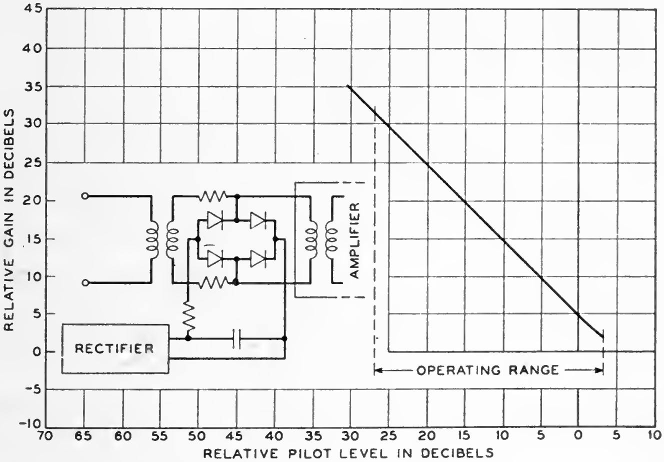

FIG. 4. Compressor schematic and characteristic. The curve shows the relation of the gain of compressor and amplifier to the level of pilot tone at the rectifier input.

transmitted. For reproduction in a large auditorium this is felt to be the correct method of equalization and pick-up, although it might not be satisfactory for reproduction under considerably different conditions. The overall air-to-air response of the system as calculated from the microphone, loud speaker, and electrical system characteristics, appears as Fig. 3.

The 40-cycle high-pass filters were employed to protect the loud speakers from injury caused by very low-frequency transients which sometimes arise in the system from power-line disturbances or injudicious switching. At frequencies below the cut-off of the low-frequency horn (40 cycles) there is little acoustic load on the diaphragm and a small voltage may cause a large displacement and consequent injury.

COMPANDOR-RECORDING-REPRODUCING SYSTEM

The compressors and expandors are of the general types that have been described by Bennett and Doba.[6] The average characteristic of the three compressors labeled *C* in Fig. 1 is shown by Fig. 4 together with a simplified schematic drawing of the circuit. Control current is fed in longitudinally in a balanced bridge formed by the four varistor elements. The amplifier which follows the varistors and is a part of the compressor is operated at a maximum 1000-cycle output level of +14 and a hum level of −57, giving a signal-to-hum ratio of 71 db. Since the output signal of the compressor is recorded on film with a signal-to-noise ratio of only 50 db, this seems more than ample. However, the film noise covers a wide band, whereas the hum consists of fixed frequencies which will be masked only by the critical bands of the film noise. Our experience has been that a 65 to 70-db range is required for hum in the compressed portion of the circuit.

Upon leaving the compressor, the signal enters the recording amplifier A_4, which is a balanced feedback type amplifier with a very sharp upper limit of voltage output. This limiting action is employed to prevent clashing of the strings of the light-valves, an especially important point when a compandor is used. The arrow in this and other amplifier boxes indicates that the gain is adjustable.

The output of A_4 is split into three paths by the two impedance-adjusting networks N_1 and N_2. One branch is labeled monitor and connects to the expandor input potentiometer P_{10} (Fig. 2) when the full reproducing system is used for monitoring in recording or re-recording. The other branch consists of a light-valve equalizer *VE* and provision for operating the light-valves of two recording machines simultaneously with individual level control by the attenuators *P2A* and *P2B*.

The valve equalizer is a network to correct in advance for the frequency characteristic of the light-valve as measured in terms of deflection of the valve strings. This characteristic was measured by observing valve string deflection with a microscope when known voltages and frequencies were applied to the input of A_4. The overall result then is an amplitude on the sound-track proportional to the original sound amplitude except as it is purposely modified by the pre-equalization and compression.

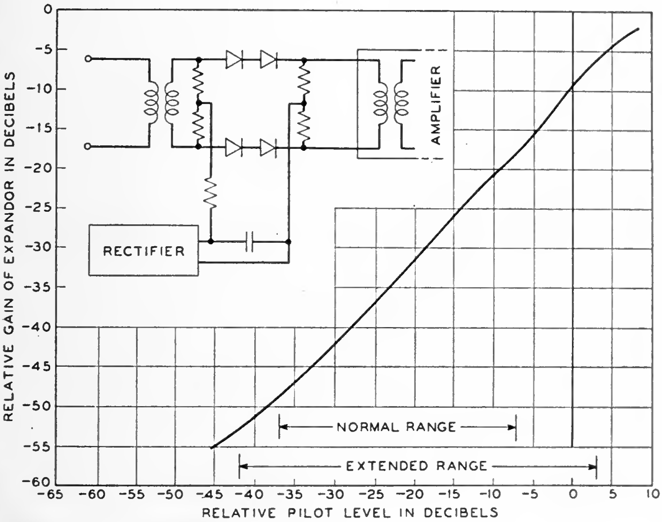

FIG. 5. Expandor schematic and characteristic. The curve shows the gain of the expandor and amplifier as a function of the level of pilot tone at the rectifier input.

The photoelectric cell output is coupled to the amplifier A_{10} (Fig. 2) by a transformer mounted in the reproducing machine and a low-impedance shielded line. The reproducing equalizer *RE* corrects for the overall optical, film, photoelectric cell, and coupling losses of the recording-reproducing chain. To obtain the characteristic, a film negative was made of a number of single frequencies recorded at constant amplitude and the output of A_{10} was observed when a positive print of this negative was reproduced. The equalizer was built to have the inverse of this characteristic and since A_{11} has a flat frequency characteristic, the signal delivered to the expandor *Ex* is the same as the signal leaving the compressor. Attenuator P_{10} is used to adjust the expandor input to a standard level. The amplifiers between compressor and expandor are very uniform in frequency characteristic and have a maximum signal-to-hum ratio of 70 db.

The expandor for this system must perform a double duty. It must automatically restore the signal to its uncompressed characteristics and in addition produce the relatively slow gain changes for enhancement of the signals. It must, therefore, be capable of operating over a wider range of pilot levels than the compressor. The characteristic of the expandor and a simplified schematic circuit are shown in Fig. 5, where in the normal range of pilot levels for reproducing original records and the extended range employed for full enhancement are indicated.

The signal channels are operated at levels which insure that the nonlinear distortion on the highest peaks is at least 35 db below the fundamental.

PILOT SYSTEM

The pilot system provides the operating mechanism for compressor and expandor and offers the possibility of enhancement. Fig. 1 shows the parts used for recording. The three pilot tones are generated by a special magnetic generator driven by a constant-speed motor. This device delivers 1260 cycles and its third and fifth harmonics, 3780 and 6300 cycles, with provision for adjusting the phase relations between them. The output is between −12 and −17 without amplification and the harmonic distortion is less than one per cent.

The three tone outputs are connected through volume controls P_3 to the three modulator inputs. The modulators[1] are similar to the expandors previously described and operate under signal control to vary the pilot tone levels. This signal control is effected by the modulator rectifiers *MR* which are bridged across the compressor input and supply rectified current to the modulators. The range through which the modulators vary the pilot tone can be adjusted and also that part of the signal amplitude range causing the change can be selected by adjusting the amplification of the rectifier.

The signal-controlled modulator outputs are combined in a network N_3 that prevents interaction between them. This combined output is at a very low level and must be amplified considerably before it can be used to operate the light-valve or compressor rectifiers. Since the lowest frequency is 1260 cycles, an 850-cycle high-pass filter is connected between A_5 and A_6 which greatly diminishes the shielding required against power hum. Amplifier A_6 is a limiting amplifier similar to A_4, in which the limiting feature is used to protect the light-valve strings from clash. The output of this amplifier is arranged to drive two recording machines simultaneously and the reproducing pilot circuit for monitoring, as in the signal channels. In addition there is a third branch of N_4 which passes through the three volume controls P_4 and feeds three band-pass filters that separate the pilot tones for operation of the compressor rectifiers. Pilot tone leaving each filter operates the appropriate compressor rectifier which in turn operates the compressor according to the characteristic of Fig. 4.

In the pilot channel reproducing circuit (Fig. 2) the photocell output of the reproducing machine is amplified by A_{15} and is then delivered to a circuit similar to that feeding the compressor rectifiers. Any irregularities in frequency characteristic can be corrected by adjustments for each pilot frequency at P_{12}. When a recording is being made the photoelectric cell circuit can be patched out and network N_{11} substituted which connects the recording pilot output direct to the reproducing pilot input for monitoring. It is important to note in either case that compressor and expandor are operated by as nearly as possible identical circuits so that no matter how the pilot tones vary, the gain changes of compressor and expandor will remain satisfactorily inverse.

In general the gain changes should take place as rapidly as possible when signals increase so that the compressor output will remain below the overload point of the limiting amplifier. However, once the compressor has reduced its gain to accommodate the wave it should not follow individual cycles. Although the pilot-operated expandor tends to restore the wave this would require an impractically perfect pilot system. This system operates with about a six-to-one ratio between attack and decay timing and will repeat a 50-cycle tone with excellent fidelity.

It was, of course, impossible to make the compressor gain changes instantaneous. Some wave-fronts are steep enough so that part of the beginning of the wave is not reduced sufficiently by the compressor and is chopped by the limiting amplifier A_4, with resultant objectionable distortion when compression begins at the limiting input of the amplifier. It was found by listening tests on symphonic music that the characteristic of Fig. 6 gave satisfactory recording. The desired

30 db of compression is retained, but the sensitivity of the pilot control is adjusted so that compression begins at a lower signal intensity and the "flat-top" portion of the characteristic is not recorded at full modulation. This must be done because the curve shown is for steady-state inputs. When a program is being recorded the compressor output continually for short intervals exceeds the values given by the curve of Fig. 6, and the "margin" between full modulation and the flat top was set to render peak-chopping unobjectionable during the listening tests.

It is important to note that the form of this curve is determined wholly by the pilot-level-to-signal characteristic of the pilot control.

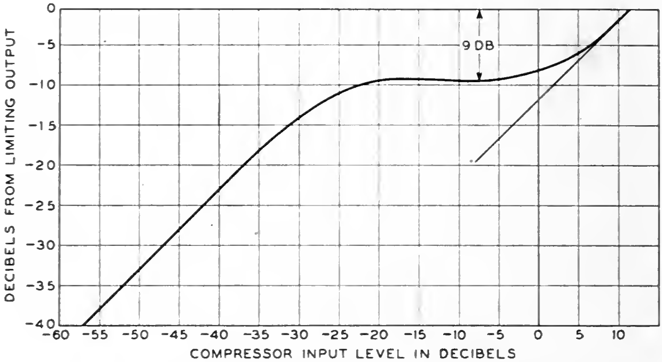

FIG. 6. Recording Characteristic. This curve shows the relationship of signal output of the recording amplifier to signal input to compressor and modulator rectifier, for a single-frequency signal.

The expandor and compressor merely respond linearly to pilot level changes. Therefore both the shape and amount of compression may be varied by adjustments at the time of recording and might even be changed for each type of program recorded.

PHYSICAL LAYOUT

All the signal equipment except the power amplifiers[4] is mounted on four tall cabinet racks, shown at the left of Fig. 7. The experimental nature of the installation is apparent. Corresponding units of all channels were mounted together to keep level differences at a minimum. It also facilitates checking levels and making substitutions and on the whole is preferable in an experimental system such as this. Another useful feature from the experimental angle is the provision of input, output, and bridging jacks with "normal-through" contacts to make the regular set-up continuous without patch cords. The rapid rearrangement and checking of the circuit which this made possible proved very useful.

In all amplifiers where the noise requirements are severe external supplies for both plate and heater power are used. These are mounted on racks which are situated a few feet away from the signal channels, thereby reducing greatly the difficulties of shielding the latter from hum pick-up. Several of the amplifiers of narrower range have small self-contained power supplies. They are mounted only on the two racks housing equipment handling compressed signals, and are well shielded.

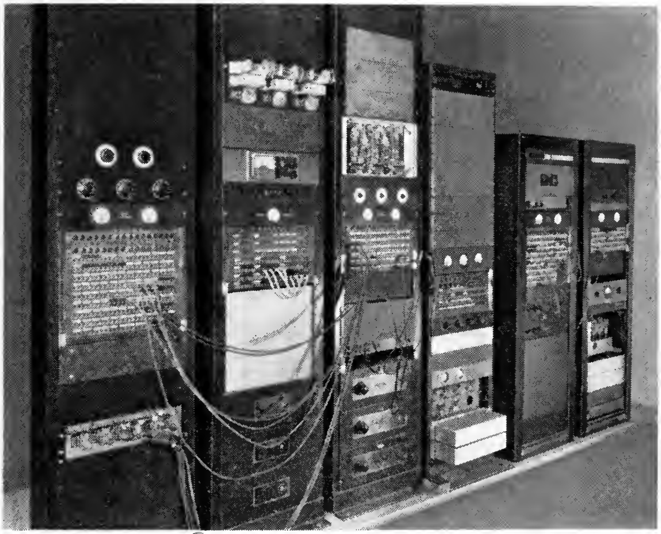

FIG. 7. Recording and reproducing channels. The three racks at the left carried the program equipment, while the two smaller cabinets on the right contained the pilot apparatus. The medium-size rack, center, contained auxiliary equipment used for some special tests but not part of the regular channels.

The apparatus associated only with the pilot circuits is installed in two short cabinets appearing at the right of Fig. 7.

All the foregoing racks must be fairly close together to facilitate operation. The other essential parts of the system may be located at the most convenient points. In the installation for our Hollywood demonstration they were all installed on the rehearsal stage of the Pantages Theater, and may be seen in rear view in Fig. 8. At the left are rectifiers for the loud speaker fields supplying 22 amperes at 32 volts. To their right are rectifiers for the exciting lamps of the machines which draw a maximum of 20 amperes at 16 volts per machine. In the second row, left, are the power amplifiers, and at the right the plate and heater power supplies for the signal channels.

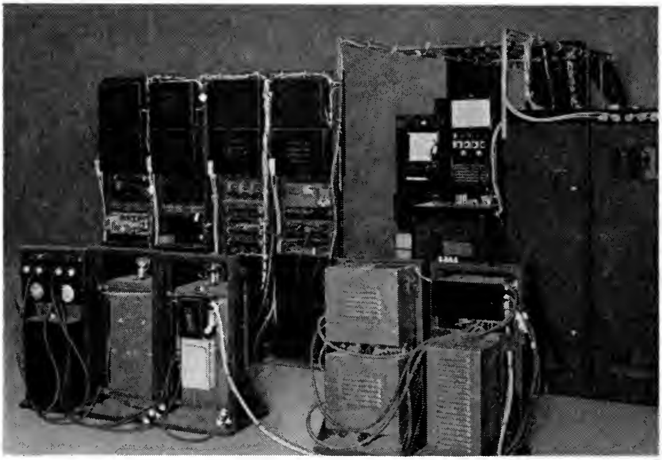

FIG. 8. Power equipment. In the foreground are rectifiers to supply low voltage direct current to loud speaker fields and exciting lamps in the machines. The next row consists of power amplifiers (*left*) and plate and heater-supply equipment in the three cabinets at the right.

If all the apparatus is at hand the following can be done: recording, recording with full-range monitoring, reproducing, or re-recording with or without enhancement plus monitoring.

OPERATION

Placement of microphones and loud speakers for stereophonic reproduction is still largely a matter of trial. For our Philadelphia Orchestra records the microphones were suspended 10 feet above the stage and 5 feet inside the front row of performers. The orchestra width was about 40 feet and our outside microphones were 28 feet apart. At the Carnegie Hall demonstration the side loud speakers were 40 feet apart and they and the center loud speaker were 11 feet behind the main curtain.

When the circuit is to be set up for recording an orchestra with monitoring, patches are made as indicated in Figs. 1 and 2. Each channel is then lined up with a single-frequency tone applied at the input of A_1 of voltage corresponding to the maximum expected from the microphone. Adjustments are made so that the compressor output just drives the recording amplifier to its limit. However, the expandor gain is set at 10 db below maximum to allow for enhancement. Then program is picked up and P_{11} is adjusted to give unity ratio reproduction on the basis of listening test or measurements. The final setting of P_1 is then made such that audible overloading does not occur on the highest program peaks, and P_{11} can be readjusted accordingly. The circuit is now set to record at proper level any sound less intense than an orchestra without further changes in gain. Of course with practice this setting can be determined by measurement.

In order to reproduce records it is desirable to have previously made a test record with the circuit conditions described for recording. This record is played over the reproducing circuit. The gain of A_{15} and the setting of volume controls P_{12} are adjusted so that the proper pilot levels are obtained at the expandor rectifier input on each pilot tone. Finally the signal levels into the expandor are adjusted to be at the allowable maximum and P_{11} is set as for monitoring. Then any record recorded with setting given above will be reproduced at the same level at which it was heard in the monitoring circuit. Any desired alteration in listening level provided it does not exceed +10 db or −5 db may be made very conveniently by changing the gain of A_{15} which changes all channels at once.

The use of a pilot-operated compandor makes it possible to increase the volume range of a re-recorded selection, or to enhance it, introducing only a slight increase in film noise. This process was described in detail in another paper.[1] Since only 30 db of the expandor gain variation are needed for automatic control the 15 db remaining is available for manual manipulation. Our amplifier capacity is sufficient for 10-db increase in orchestral sound so that the 15-db range is used as +10 and −5. It was to allow for this range that the expandor adjustments were 10 db below maximum in the recording monitoring line-up. If greater reductions in level are required they can safely be made by lowering the re-recorded signal level because the noise is inaudible with expandor gain at 5 db below normal minimum. Quality-control networks may also be switched into the signal channels.

Parts of the recording set-up are combined with the reproducing circuit to make up this arrangement. The signal from each photoelectric cell is amplified and then sent through a quality control and an attenuator of 15-db continuous range which is part of the enhancement volume control.[1] Then they are equalized, amplified, and rerecorded. The pilot track is picked up, amplified, and separated into its components by the filters used with the compressors during recording. After separation each tone passes through an attenuator of 15-db continuous range. The tones are recombined, amplified, and re-recorded. Monitoring is accomplished in the same manner as when recording. The attenuators for each channel in the signal path and pilot are controlled by the same lever and arranged so that in the normal position there are 10 db of loss in the pilot channel and none in the signal. The lever can be moved up to zero loss in both channels and down to 15 db in the pilot circuit with no loss in the signal channel

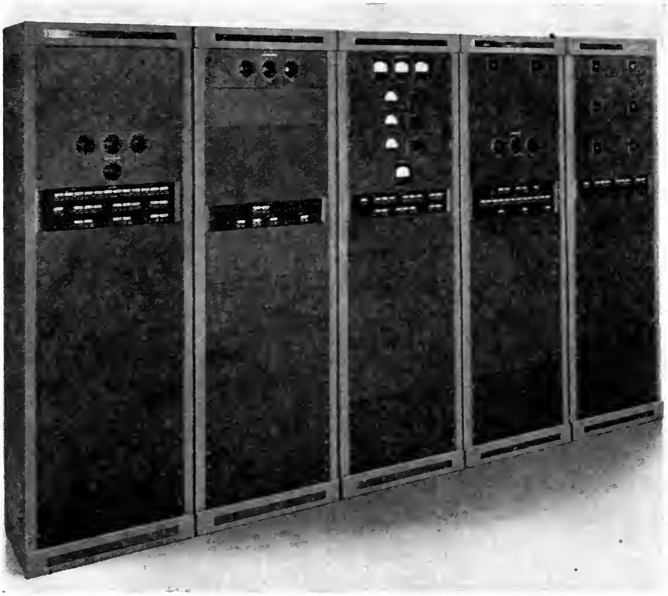

FIG. 9. Recording channels of new stereophonic system.

and then still farther down to hold 15 db in the pilot and add up to 15 db to the signal loss. The enhancement volume control levers and the quality-control keys are mounted in a control cabinet and are so arranged that they can be conveniently manipulated by an operator while he is listening to the music and can hear the effects of any changes he makes. Of course these changes are all recorded at the same time on the re-recorded negative.

CONCLUSION

During the past summer another complete stereophonic sound-film system was built for Electrical Research Products, Inc., by the Laboratories. Throughout this design commercial equipment was used except in the pilot and compandor systems where standard articles were not available. The new system always equalled and at many points exceeded the performance of the experimental one described in this paper. Fig. 9 shows the improved appearance of the recording system and the standard height cabinet rack used throughout.

The authors have had the full coöperation of many members of the Laboratories' staff. In particular they wish to thank Mr. K. D. Swartzel who developed the expandor circuit and Mr. R. W. Buntenbach for his aid in equalizing and operating the system.

REFERENCES

[1] FLETCHER, H.,: "The Stereophonic Sound-Film System—General Theory" (this issue of the JOURNAL, p. 331).

[2] WENTE, E. C., BIDDULPH, R., ELMER, L. A., AND ANDERSON, A. B.: "Mechanical and Optical Equipment for the Stereophonic Sound-Film System" (this issue of the JOURNAL, p. 353).

[3] STEINBERG, J. C.: "The Stereophonic Sound-Film System—Pre- and Post-Equalization of Compandor Systems" (this issue of the JOURNAL, p. 366).

[4] SCRIVEN, E. O.: "Auditory Perspective—Amplifiers," *Electrical Engineering*, **LIII** (April, 1934), p. 278.

[5] WENTE, E. C., AND THURAS, A. L.: "Auditory Perspective—Microphones and Loud Speakers," *Electrical Engineering*, **LIII** (Jan., 1934), p. 17.

[6] BENNETT, W. R., AND DOBA, S.: "Vario-Losser Circuits," *Electrical Engineering*, **LX**, Trans. No. 17 (Jan., 1941), p. 17.

DISCUSSION

MR. KELLOGG: Was a special copper oxide rectifier used with the compressor?

MR. SOFFEL: The copper oxide rectifiers were made especially for the job in the Bell Telephone Laboratories and possess characteristics that give the compressors and expanders a wide linear gain change without harmful effects caused by rectifier shunt capacity.

MR. CRABTREE: In listening to the records from which the background noise was not eliminated and attempting to eliminate the background noise mentally, I got the impression that the sound quality was better than in the record that had been subjected to equalizaton; that is, in going through the mill of equalization and compression, some quality has been lost. This demonstration would seem to stress the necessity of eliminating background noise by the use of even still finer grained emulsions in recording.

MR. SOFFEL: If it were possible to get a film with a signal-to-noise ratio 40 db better, the quality would be slightly superior on sounds of very impulsive nature, but for ordinary sounds there would be little difference.

MR. MAURER: Is any information available as to the overall harmonic distortion of the system?

MR. SOFFEL: Each unit in the sytsem was designed to have a total harmonic distortion of a pure tone of 400 cycles, 35 db below the fundamental at all levels. The distortion of the complete system is probably slightly greater.

MR. KELLOGG: Are there certain frequency ranges of film noise that are more disturbing than others? There is also the question as to the effect of a narrow band of noise frequencies *vs.* a wide band.

MR. STEINBERG: Although studies reported by Professor Donald Laird of Syracuse University tend to indicate that high-frequency noise would be more disturbing than low-frequency noise when the two are equally loud, more study will be needed with particular reference to film noise as a background to program signals before a final answer can be given to that question.

A LIGHT-VALVE FOR THE STEREOPHONIC SOUND-FILM SYSTEM*

E. C. WENTE AND R. BIDDULPH**

Summary.—*This paper describes a light-valve incorporating large electromagnetic damping and operating directly through the ribbon resonance region. Resonance-region response, 5 db above that at low frequencies, is equalized by a suitable equalizer to provide uniform ribbon displacement per unit driving voltage over the band 30–14,000 cycles with very nearly constant phase-shift per cycle. Problems of structure and size have furnished a mechanical design with several interesting features, among which are mechanical robustness, protection against dirt and moisture, built-in ribbon and optical adjustments, and an optical system integral with the valve structure. This unit has proved a rugged, stable, light-modulator especially free from intermodulation products.*

The light-valve for recording sound-on-film consists essentially of a pair of coplanar ribbons, supported in a transverse magnetic field forming a light-slit which varies in size in accordance with the current flowing through the ribbons. Its design involves the solution of a combination of mechanical, electrical, magnetic, and optical problems. Because of the limitations in the physical properties of materials, the vibrating elements must be very small—a circumstance which demands close tolerances and great stability in the mechanical construction. However, the light-valve is well adapted to fulfill the general requirements for a light-modulator in a high-quality sound-recording system. It is simple in principle, and can be built in a stable, convenient, and rugged form.

THEORY OF OPERATION

In order to obtain an analytical expression for the operating characteristics of the light-valve in terms of its physical constants, we shall assume that the ribbons are connected to an alternating source of emf having an internal resistance equal to R_i. Except at very high or very low audio-frequencies, this condition corresponds with

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received March 18, 1941.

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

that under which the valve is used in practice. In order to simplify the discussion, let us assume that the ribbons have exactly the same physical constants, so that the motion of the two ribbons is the same for a given current flow. We can then treat the two ribbons as a unit. Our discussion will, therefore, proceed as if we were dealing with a valve having a single ribbon. For reasons that will become evident, the ribbon is preferably provided with a resistance shunt. If this resistance is R_s, if the impedance of the valve is Z_v, and if the emf of the source is $E'e^{j\omega t}$, the circuit diagram for the system is analytically equivalent to that shown in Fig. 1, where E is equal to $E'R_s/(R_i + R_s)$ and R is equal to $R_iR_s/(R_i + R_s)$.

Only the central portion of the ribbon is used in controlling the light transmitted by the valve; we shall therefore restrict our interest to the motion of this region. If the displacement is designated by x, the problem of finding the response frequency characteristic then consists in the determination of $|x/E|$. The ribbon is ordinarily tuned to a frequency which is near the upper part of the operating frequency range. When current flows through the ribbon, it will, therefore, be displaced into a form which is close to that of one lobe of a sine-wave for all frequencies of practical interest. Assuming this form of displacement we can readily determine the equivalent simple harmonic system in which the constants are lumped and in which the motion is the same as that of the middle of the ribbon. The effective mass of the ribbon in this equivalent system is equal to that mass which, when moved at the velocity of the middle of the ribbon, has the same kinetic energy as the ribbon itself. The effective stiffness is equal to the effective mass multiplied by ω_0^2 where ω_0 is the angular frequency at resonance. The effective force is equal to that force which, when multiplied by the displacement of the center of

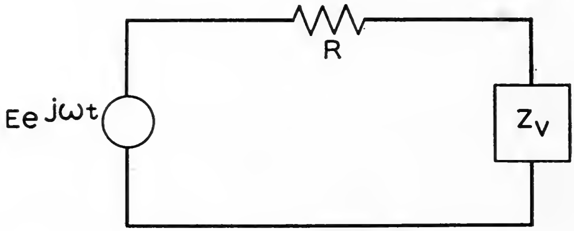

FIG. 1. Equivalent electrical circuit of recording amplifier and light-valve.

the ribbon, will represent as much work as that which is actually done in displacing the ribbon. If m, s, and F are the effective mass, stiffness, and force, respectively, for the sinusoidal form of ribbon displacement, we get, on applying the definitions just given,

$$m = \frac{\rho a l}{2},\quad s = \frac{\rho a l}{2}\omega_0^2;\quad F = \frac{2Bl}{10\,\pi}i = k\,\frac{i}{10}$$

where ρ is the density of the ribbon material; a is the cross-sectional area, and l the length of the ribbon; B is the flux-density, which is assumed to be uniform along the full length of the ribbon; and i is the current in amperes. We find also that the potential developed between the ends of the ribbon when it vibrates is equal to

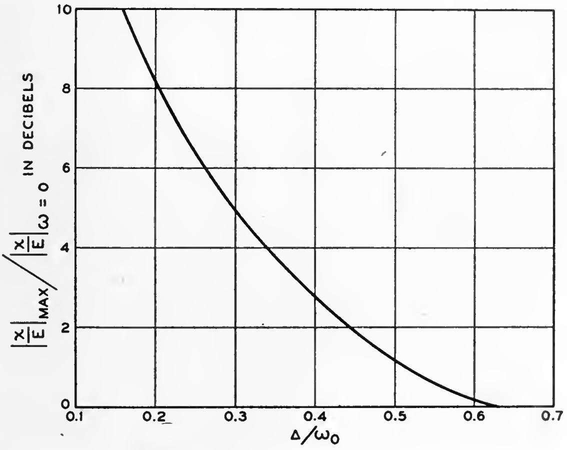

FIG. 2. Effect of damping upon resonance response.

$$\frac{2Bl}{\pi}\,\dot{x}\,10^{-8} = k\,\dot{x}\,10^{-8}\ \text{volts}$$

We can now set up the following dynamical equation

$$m\ddot{x} + m\,\omega_0^2\,\dot{x} = \frac{k}{10}\,i \tag{1}$$

If R_v is the resistance of the ribbon when its motion is fully constrained, we have the following relationship for the circuit of Fig. 1:

$$E = (R + R_v)i + k\,\dot{x}\,10^{-8} \tag{2}$$

If $E = Ee^{j\omega t}$, we get from these two equations

$$x = \frac{\dfrac{kE}{10(R + R_v)}}{j\omega\left[\dfrac{k^2 10^{-9}}{R + R_v} + j\omega\left(\dfrac{\omega^2 - \omega_0^2}{\omega}\right)\right]} \qquad (3)$$

This is the equation of motion for a simple vibrating system having the angular resonance frequency ω_0, a mass m, and a mechanical resistance $10^{-9}k^2/(R + R_v)$, when subjected to a driving force equal to $kE/10(R + R_v)$. The damping constant Δ of the system is equal to $10^{-9}k^2/2(R + R_v)m$. Substituting this value in equation *3*, and setting $\eta = \omega/\omega_0$, we obtain the desired solution:

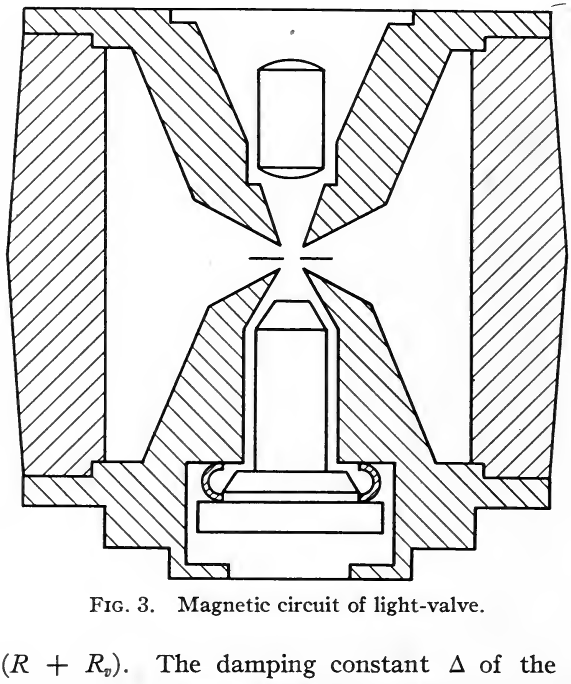

Fig. 3. Magnetic circuit of light-valve.

$$\left|\frac{x}{E}\right| = \frac{k}{10(R + R_v)m\omega_0^2} \; \frac{1}{\left[\left(\dfrac{2\Delta\eta}{\omega_0}\right)^2 + (\eta^2 - 1)^2\right]^{1/2}} \qquad (4)$$

The greatest uniformity of response is obtained when ω_0 is made greater than the highest angular frequency to be impressed. This procedure is impracticable for a broad-band system. ω_0 is increased either by shortening the ribbon or increasing its tension. For optical reasons, the maximum displacement of the ribbon must not be too small and so the ribbon must not be too short. The fatigue limit of ribbon materials restricts the working tension. Because of these limitations, it becomes practically necessary to keep ω_0 within the operating frequency range.

In this case, however, it is impossible to adjust the constants of a simple vibrating system, such as the ribbon presents, so that the response will be uniform. Equalization must be introduced into the electrical circuit if the system as a whole is to have a uniform response. Networks may be designed to equalize for almost any characteristic, but the tolerance limits both in the construction and for stability become prohibitively severe for a sharply tuned system. The equalization problems become increasingly simpler as the height of the resonance peak is reduced.

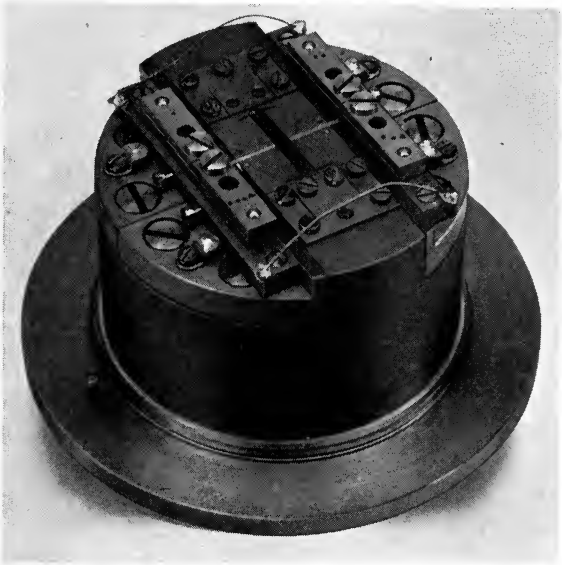

FIG. 4. Photograph of ribbon supporting structure.

Unless a unique kind of circuit closely coupled to the ribbon is used for the equalization, such networks can not eliminate so-called "valve clash." When the ribbons of a valve are over-modulated and not well damped, they will oscillate every time they strike each other. These oscillations are free oscillations at the resonance frequency, which were not in the original signal. The damping of these oscillations is practically unaffected by equalization in some other part of the circuit. The effect of valve clash can be reduced only by an increase in the damping of the valve. For this reason, as well as because of the greater ease of equalization, the ribbon should be as well damped as is practically possible.

From equation *4* we see that the maximum response occurs when $\omega^2 = \omega_0^2 - 2\Delta^2$. The ratio of peak response to the response at $\omega = 0$ is, therefore,

$$\frac{\left|\frac{x}{E}\right|_{max}}{\left|\frac{x}{E}\right|_{\omega=0}} = \frac{1}{2\frac{\Delta}{\omega_0}\left[1 - \left(\frac{\Delta}{\omega_0}\right)^2\right]^{1/2}} \tag{5}$$

This ratio thus depends solely upon Δ/ω_0. The relationship is shown graphically in Fig. 2. The relative height of the resonance peak thus can be decreased to any desired value down to unity by increasing Δ/ω_0. We should therefore try to make Δ/ω_0 as large as is practically possible. The limit to which ω_0 can be reduced is set by the fact that for frequencies very far above resonance, the displacement of the ribbon no longer is sinusoidal, but takes on the form of a higher mode of motion. This change will result in irregularities in the response characteristic which are not easily controlled. Stability of ribbon adjustment also sets a lower limit in the ribbon tension.

Having reduced ω_0 to the lowest practical value, we must seek an increase in Δ. The damped resistance R_v of the ribbon is equal to $\sigma l/a$, where σ is the resistivity of the ribbon material. Let $R_v/(R + R_v) = \alpha$. We then get

$$\frac{\Delta}{\omega_0} = \frac{4\alpha B^2}{\sigma\rho\omega_0\,\pi^2}\,10^{-9} \tag{6}$$

According to equation *6*, the best ribbon material is one having the lowest value of $\sigma\rho$. This criterion, together with the fact that a comparatively high value of ω_0 must be maintained, indicates that duralumin is probably the most satisfactory ribbon material available. For greatest reduction in the relative height of the peak value of response, α should be made as large as possible, but the advantage in going in this direction is limited, since the maximum value of α is unity and a recording amplifier of increasingly greater power capacity is required. Δ varies as the square of B and the power required to operate the valve decreases as B is increased. For these reasons, much is gained in making the flux-density as great as is practically possible.

CONSTRUCTION AND PERFORMANCE

The magnetic circuit of the valve used in making four-channel stereophonic records is shown in Fig. 3. Two conical pole-pieces, spaced by a surrounding supporting cylinder of permanent-magnetic material, form the air-gap in which the ribbons move. The flux-density produced in this air-gap is 32,000 gauss.

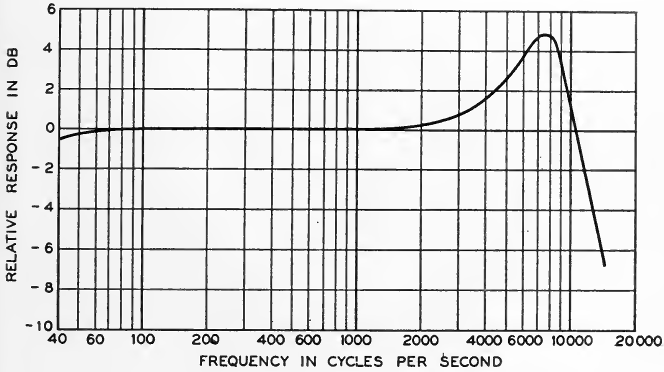

FIG. 5. Response *vs.* frequency characteristic.

Mounted securely on one of the pole-pieces is a ring structure carrying clamping blocks for the ribbons, as shown in the photograph of Fig. 4. These blocks are adjustable and the ribbons can be readily placed in their correct position relative to the pole-piece structure and tuned to the required frequency. The adjustment provisions include means for moving the ribbons in the axial direction in order that they may be made accurately coplanar. When all adjustments of position and tension have been made, the clamps are fastened solidly to their supporting base. Ribbons are spaced 0.004 inch apart, and each is tuned to a resonance frequency of 8400 cps. In order that all contact surface resistances may be kept to a small and stable value, all ribbon clamps and the base upon which they mount are gold-plated. A shunting resistance across each ribbon is also fastened directly to the ribbon clamps. While these shunt circuits increase the power requirements for operating the valve, they add to the damping constant and decrease the dependence of the frequency response characteristic upon the output impedance of the recording amplifier.

The response-frequency characteristic of the completed valve when connected directly to the recording amplifier without any further equalization is given in Fig. 5. This response has a broad maximum in the neighborhood of 8000 cps and is easily equalized with electrical networks.

FIG. 6. Photograph of assembled valve.

The light-source is focused directly in the ribbon plane by a condensing lens mounted in one pole-piece of the valve, and a microscope objective focusing the ribbons directly on the film is mounted in the other pole-piece. These lenses, as well as the ribbons of all valves, are adjusted in a common fixture. The completed valves after adjustment in this fixture are nearly enough alike, optically and mechanically, so that they can be mounted on the fixed brackets of the recording machine without the need of further adjustment for position or focus of the recording image on the film. Condensing and objective lenses in the pole-pieces serve also to close the valve structure against dirt and dust, and the interior may be hermetically sealed if so desired. A photograph of one of the valves is shown in Fig. 6.

A lot of ten such valves has been used for a considerable amount of experimental recording over an extended period and in various parts of the country. Operated from a feedback amplifier acting both as a driver and a voltage limiter, no difficulty has been experienced with broken ribbons, and no readjustment of either ribbon tuning or ribbon spacing was required during this time. This valve has proved to be rugged in all experimental work where reasonable precautions were observed and is free of the instability frequently characterizing compact vibrating structures.

The writers are indebted to Mr. L. A. Elmer for a number of important suggestions in connection with the design of this valve.

DISCUSSION

MR. KELLOGG: What is the magnification in the horizontal plane?

MR. BIDDULPH: The objective in this valve operates at a lateral magnification of 10× in the horizontal plane to form an unmodulated track 0.040 inch wide on the film.

MR. STEPHENS: Is the valve equally well adapted for variable-area and variable-density recording?

MR. BIDDULPH: Variable-area recording methods were employed in our stereophonic work; hence the light-valve was designed to operate in conjunction with an optical system producing a satisfactory variable-area trace. To employ this valve for variable-density work would require some modifications of both valve geometry and optics.

INTERNALLY DAMPED ROLLERS*

E. C. WENTE AND A. H. MÜLLER**

Summary.—*Special damping rollers, capable of damping oscillations of rotating shafts without adding a steady load, were first devised by Prof. H. A. Rowland. These rollers had either an annular channel along the periphery filled with a liquid, or a wheel mounted loosely on a shaft coaxially fixed in an outer shell, the interspace being filled with a liquid. The theory of the action of such rollers in reducing fluctuations in the speed of rotation caused by disturbances from either the load or the driving side is developed and the results are illustrated by graphs. A new form of roller is described in which liquid filling an annular channel within the shell of the roller is coupled to the shell by a mechanical resistance.*

A flywheel elastically connected to the shaft of a machine will hunt, *i. e.*, execute resonance oscillations as the result of any departures from steady-state conditions, unless the effective torque load on the flywheel increases at an adequate rate with the speed of rotation. In most machines, a small amount of hunting is not harmful. In some cases, however, means must be provided for keeping the oscillations below undesired amplitudes. Special devices for preventing hunting are, for instance, commonly applied to synchronous motors, in which the rotor has enough moment of inertia to behave as a flywheel. These devices are usually of a kind that do not in any way impede the steady rotation, *i. e.*, they absorb no power when the speed is constant, an important characteristic here and in some other applications.

Prof. H. A. Rowland early made use of the viscosity of liquids for damping rotating shafts in a way that did not produce an increase in the steady load. His method was disclosed in U. S. Patents Nos. 691,667 and 713,497, relating to a printing telegraph—both of the year 1902. Its particular purpose there was to reduce hunting in synchronous motors. "Viscous damper" was the name given to the device by Rowland.

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received March 15, 1941.

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

One form of this viscous damper is shown in Fig. 1, taken directly from the patent specification. This consists of a shell, or casing, having a hollow annular channel enclosing a liquid. When the shell is revolving, the liquid is distributed by centrifugal action along the outer boundary of the channel. When the speed is uniform, the liquid and shell move together as a unit. If the speed of the shell changes, the liquid is gradually brought back into step by viscous shear in the liquid. This shear involves dissipation of energy and consequent damping of oscillations of the rotating shell. The amount of damping that can be obtained in this way depends upon a number of factors, among which the viscosity and density of the liquid are of first importance.

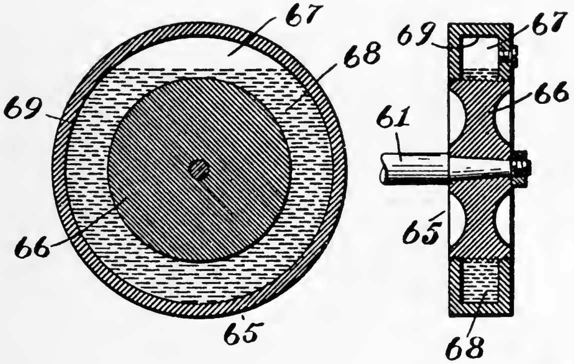

FIG. 1. Liquid form of Rowland "viscous damper."

Almost any value of resistance per unit length of channel may be obtained by a proper choice of liquid and cross-sectional area. The damping of an oscillating system, however, depends, not upon the resistance alone, but upon the ratio of resistance to mass, and, in this type of damper, anything that will increase the resistance will also increase the mass reactance by an equal or greater amount. The amount of damping that can be applied by this method is therefore restricted. Within limits, the resistance is proportional to the square-root of the product of density and viscosity of the liquid. Liquids of high viscosity generally have relatively low density, so that, when such liquids are used, the damper will be relatively bulky since a certain amount of inertia in the liquid is required against which the mass of the casing may react. Rowland, therefore, while men-tioning oil, preferred to use mercury in his damper, as this has much greater density than any other normally liquid substance. Mercury dampers of this general type have been used in certain forms of printing telegraph for many years.

Another form of damping wheel was disclosed by Rowland, also in U. S. Patent No. 713,497, and is here reproduced in Fig. 2. In this form, a wheel is mounted freely on an axle, fixed within a shell, coaxially with the main shaft. Liquid is placed in the shell which, by centrifugal action, fills the peripheral clearance spaces between the wheel and the shell when the shell rotates. Rowland, comparing this form of damper with that of Fig. 1, states, "The loose body has the effect of making a light liquid, such as oil, act as a heavier liquid."

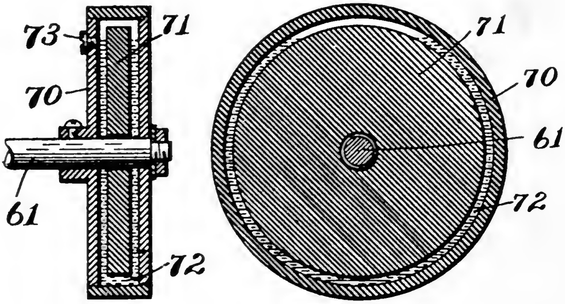

FIG. 2. Wheel form of Rowland "viscous damper."

This structure has a further advantage in that the dissipation of energy for a given rate of annular displacement between the inner and outer members is determined entirely by the viscosity of the liquid, the clearances, and the effective shearing area, all of which can be independently controlled.

The use of a viscous damper of the general form shown in Fig. 2 in sound-film apparatus was first described by E. D. Cook.[1] Cook developed the theory of operation of the device and gave the mechanical circuit diagram for it when connected to a film-driven scanning roller shaft. He showed that the system could not be made aperiodic unless the moment of inertia of the inner wheel was about eight times as great as that of the shell.

The chief disadvantages of the solid over the liquid mass within the shell of the roller are: the inner wheel must be supported on a bearing which may not always be free, particularly when the oscillations are small; since, in operation, the shell and wheel may have any angular position relative to each other, they must be balanced independently and the geometrical form of the wheel and the inner surface of the shell must be such that the liquid as distributed in the interspace during rotation is also maintained in balance. These difficulties are avoided in dampers having a homogeneous liquid only as the movable substance within the shell. There can then be no question of static frictional forces, and, if a completely assembled damper has once been dynamically balanced, it will not be thrown out of balance by any angular shift of the liquid.

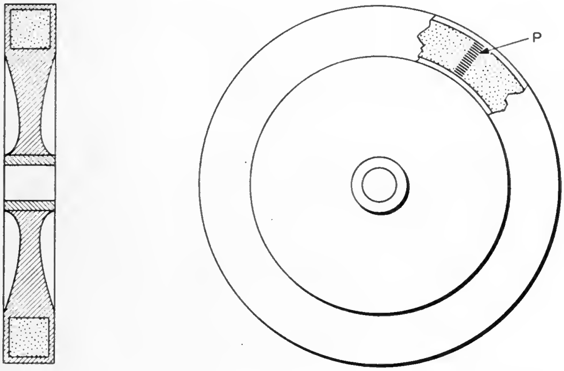

FIG. 3. Damped roller used in stereophonic film system.

The difficulty inherent in the device of Rowland, as shown in Fig. 1, namely, limitation in the control of the coupling resistance between the liquid and shell, is overcome in the structure shown in Fig. 3. Here, as in Fig. 1, there is a shell with a closed annular channel carrying a liquid. The coupling between the liquid and the shell is, however, not determined by the frictional drag between the channel walls and the liquid, but is controlled by a porous partition *P* placed transversely across the channel so that the liquid can not move circumferentially without forcing liquid through the pores of the partition. This partition will act as a pure resistance* to the motion of the

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* Throughout this paper, the term "impedance" is to be understood as "mechanical impedance," *i. e.*, the ratio of force to velocity. When expressed in complex form, the term "resistance" is to be understood as the real part and "reactance" as the imaginary part of this ratio.

liquid relative to the casing, if certain conditions are fulfilled. One of these is that the ratio of reactance to resistance for each pore be small at the resonance frequency, where energy dissipation is to be effected. For example, if the pores are small and circular in section, the resistance of each hole has a value equal to $8\mu l/r^2$ and a mass reactance of $4\omega\rho l/3$ per unit area,[2] where μ is the viscosity and ρ the density of the liquid, r the radius and l the length of the hole, and ω is the angular frequency. r should, therefore, be small compared with $(6\mu/\omega\rho)^{1/2}$. If this condition is satisfied, the resistance of the whole partition will be equal to $\sigma l A^2/a$, where A is equal to the sectional area of the channel, a is the total area of all the pores in the partition, and σ is the resistance of the pores per unit area per unit length. The coupling resistance between the shell and the liquid can, therefore, be given almost any desired value for any liquid by a proper choice of size and number of pores.

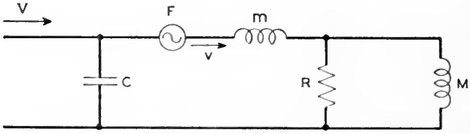

FIG. 4. Mechanical circuit diagram of damped roller system.

The mechanical circuit diagram for a system in which a roller of this kind is driven through an elastically yielding coupler is shown in Fig. 4. For the particular case where the roller is driven by a resilient film running over a scanning drum rigidly connected to the shell of the roller, C is the compliance of the portion of film connecting the driving sprocket and the scanning drum. M is the mass of the liquid, m the mass of the shell and other parts that may be rigidly connected to it, and R the resistance of the partition—each divided by the square of the ratio of its own radius of gyration to the radius of the scanning drum. This circuit is of the same form as that given by Cook for the film-driven roller having a solid internal member.

In this system, there are two principal types of disturbances which can produce variations in the speed of rotation of the scanning drum to which the shell of the roller is assumed to be rigidly connected. These may be designated as driving-side disturbances and load-side disturbances. The former are variations in the speed of film travel at the driving sprocket and are represented in the circuit diagram by V. The latter are such disturbances as variations in the friction of the sound roller bearings and in the film compliance C. Their combined effect is equivalent to that of an alternating force acting at the periphery of the scanning drum and can be represented by the force F at the point indicated in the diagram. The variation in the speed of the roller resulting from either type of disturbance is represented in the diagram by v. An analysis of the circuit should, therefore, give expressions for v/V and v/F as a function of frequency and the physical constants of the system. Our interest is, however, restricted to the absolute value of these ratios.

We readily derive the relation

$$\left|\frac{v}{V}\right|^2 = \frac{R^2 + M^2\omega^2}{R^2[1 - C\omega^2(m + M)]^2 + M^2\omega^2(1 - m\omega^2C)^2} \qquad (1)$$

If now we set

$$k = \frac{m}{M + m}; \quad \omega_0 = \left[\frac{1}{C(M + m)}\right]^{1/2}; \quad Q = \frac{M\omega_0}{R} \text{ and } x = \left(\frac{\omega}{\omega_0}\right)^2$$

Equation *1* reduces to

$$\left|\frac{v}{V}\right|^2 = \frac{1 + Q^2x}{(1 - x)^2 + Q^2\, x\, (1 - kx)^2} \qquad (2)$$

When x is small, this expression approaches unity, and when x is large it approaches $1/k^2x^2$. Intermediately, it passes through a maximum, the magnitude and frequency of which depend upon Q and k. In the region of this maximum and at all lower values of x, it is greater than 1. This means that, in this range, the system does not attenuate, but actually amplifies the speed flutter that may be present at the driving sprocket. It is an advantage, therefore, to make the resonance frequency ω_0 as low as possible and to keep the peak value of this amplification to a low value, so far as this can be accomplished without impairing the effectiveness of the filtering action at other frequencies. In order to find the lowest peak that it is possible to obtain for a given value of k by adjustment of Q, we set

$$\frac{\partial}{\partial Q^2}\left|\frac{v}{V}\right|^2 = 0 \text{ and } \frac{\partial}{\partial x}\left|\frac{v}{V}\right|^2 = 0$$

and solve the two simultaneous equations so obtained. When this is done, we find

$$x = \frac{2}{1 + k} = x_c \qquad (3)$$

$$Q^2 = \frac{1 + k}{2k} = Q_c^2 \tag{4}$$

When these values are substituted in equation *2*, we obtain, for the height of this minimum peak

$$\left|\frac{v}{V}\right|^2 = \left[\frac{1 + k}{1 - k}\right]^2 = \left|\frac{v}{V}\right|_c^2 \tag{5}$$

In deriving corresponding expressions for the load-side disturbances, let us set F/v equal to z, and $(M + m)\ \omega_0$ equal to z_0, the impedance that would obtain for the load-side disturbances at the angular frequency ω_0 if the liquid and the casing were rigidly interlocked and the compliance C were very large. z_0/z is then the ratio of the velocity of the shell to its velocity at the frequency ω_0, if the same force were acting on the combined liquid and shell masses alone. From the circuit diagram, we see that

$$\begin{aligned}\left|\frac{Z_0}{Z}\right|^2 &= \frac{(Q^2x + 1)x}{Q^2x(1 - kx)^2 + (1 - x)^2} \\ &= \left|\frac{v}{V}\right|^2 x\end{aligned} \tag{6}$$

This function also passes through a maximum. In order to find the lowest value that the peak can have for a given value of k, we proceed as before and set

$$\frac{\partial}{\partial Q^2}\left|\frac{Z_0}{Z}\right|^2 = 0 \text{ and } \frac{\partial}{\partial x}\left|\frac{Z_0}{Z}\right|^2 = 0$$

Solving the two equations so obtained, we have

$$x = \frac{2}{1 + k} \tag{7}$$

and

$$Q^2 = \frac{1 + k}{2}\,\frac{3 + k}{3k + 1} \tag{8}$$

Substituting these values in equation *6*, we get for the minimum possible peak value at a given value of k

$$\left|\frac{Z}{Z}\right|^2 = \frac{2(1 + k)}{(1 - k)^2} \tag{9}$$

Equations *3*, *4*, *7*, and *8* show that if k, the ratio of the mass of the shell to the total mass of the roller, is kept constant, and Q is adjusted so that the peak value of flutter is a minimum, the peak frequency will be the same whether the adjustment is made for load-side or for driving-side disturbances, but that the values of Q required to reduce these two peak values to a minimum are different. These values of Q differ more and more as k is decreased. This statement gives one good reason why k should not be made too low. However, we can not draw the general conclusion that a sound-film machine, equipped with a roller having a small value of k, is necessarily going to exhibit a relatively large amount of flutter in the resonance region for one or

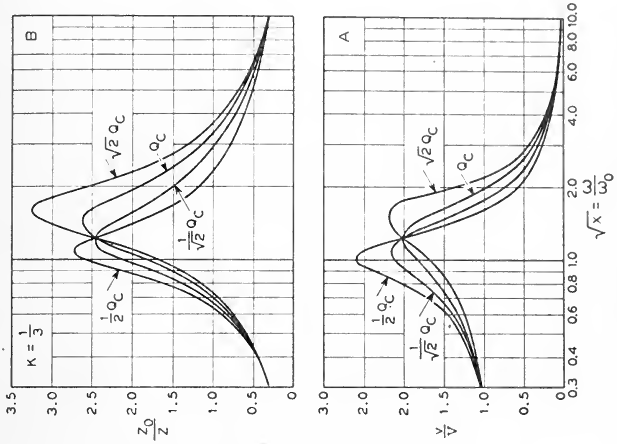

FIG. 6. Theoretical curves of performance of damped roller film propulsion system.

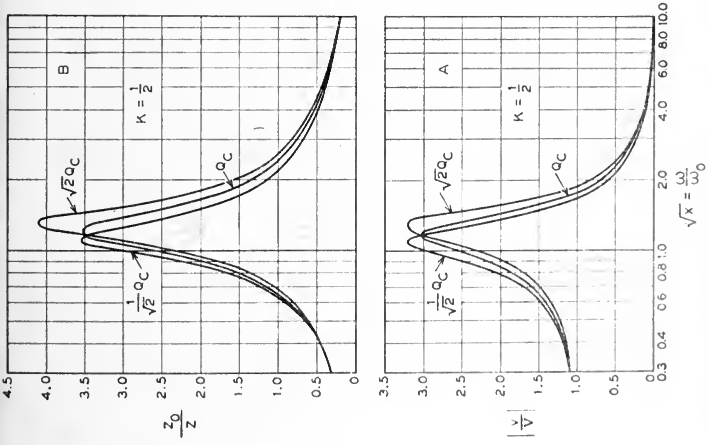

FIG. 5. Theoretical curves of performance of damped roller film propulsion system.

the other of the two types of disturbances. This would depend upon a number of other factors—primarily the frequency of resonance and the magnitude of the disturbances. It can safely be said that if

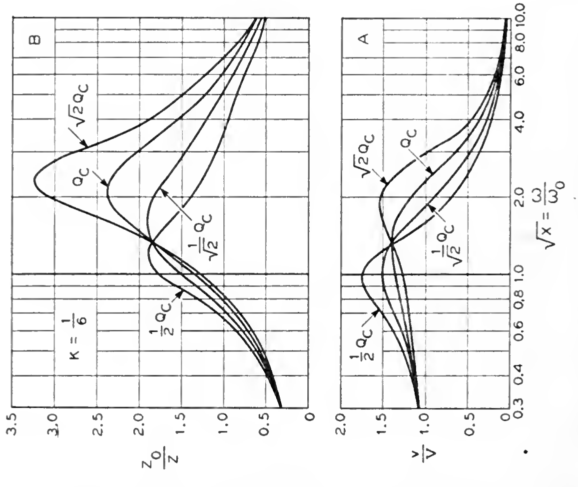

FIG. 7. Theoretical curves of performance of damped roller film propulsion system.

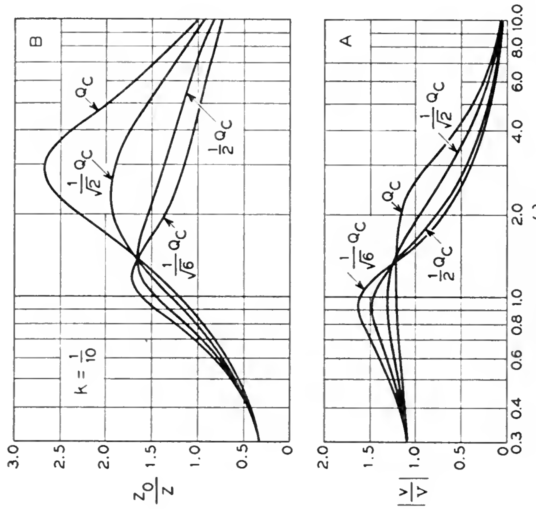

FIG. 8. Theoretical curves of performance of damped roller film propulsion system.

all other factors remain the same, an increase in the liquid mass always leads to an improved flutter *vs.* frequency characteristic. Aside from cost, the disadvantages of such an increase are that the load on the bearing carrying the roller will be greater and that either a greater starting torque or a longer starting time will be required. An increase in bearing load means an increase in the load-side disturbances and a decrease in the compliance C of the driving film link. Both effects operate to give an increase in flutter. In an analysis of the effect of k on performance, it is more rational to proceed under the assumption that the total mass $M + m$ of the roller remains fixed. Then the bearing load, the angular resonance frequency ω_0, and the starting conditions will all remain the same. In the discussion immediately to follow, this condition will be assumed.

From equations *2* and *6*, we see that when x is large

$$\left|\frac{v}{V}\right|^2 = \frac{1}{k^2x^2} \text{ and } \left|\frac{Z_0}{Z}\right|^2 = \frac{1}{k^2x}$$

We therefore conclude that for greatest protection against high-frequency flutter, k should be as large as possible. On the other hand, equations *5* and *9* show that where the main interest lies in keeping the flutter small in the resonance region, k should have the owest possible value.

In order to present a better picture of these various relations for a vider frequency range, a series of plotted curves are reproduced in Figs. 5 to 8. In these figures, Q_c is set equal to $[(1 + k)/2k]^{1/2}$, the critical value of Q which will reduce the peak value of the flutter resulting from driving-side disturbances to a minimum.

On comparing the curves for $k = {}^1/_2$ with those for which $k = {}^1/_3$, ve see that both for the load-side and for the driving-side disturbances, there is a marked improvement in the peak flutter in going o the smaller value of k. Unless ω_0 can be made so low in frequency hat no flutter is easily noticeable in this frequency region, it will enerally be advisable to go to the smaller ratio—even though the ttenuation at the higher frequencies is only half as great. In going o still lower values of k, a high price has to be paid in high-frequency ttenuation for a little gain in low-frequency performance. The reatest possible gain in the resonance region would be a reduction f the peak value of the flutter by a factor of 2. But this gain could ot be obtained for both types of disturbances since the peak frequency separation is increased as k is decreased. Referring to the gures, we see that as a rule Q is advantageously adjusted to a value wer than Q_c. For instance, if Q is made equal to $Q_c/\sqrt{2}$, when k is qual to 2, the peak flutter produced by the driving-side disturbances is raised about 10 per cent, but the peak occurs at a lower frequency, where a given amount of flutter is less audible, and, at slightly higher frequencies, the attenuation is greater. For example, at $\omega = 2\omega_0$, it is 30 per cent greater. Fig. 6(*B*) shows that, as regards flutter caused by load-side disturbances, the larger value of *R* gives improved performance in every respect.

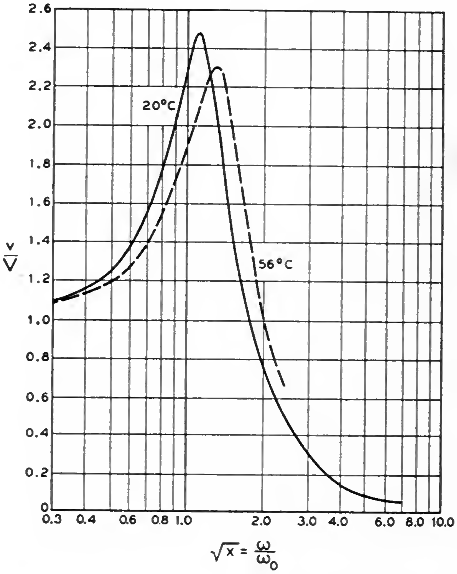

FIG. 9. Experimental performance curves of damped roller used in stereophonic film system.

The curves show that relatively little is gained in respect to the height of the peaks in going to values of *k* less than $^1/_3$, and much is lost in attenuation at the higher frequencies, particularly for the load-side disturbances. A general statement about an optimal value of *k* with reference to flutter attenuation can not be made, as in sound-film apparatus this would depend upon the relative audibility of flutter in the various frequency regions, the resonance frequency of the system, and the magnitudes and frequencies of the disturbances on both the driving and the load sides.

Fig. 9 shows the characteristics of a roller of one of the machines used in making the stereophonic orchestra records.* The roller was hung by a wire with the wire and roller coaxial, to form a torsional pendulum. Means were provided for twisting the top of the wire sinusoidally at a controllable frequency. One curve shows the amplitude of oscillation of the roller so supported when the amplitude of the "disturbance" at the point of support was held constant and the frequency varied. This curve was taken at room temperature. The other curve was obtained in the same way, but at a temperature of 56°C. The effect of raising the temperature is a decrease in the viscosity of the liquid and a consequent lowering of the coupling resistance. From the coördinates of the point of intersection of these two curves, k and Q may be determined by expressions 3 and 4. These measurements showed that the effective masses of the liquid and shell were in the ratio of 1.59, whereas the roller was designed to have a value of 2 for this ratio. When subsequently better account was taken of the amount of liquid that effectively adheres to the walls of the shell at the resonance frequency, excellent agreement was found between the computed and empirical values.

REFERENCES

[1] COOK, E. D.: "The Technical Aspects of the High-Fidelity Reproducer," *J. Soc. Mot. Pict. Eng.*, **XXV** (Oct., 1935), p. 289.

[2] CRANDALL, I. B.: "Theory of Vibrating Systems and Sound," *D. Van Nostrand Co.* (New York) p, 235.

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* The writers are indebted to Mr. L. A. Elmer for these measurements.

A NON-CINCHING FILM REWIND MACHINE*

L. A. ELMER**

Summary.—*Cinching, or the sliding between layers of film within a reel, produces scratches and surface abrasions which increase the film noise level. Cinching is more likely to occur in rewinding than anywhere else in the normal usage of sound-film. At the beginning of rewinding, when the supply reel is full and the take-up reel is empty, a small amount of torque is needed for rotating the take-up reel. Under this condition the film will be wound rather loosely. When the supply reel is nearly empty, relatively high film tension is required to produce a given torque on the supply reel. The torque to be applied to the take-up reel will then be high, on account of both the high film tension and the large radius arm of the film spiral on the reel. This high torque is almost certain to cause cinching in the loosely wound bottom portion of the reel. The conditions to be satisfied if cinching is to be avoided are analyzed. A power-driven rewind is described which meets these requirements. The film tension is controlled by the weight of the film on the supply reel at all times during the rewind.*

It is generally known that a sound-film record becomes more noisy with successive playings. Some of this increased noise is the result of dust and grease which accumulate on the film while it passes through the projector. More of it is caused by scratches and abrasions on the film. In modern projectors and sound-heads and other film-handling machinery, that area of the film which carries the sound record never comes into contact with anything which could mar its surface except the adjacent layers of film on the supply and take-up reels. The sound record areas of film, therefore, should suffer very little damage during projection if sliding of the layers of film within the reels is prevented. In every operation involving the handling of stereophonic films, care was taken that this sliding or cinching did not occur.

A rewind machine was needed that could handle a 2000-ft reel of film rapidly and protect the film from cinching and exposure to even small amounts of dust. A commercial automatic rewind machine was found where the film was wound directly from the upper supply

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

reel to the lower take-up reel in a closed cabinet. The supply reel, however, supplied a constant torque and this would cause the film to be wound on the take-up reel at the start with a comparatively low tension and at the end with about three times the tension. Such a condition is conducive to serious cinching, especially if the film on the supply reel spindle is on a 2-inch diameter core instead of the usual 5-inch diameter reel core. To overcome this, a device was designed that provided a supply reel torque controlled by the amount of film on that reel.

A diagrammatic sketch of the machine is shown in Fig. 1. If the film is wound upon the take-up reel with such a tension as to give a constant torque to the take-up reel, it obviously can not cinch on this reel in the rewind process. It should be wound with a certain minimum tension at the outside of the take-up reel so it can be handled or threaded in a machine without danger of cinching. If this minimum tension was 250 grams for a 15-inch reel with a 5-inch diameter core, the maximum tension at the start of the reel would be 750 grams. With the machine of Fig. 1, this tension must be supplied by the feed reel, and this would cause cinching to occur on the supply reel at the start of the rewinding, unless the supply reel had been wound very tightly. Such a process would not be a convenient one.

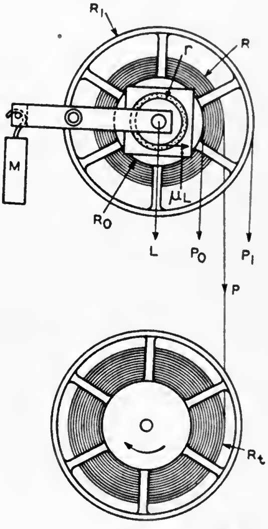

FIG. 1. Diagram of rewind machine and forces involved (Case *1*).

At times it was necessary to transfer the film from a 2-inch core to a reel with a 5-inch diameter hub or *vice versa*. To fit these many conditions, it was decided to make the initial and final winding tensions the same, so that a supply reel would have the same initial pull as it had final pull when it was in the take-up position. These tensions were set at about $^1/_2$ pound.

The supply reel is mounted on a shaft that is carried in the end of a lever pivoted on ball bearings. A friction drum, keyed to the shaft and supply reel, rotates with a loose fit in a ring lined with a brake material fixed in position and held against rotation. At the other end of the lever a means is provided for attaching weights which partially counterbalance the weight of the film, reel or plates friction drum, *etc.* The friction drag of the supply reel is caused by the weight of the film, reel, lever, and film tension pressing the drum against the brake shoe. The characteristics will be determined for such a rewinder when the film is fed (*1*) downward from the supply reel, (*2*) upward, and (*3*) horizontally. In the last two cases, the film would be fed over suitable rollers not shown in Fig. 1.

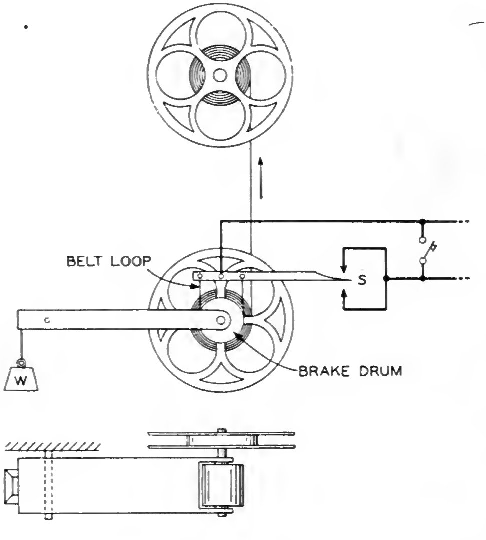

FIG. 2. Diagram of preferred arrangement of rewind machine (Case *2*).

The following notation will be used:

L = the desired load on the brake shoe due to the weight of the film, reel lever, and pull of the film (latter may be positive, negative, or zero)
μ = coefficient of friction between drum and brake shoe.
P = tension in the film between reels at any instant.
P_0 = pull of the film when the supply reel is nearly empty.
P_1 = pull of the film when the supply reel is nearly full.
W = weight of the empty reel (or plates and core), drum, and lever reaction
W_0 = the portion of W required to give the desired film tension.
w = weight of the film on the supply reel at any instant.
w_1 = weight of 2000 feet of film = 8.44 pounds.
r = radius of friction drum.
R = radius to outside of supply reel film at any instant.
R_t = radius to outside of take-up reel film at any instant.

R_0 = radius of supply reel core.
R_1 = radius to outside layer of supply reel film when full.
L_1/L_2 = lever ratio (reel arm/weight arm).
M = weight to be hung on lever to give proper film tension.

Case 1. Film Pulled Downward from Supply Reel.—By taking noments about the reel axis $\mu Lr = PR$ and since $L = W_0 + w + P$,

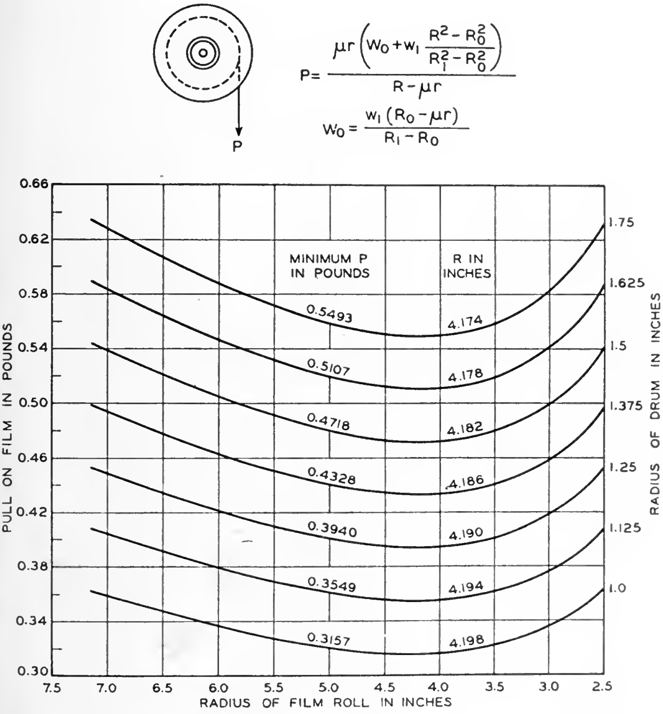

FIG. 3. Chart of film tension for Case *1*, downward pull.

ie moments equation becomes $\mu r(W_0 + w + P) = PR$, which reuces to

$$P = \frac{\mu r(W_0 + w)}{R - \mu r} \tag{1}$$

Since it is desired to have P the same for a full or empty reel

$$P = \frac{\mu r(W_0 + w_1)}{R_1 - \mu r} = \frac{\mu r W_0}{R_0 - \mu r} \tag{2}$$

Solving for the necessary pressure on the brake shoe

$$W_0 = \frac{w_1(R_0 - \mu r)}{R_1 - R_0} \tag{3}$$

The weight to be hung on the other end of the lever is

$$M = (W - W_0)\frac{L_2}{L_1} \tag{4}$$

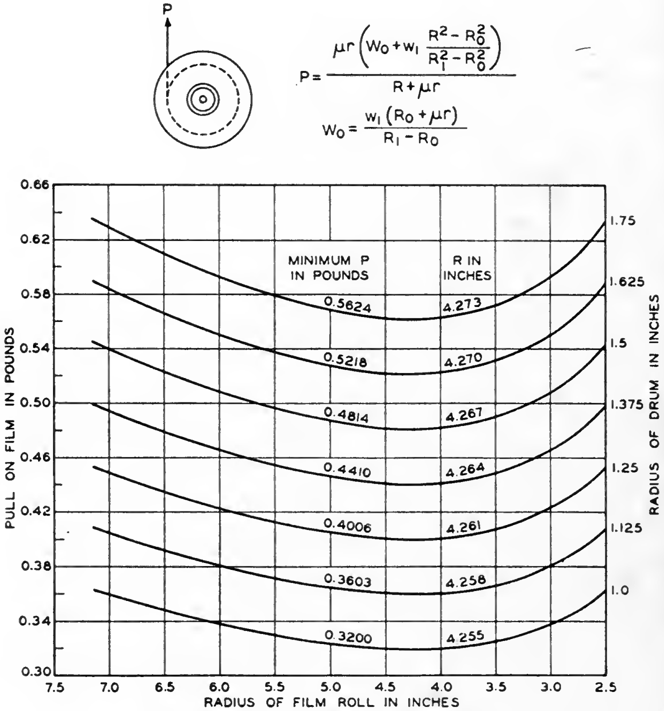

FIG. 4. Chart of film tension for Case *2*, upward pull.

Case 2. Film Pulled Upward from the Supply Reel.—In this case μr in the denominator of equation *1* has a positive sign and

$$P = \frac{\mu r(W_0 + w)}{R + \mu r} \tag{5}$$

and

$$W_0 = \frac{w_1(R_0 + \mu r)}{R_1 - R_0} \tag{6}$$

and the weight to be used as a counterbalance will be found by equation *4* with the new value of W_0 used (see Fig. 2).

Case 3. Film Pulled Horizontally from the Supply Reel.—In this case $L = W_0 + w$ and as before $\mu Lr = PR$ so

$$P = \frac{\mu r(W_0 + w)}{R} \tag{7}$$

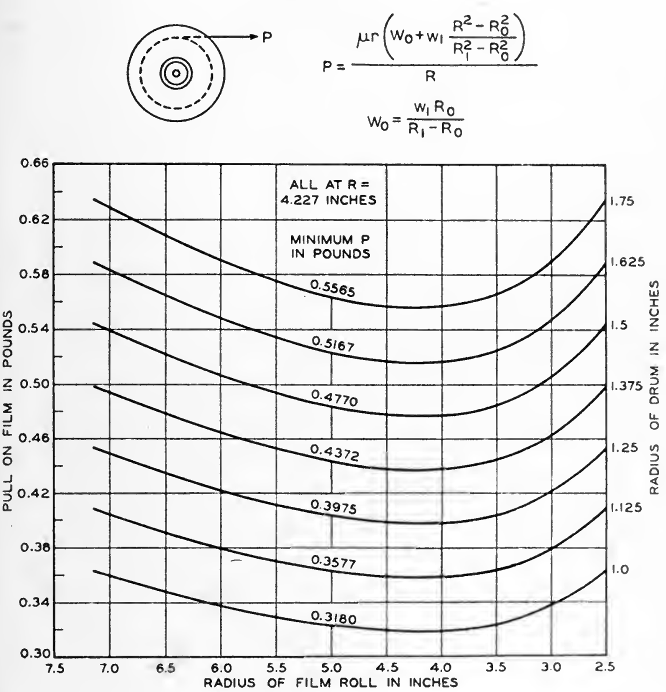

FIG. 5. Chart of film tension for Case *3*, horizontal pull.

nd

$$P = \frac{\mu r(W_0 + w_1)}{R_1} = \frac{\mu r W_0}{R_0} \tag{8}$$

nd

$$W_0 = \frac{w_1 R_0}{R_1 - R_0} \tag{9}$$

or Case *3* with a horizontal pull, W_0 may be calculated directly rom the known factors in equation *9*. Placing this in equation *8*, r

may be obtained from the value of P that was chosen as desirable This value of r will give a film tension, P, between the values from corresponding curves of Figs. 3 and 4. If P is to be $^1/_2$ pound, is $1^3/_8$ inches, assuming a coefficient of friction of 0.2.

For Cases *1* and *2*, the solution is slightly more complicated as the size of the drum radius, r, must be assumed. If the r found for Case is used for Cases *1* and *2*, the film tension will be very nearly equa to that given by equation *8* and will be the same for the start of reel as for the end of a reel. The weight of the film on the suppl reel is at any instant.

$$w = w_1 \frac{R^2 - R_0^2}{R_1^2 - R_0^2} \tag{10}$$

Placing this in *1*

$$P = \frac{\mu r \left(W_0 + w_1 \dfrac{R^2 - R_0^2}{R_1^2 - R_0^2} \right)}{R - \mu r} \tag{11}$$

A similar formula is obtained for Case *2:*

$$P = \frac{\mu r \left(W_0 + w_1 \dfrac{R^2 - R_0^2}{R_1^2 - R_0^2} \right)}{R + \mu r} \tag{12}$$

If it is desired to find the maximum departure of the film tension from a constant value, equation *11* may be differentiated with respect to R and setting

$$\frac{dP}{dR} = 0$$

R will be a minimum at

$$R = \mu r + \sqrt{\mu^2 r^2 + R_1 R_0 - \mu r(R_1 + R_0)} \tag{13}$$

by substituting the value of W_0 given in equation *3*. For example r may be chosen as 1.375 inches and let $\mu = 0.2$, $R_1 = 7.15$ inches and $R_0 = 2.5$ inches. Then P is a minimum at $R = 4.186$ inches and $P =$ 0.433 lb at this radius. At the start and end of the reel, $P = 0.5$ lb

If the film is pulled upward from the supply reel, the pull wil reach a minimum in a similar manner. The pull is a minimum at

$$R = -\mu r + \sqrt{\mu^2 r^2 + R_1 R_0 + \mu r(R_1 + R_0)} \tag{14}$$

Using the same dimensions as before, P is a minimum for Case at $R = 4.264$ inches. W_0 is found from equation *6* to be 5.035 lbs and the pull $P = 0.441$ lb at this minimum point. At the beginning and end of the rewinding P is again 0.5 lb.

Figs. 3 and 4 show curves for the film pull plotted against radius to outside turn on the supply reel for Cases *1* and *2*, respectively, for various drum radii. Fig. 5 is a similar chart for Case *3*, the condition where the film is pulled horizontally from the supply reel. The film pull for the three directions has been plotted on a combined chart, Fig. 6, for comparison.

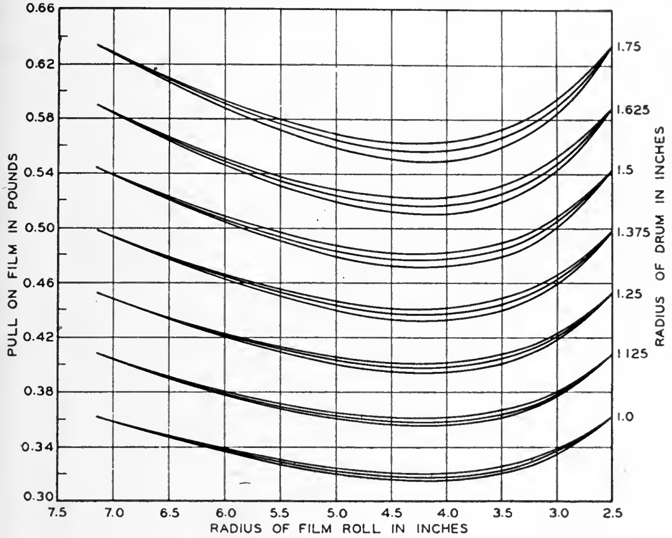

FIG. 6. Comparison of film tensions for Cases *1*, *2*, and 3.

The weight M to be hung on the other end of the lever depends upon the size and weight of reel or plates and core to be used, as these determine the W in equation *4* and the R_1 and R_0 in equations *3*, , and *9*.

Case *2* has an advantage over the other designs in that the friction can never become so great as to break the film. A brake-band as shown in Fig. 2 is preferable to a brake shoe, as it can be made to give a more constant drag. The rocking lever to which the belt loop s fastened operates a contact switch S if the supply reel is rotating n either direction. If the supply reel is stationary, a pair of springs, not shown, return the lever to its mid-position, opening the contact switch. The key shown in parallel with switch S is a jogging switch for starting the rewind.

DISCUSSION

MR. CRABTREE: Does this machine insure the winding of a tight roll? Even though the roll is wound at a constant tension, unless it is tight, cinches and scratches will result from subsequent handling.

MR. ELMER: The machine insures the winding of a tight roll with the proper weight hanging on the lever arm. Cinches and scratches will result from handling unless the roll is wound under sufficient minimum tension. The machine is designed to allow sufficient tension at a substantially constant and predetermined value.

CURRENT LITERATURE OF INTEREST TO THE MOTION PICTURE ENGINEER

The editors present for convenient reference a list of articles dealing with subjects cognate to motion picture engineering published in a number of selected journals. Photostatic copies may be obtained from the Library of Congress, Washington, D. C., or from the New York Public Library, New York, N. Y. Micro copies of articles in magazines that are available may be obtained from the Bibliofilm Service, Department of Agriculture, Washington, D. C., at prevailing rates.

American Cinematographer	
22 (August, 1941), No. 8	
Let's Design Pictures for the Camera (pp. 366–367, 394)	G. WILES
A Versatile New Lighting-Control Switchboard (pp. 368, 396)	H. NYE AND M. MORAN
Canada's War Movies (pp. 370, 396–397)	C. W. HERBERT
Filming Underwater Movies from the "Hole" in the Water (pp. 371, 397–398)	L. KNECHTEL
Electronics	
14 (August, 1941), No. 8	
Photographic Analysis of Television Images (pp. 24–29)	D. G. FINK
Institute of Radio Engineers, Proceedings	
29 (July, 1941), No. 7	
The Synthetic Production and Control of Acoustic Phenomena by a Magnetic Recording System (pp. 365–371)	S. K. WOLF
International Projectionist	
16 (May, 1941), No. 5	
First Commercial Television Theater in America Is Rialto, New York City (pp. 7–9)	L. CHADBOURNE
Screen Brightness, Theater Design, Power Survey on SMPE Agenda (pp. 11–15)	
A Report of the Theater Engineering Committee of the SMPE	
A Unique Film Scanner for Testing Television Transmission Images (pp. 18–19)	W. A. KNOOP
16 (June, 1941), No. 6	
Lubricants and Their Applications (pp. 7–8, 10)	L. CHADBOURNE
"Increased Range" System Promised to Revolutionize Photography (pp. 11–12)	W. KAEMPFFERT
The Intermittent Carbon Arc (pp. 13–18)	F. T. BOWDITCH, R. B. DULL, AND H. G. MACPHERSON

RCA Theater-Television Technical Data (pp. 19–21) — I. G. MALOFF AND W. A. TOLSON

Motion Picture Herald (Better Theaters Section)
144 (August 23, 1941), No. 8

Determining the Picture Size and Screen Light Required (pp. 24, 26–27)

Ventilating Projection Rooms and Arc Lamps (pp. 32–35, 37)

BACK NUMBERS OF THE TRANSACTIONS AND JOURNALS

Prior to January, 1930, the *Transactions* of the Society were published quarterly. A limited number of these *Transactions* are still available and will be sold at the prices listed below. Those who wish to avail themselves of the opportunity of acquiring these back numbers should do so quickly, as the supply will soon be exhausted, especially of the earlier numbers. It will be impossible to secure them later on as they will not be reprinted.

	No.	Price		No.	Price		No.	Price
1924	19	$1.25	1926	25	$1.25	1928	33	$2.50
	20	1.25		26	1.25		34	2.50
1925	21	1.25		27	1.25		35	2.50
	22	1.25		28	1.25		36	2.50
	23	1.25	1927	29	1.25	1929	37	3.00
	24	1.25		32	1.25		38	3.00

Beginning with the January, 1930, issue, the JOURNAL of the Society has been issued monthly, in two volumes per year, of six issues each. Back numbers of all issues are available at the price of $1.00 each, a complete yearly issue totalling $12.00. Single copies of the current issue may be obtained for $1.00 each. Orders for back numbers of *Transactions* and JOURNALS should be placed through the General Office of the Society and should be accompanied by check or money-order.

FIFTIETH SEMI-ANNUAL CONVENTION

OF THE

SOCIETY OF MOTION PICTURE ENGINEERS

HOTEL PENNSYLVANIA, NEW YORK, N. Y.
OCTOBER 20TH–23RD, INCLUSIVE

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Hotel Reservations and Rates

Reservations.—Early in September, room-reservation cards will be mailed to members of the Society. These cards should be returned as promptly as possible in order to be assured of satisfactory accommodations. Reservations are subject to cancellation if it is later found impossible to attend the Convention.

Hotel Rates.—Special *per diem* rates have been guaranteed by the Hotel Pennsylvania to SMPE delegates and their guests. These rates, European plan, will be as follows:

Room for one person	\$3.50 to \$8.00
Room for two persons, double bed	\$5.00 to \$8.00
Room for two persons, twin beds	\$6.00 to \$10.00
Parlor suites: living room, bedroom, and bath for one or two persons	\$12.00, \$14.00, and \$15.00

Parking.—Parking accommodations will be available to those motoring to the Convention at the Hotel fireproof garage, at the rate of $1.25 for 24 hours, and $1.00 for 12 hours, including pick-up and delivery at the door of the Hotel.

Convention Registration.—The registration desk will be located on the 18th floor of the Hotel at the entrance of the *Salle Moderne* where the technical sessions will be held. All members and guests attending the Convention are expected to register and receive their badges and identification cards required for admission to all the sessions of the Convention, as well as to several *de luxe* motion picture theaters in the vicinity of the Hotel.

Technical Sessions

The technical sessions of the Convention will be held in the *Salle Moderne* on the 18th floor of the Hotel Pennsylvania. The Papers Committee plans to have a very attractive program of papers and presentations, the details of which will be published in a later issue of the JOURNAL.

Fiftieth Semi-Annual Banquet and Informal Get-Together Luncheon

The usual Informal Get-Together Luncheon of the Convention will be held in the Roof Garden of the Hotel on Monday, October 20th.

On Wednesday evening, October 22nd, will be held the Silver Anniversary Jubilee and Fiftieth Semi-Annual Banquet at the Hotel Pennsylvania. The annual presentations of the SMPE Progress Medal and the SMPE Journal Award will be made and officers-elect for 1942 will be introduced. The proceedings will conclude with entertainment and dancing.

Entertainment

Motion Pictures.—At the time of registering, passes will be issued to the delegates of the Convention admitting them to several *de luxe* motion picture theaters in the vicinity of the Hotel. The names of the theaters will be announced later.

Golf.—Golfing privileges at country clubs in the New York area may be arranged at the Convention headquarters. In the Lobby of the Hotel Pennsylvania will be a General Information Desk where information may be obtained regarding transportation to various points of interest.

Miscellaneous.—Many entertainment attractions are available in New York to the out-of-town visitor, information concerning which may be obtained at the General Information Desk in the Lobby of the Hotel. Other details of the entertainment program of the Convention will be announced in a later issue of the JOURNAL.

Ladies' Program

A specially attractive program for the ladies attending the Convention is being arranged by Mrs. O. F. Neu and Mrs. R. O. Strock, *Hostesses*, and the Ladies' Committee. A suite will be provided in the Hotel where the ladies will register and meet for the various events upon their program. Further details will be published in a succeeding issue of the JOURNAL.

PROGRAM

Monday, October 20th

9:00 a. m. *Hotel Roof;* Registration.

10:00 a. m. *Salle Moderne;* Technical session.

12:30 p. m. *Roof Garden;* Informal Get-Together Luncheon for members, their families, and guests. Brief addresses by prominent members of the industry.

2:00 p. m. *Salle Moderne;* Technical session.

8:00 p. m. *Salle Moderne;* Technical session.

Tuesday, October 21st

9:00 a. m. *Hotel Roof;* Registration.

9:30 a. m. *Salle Moderne;* Technical session.

2:00 p. m. *Salle Moderne;* Technical session.
Open evening.

Wednesday, October 22nd

9:00 a. m. *Hotel Roof;* Registration.

9:30 a. m. *Salle Moderne;* Technical and Business session.
Open afternoon.

8:30 p. m. Fiftieth Semi-Annual Banquet and Dance.
Introduction of officers-elect for 1942.
Presentation of the SMPE Progress Medal.
Presentation of the SMPE Journal Award.
Entertainment and dancing.

Thursday, October 23rd

10:00 a. m. *Salle Moderne;* Technical session.

2:00 p. m. *Salle Moderne;* Technical and business session.
Adjournment

W. C. KUNZMANN,
Convention Vice-President

ABSTRACTS OF PAPERS

FOR THE

FIFTIETH SEMI-ANNUAL CONVENTION

HOTEL PENNSYLVANIA
NEW YORK, N. Y.
OCTOBER 20-23, 1941

The Papers Committee submits for the consideration of the membership the following abstracts of papers to be presented at the Fall Convention. It is hoped that the publication of these abstracts will encourage attendance at the meeting and facilitate discussion. The papers presented at Conventions constitute the bulk of the material published in the Journal. The abstracts may therefore be used as convenient reference until the papers are published.

A. C. Downes, *Editorial Vice-President*
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G. E. Matthews
W. H. Offenhauser
R. R. Scoville
S. P. Solow
W. V. Wolfe

Dynamic Screen—a Speculation; Robert W. Russell, *Training Film Production Laboratory,* Ft. Monmouth, N. J.

Within its present limits, various phases of the motion picture have been brought close to technical exhaustion and artistic satisfaction. Competition with color television and other forms of entertainment require that motion pictures come forth with another "sudden impact of novelty" similar to its other great discoveries: screen personalities, story, montage, sound, color. One great frontier remains for film-makers and engineers: the selective delimitation of the screen. The familiar rectangular screen shape forces the motion picture to accomplish everything within a rigid opening like a window. Feeble attempts have been made to vary this arbitrary shape, usually by trying to substitute other arbitrary shapes: the "Grandeur" wide-film, the square frame, the circular "iris-in," camera matte shapes. Unprogressive justification for the present rectangle is in static painters' composition, in commercial standardization, and in a false claim of relationship to the "Golden Section" rectangle. It is possible to speculate on a new type of motion picture production using the unlimited, unframed "Dynamic Screen," permitting another "sudden impact of novelty" to meet the increasing competition of similar medium of entertainment. Great new frontiers of cinematic effect are opened up by making the screen area the entire proscenium wall, by employing a projector lens that will throw the 35-mm frame to cover this whole wall as a potential, and by selectively limiting the projected image to smaller pictures within this potential, using peculiarly appropriate or eccentric delimitations in an overall montage of boundaries. Such a production can be imagined, described, and even accomplished with present-day equipment.

Mobile Television Equipment; R. L. CAMPBELL, R. E. KESSLER, R. E. RUTHERFORD, AND K. V. LANDSBERG, *Allen B. DuMont Laboratories*, Passaic, N. J.

While portability is a necessary requirement for outside pick-up equipment, several advantages result when portability is carried into the studio. To equip a studio of adequate size with fixed equipment for operation of several cameras involves considerable time and expenditure. However, with portable studio equipment, the entire equipment installation can be located to suit studio needs, as well as moved to different studios or outside locations.

The dolly type of equipment is described in some detail, and systems for program control are discussed. Some of the design features discussed are portability and flexible synchronizing equipment; electronic view finders; oscilloscope monitors; and other operating facilities.

Production and Release Applications of Fine-Grain Films for Variable-Density Sound Recovery; C. R. DAILY, *Paramount Pictures, Inc.*, Hollywood, Calif.

Fine-grain film materials have supplanted the normal positive type emulsions for all variable-density sound-recording and printing operations. The sound-quality improvement realized by the reduction in noise and distortion is now available for all sound operations, including release prints. The paper describes a number of problems encountered and solved in the commercial application of such films for sound recording, including factors affecting the choice of negative and print materials, noise, distortion, sensitometric characteristics, recorder lamp supplies, and noise problems on stages.

Laboratory Modification and Procedure in Connection with Fine-Grain Release Printing; J. R. WILKINSON AND F. L. EICH, *Paramount Pictures, Inc.*, Hollywood, Calif.

While fine-grain emulsions have been in general use for specialty purposes for three years or more, their use as a medium for release prints is comparatively recent. This paper discusses the necessary modifications required in a release print laboratory to produce satisfactory fine-grain release prints. The discussion covers the light-source, power supply, light-testing, and printing equipment. Observations noted while processing the first thirty million feet of release prints are made relative to the behavior and characteristics of the film.

A Note on the Processing of Eastman 1302 Fine-Grain Release Positive in Hollywood; V. C. SHANER, *Eastman Kodak Co.*, Hollywood, Calif.

A brief historical résumé is given of a series of fine-grain films that have been put upon the market during the past four years. This series of fine-grain films culminated with the acceptance of Eastman *1302* fine-grain release positive at one Hollywood laboratory to the exclusion of regular positive of the *1301* type for release printing. Experimental data are presented to show the comparative sensitometric characteristics of fine-grain positive *1302* and regular positive *1301* at various *p*H values and potassium bromide concentrations typical of Hollywood positive developers. A basic positive developer formula derived from chemical analyses of every release positive developer in Hollywood was used in the experimental work. Some practical facts are discussed, based upon the experiences obtained from the initial use of the fine-grain film in Hollywood.

A Frequency-Modulated Control Track for Movietone Prints; J. G. FRAYNE AND F. P. HERRNFELD, *Electric Research Products, Inc.*, Hollywood, Calif.

A 5-mil frequency-modulated track located between sound and picture areas is proposed to control reproduction in the theater from one or more sound-tracks. A variation of approximately one octave in the control frequency provides a 30-db change in volume range which may be used in part for volume expansion of loud sounds or as noise reduction for weak sounds. The control-track frequency is varied manually and recorded simultaneously with the sound-track in the dubbing operation, the gain of the monitoring channel being varied in accordance with the control frequency to produce automatically the enhanced volume range desired from the release print. The track is recorded in line with the standard sound-track, and does not require separate printing or reproducing apertures. It is scanned by a separate photosensitive surface, the output being converted from frequency to voltage variations by a frequency-discriminating network identical to that used in the monitoring channel. The output from the network, applied to the grid of a variable-gain amplifier in the sound channel, controls automatically the volume of the reproduced sound in accordance with that observed in the dubbing operation.

The Design and Use of Film Noise-Reduction Systems; R. R. SCOVILLE AND W. L. BELL, *Electrical Research Products, Inc.*, Hollywood, Calif.

The factors underlying the design and use of biased recording systems are described. In order to minimize noise and "shutter bump" special precautions in filtering must be taken. Suitable values for "attack" and "release" times are dependent upon the type of recording, margin settings, and reproducing conditions. Comparison of variable-density and variable-area requirements is made. Methods used in designing the rectifiers, filters, and other circuit details are given and the application to a new equipment known as the *RA-1124* noise-reduction unit is shown.

Streamlining a Sound Plant; L. L. RYDER, *Paramount Pictures, Inc.*, Hollywood, Calif.

This paper discusses the trend in modern sound-recording equipments. It reviews the objectives and requirements that are now existing in regard to studio recording as contrasted to previous recording systems. Several new developments in the art of sound recording are discussed and from this group are selected a complementary series of improvements which together are streamlined into a new recording plant.

A Precision Direct-Reading Densitometer; M. H. SWEET, *Agfa Ansco Corp.* Binghamton, N. Y.

The history of physical densitometers is briefly discussed. In spite of developments in modern electronic circuits, simple photoelectric instruments suitable for routine sensitometry are not yet in common use. The present densitometer is designed to fill this need.

The minimum requirements for a satisfactory instrument are outlined. Photographic density as such, and density standardizations are discussed.

The densitometer density of the present instrument as related to that of other types is demonstrated. The optical aspects, including the geometry and spectral qualities of the system, are explained, and the problem of calibration discussed. Emphasis is placed upon the practical agreement of different optical systems suitably calibrated, and specific examples are shown.

The circuit arrangements of previous photoelectric densitometers are outlined. The theory and practical development of the present electrical circuit are described, and the effects of the novel features are shown. An accurate linear density scale is obtained in a single-stage d-c amplifier, and the sensitivity is sufficient to permit the use of a rugged output meter. A density range of 0 to 3.0 is covered, and the characteristics of the output meter are given.

The technics used in prior densitometers in attempting to secure a linear density scale and adequate scale length for good legibility are discussed, and the technic used in the present instrument is compared with them. The performance characteristics of the electrical circuit make it suitable for application to recording instruments.

The routine operation is described and the permanence of calibration is shown. Data are given on the warm-up period and drift, and on the influence of varying line voltage. Operation is entirely by alternating current. Practical performance considerations such as convenience in reading, eye fatigue, *etc.*, are reviewed, and figures showing the comparative speed of operation and reading accuracy are given.

A Review of the Question of 16-Mm Emulsion Position; WM. H. OFFENHAUSER, JR., *Precision Film Laboratories*, New York, N. Y.

When a 16-mm sound-film is properly threaded in a 16-mm projector, the emulsion of the film may face the screen (which position is called the "standard" position), or it may face the projector light-source (the "non-standard" emulsion position). The well designed 16-mm sound projector of today should be capable of projecting either "standard" or "non-standard" prints.

In the case of 35-mm film, the standard position for the emulsion of a print is opposite that for 16-mm; in 35-mm, the emulsion faces the light-source of a projector. The anomaly of the 16-mm emulsion position arose from the fact that a large number of the earliest 16-mm commercial sound-films were made by optical reduction from 35-mm negatives. Since the "standard" was established, however, numerous developments have occurred in direct 16-mm production which now practically compel the recognition of so-called "non-standard" prints as a factor of fast-growing importance in our rapidly growing 16-mm industry. The expression "non-standard" emulsion position no longer carries the stigma ordinarily associated with other things that are called non-standard.

Motion picture films may be printed either by contact (the emulsion of the film to be copied is in physical contact with the raw film upon which the copy is to be made) or by optical printing (the emulsions of the two films are not in physical contact; some form of lens system is interposed between the film to be copied and the raw film upon which the copy is to be made). By far, the largest percentage of picture film printed today is printed by contact methods. It does not seem likely that 16-mm picture film will be printed optically in the near future for a number of reasons, not the least of which is the lack of available lenses due to the defense program.

The use of Kodachrome duplicates has been growing very rapidly and since contact printing of Kodachrome originals will continue to be used for some time, the "non-standard" emulsion position will continue to be a rapidly growing factor in 16-mm sound-projection that can not be ignored.

Some Equipment Problems of the Direct 16-Mm Producer; L. THOMPSON, *The Calvin Company,* Kansas City, Mo.

The production of industrial films by the direct 16-mm method is now definitely out of the experimental stage.

As more industrial work is done by this method there is an increasing demand for more and better 16-mm equipment suitable for professional use. Such equipment can be developed successfully only after the professional user has found by actual experience what he needs and wants.

A number of 16-mm professionals were asked for suggestions as to what is needed. These suggestions, combined with the author's own ideas gained over a period of 10 years in the professional 16-mm field, form the basis of this paper. Some of the ideas presented could be acted upon immediately; some of them can not be put into practice until the demand for 16-mm service becomes even greater.

A Constant-Torque Friction Clutch for Film Take-Up; WILLIAM HOTINE, *The Rotovex Corp.,* East Newark, N. J.

From the standpoint of film protection, a take-up mechanism should be reliable, wear should not appreciably alter its characteristics, and it should maintain the film tension between safe limits. These objects are attained by driving the take-up spindle through a constant-torque clutch of novel construction and design. A new type of friction-clutch is described, which, when adjusted initially to deliver a given safe torque to the take-up spindle, maintains this torque at a constant value which can not be exceeded. The clutch construction is simple and rugged, and wear of the friction element does not appreciably affect the operation. Due to the fact that the torque at the take-up spindle is maintained at a constant value, a safe value of film tension is not exceeded. An analysis of the forces and mechanical constants of the clutch mechanism is given, deriving an equation of these in terms of torque delivered.

Recent Developments in Projection Machine Design; E. L. BOECKING AND L. W. DAVEE, *Century Projector Corp.,* New York, N. Y.

This paper discusses the design features of a new projector to meet the ever-increasing demands for accuracy and simplicity required by modern projection in the theater. Basic, fundamental, scientific functions of motion picture mechanism design are discussed relative to perfection of film motion, clearer definition, light transmission, and picture steadiness.

As in the design of any scientific mechanical device, the stability and inherent durability must first begin with perfection in the basic design and it must be built upon a foundation of engineering knowledge proved by practical operating experience. In order that these design features may be appreciated it will be the purpose to show how every step of the engineering design, every part of the mechanism, and every motion were carefully planned so that mechanical perfection could be achieved.

The design and operation of the gear-train are discussed with respect to its simplicity, mechanical accuracy, and long life; the design and operation of the bearings are reviewed in the light of recent developments relating to permanent operation with minimum servicing; and the intermittent movement operation is analyzed in relation to more stable operation and steadier picture reproduction.

The film-gate and film-trap design, providing more uniform film travel at less film tensions, is described as well as methods of obtaining perfect placement of the film plane with respect to the optical axis. Finally, the theoretical design features of single- and double-shutter operation are outlined and the actual operating results expected and realized discussed.

Economic and Technical Analysis of Arc Lamp and Screen Light Characteristics; H. D. BEHR, New York, N. Y.

Many exhibitors do not understand what is meant by the relative inefficiency of power for ultimate consumption at the arc in comparison to power actually delivered at arc. Deficiencies in various parts of the projection plant are described and a value is placed upon losses to emphasize the need for constant attention to details.

Tables are presented showing the excessive carbon and current costs that result when arcs are operated at higher currents due to defects in equipment. Emphasis is placed upon the fact that too many arcs operate at or near the upper limits for which they were designed and too little leeway is left for extra current to increase light for dull prints or color-prints.

Some ideas are given as to what to look for in competitive arc equipments. Various procedures are described for minimizing current and carbon waste due to poor reflector mirrors.

Suggestions of projectionists have too long been ignored by managements. The latter should take a little time from their booking and other problems to ascertain that poor screen light is costly and definitely contributes to drops in attendance.

The IR System: An Optical Method for Increasing Depth of Field; ALFRED N. GOLDSMITH, *Consulting Engineer*, New York, N. Y.

This paper is submitted as a report of progress made in the development of the increased range (IR) system. In it is described the solution of a long-standing problem in the field of optics, namely: the attainment of greater depth of field than is attainable by any previous method of utilizing a lens system for image formation.

The solution is particularly applicable in the fields of photography and television under conditions of controllable lighting of the external objects to be depicted. In this paper there will also be included methods for demonstrating the correctness and effectiveness in practice of the increased-range system which, as stated, has been invented to meet the need for increased depth of field, as well as indications of certain of the directions in which the practical evolution of the IR System may reasonably be expected to proceed under studio conditions.

Adventures of a Film Library; RICHARD GRIFFITH, *Museum of Modern Art Film Library,* New York, N. Y.

Collecting and circulating important films of the past is not as dusty an occupation as it sounds, as the director and curator of the Museum of Modern Art Film Library discovered when this institution was founded in 1935 for the purpose of instituting a considered study of the motion picture as art, industry, and social influence. Even the mechanical acts of collecting and preserving film have involved the human factor: people feel strongly about works that they themselves have created, criticized, or merely seen, and the collection of films both in this country and in Europe has been fraught with emotional, financial, and even political complications, while the number of illustrious personalities who have in one way or another become involved in the Film Library's work is prime evidence of the ability of even the most ancient fragments of celluloid to retain a contemporary as well as an archaeological interest.

Circulation of the Film Library's motion picture programs has also proved illuminating in its revelation of the attitude taken toward the film medium by all varieties of persons. The Film Library's purpose has from the first been to provide students with the opportunity to form a critical attitude by examining important films at first hand. But experts as well as laymen so warmly enjoy movies that many were at first reluctant to "spoil" their pleasure in films by examining them critically. As more and more historic films have been restored to the screen, however, there has gradually grown up throughout the United States a new appreciation which has learned not only to marvel at the rapid development of this new medium but also to discern its enormous and largely untapped potentialities.

A New Electrostatic Air-Cleaner and Its Application to the Motion Picture Industry; HENRY GITTERMAN, *Westinghouse Electric & Manufacturing Co.,* New York, N. Y.

The principle of electrostatic precipitation is not new. To the best of our knowledge, it was first enunciated in 1824. It was used in England in the late 80's of the last century. In this country the Cottrell process has been in use for approximately 30 years with great success. However, it was not until 1932 that Dr. G. W. Penney of the Westinghouse Research Laboratories produced an electrostatic precipitator that could be used in connection with atmospheric air breathed by human beings. This advance was due to the fact that Dr Penney's apparatus did not produce ozone in any appreciable amounts. Much lower voltages and currents have been possible through the use of this system. Instead of imposing huge voltages and currents upon a single system, in which ionization and precipitation took place in the same chamber, the new system consists of two parts. The first is made up of cylindrical rods alternating with small tungsten wires on which a potential of 12,000 volts at very low current is imposed. This creates an electrostatic field that charges all solid particles passing through it. The air-stream carrying these charged particles then passes through plates alternately charged negative and positive. The charged particles are precipitated against the oppositely charged plates. The efficiency of the system is such that guarantees can be made to remove 90 per cent of all solid particles in the air-stream down to and including $^1/_{10}$ of one micron in size. Ordinary air filters range in efficiency from 12 to about 40 per cent by particle count.

Of particular interest to motion picture engineers is the fact that three of the leading film-producing manufacturers in this country have adopted this system for air-cleaning in their plants. Several of the more prominent exhibitors are considering using it in some of their theaters. It is possible to maintain a much cleaner condition in the theaters themselves and thereby produce economy in redecorating the interiors. Furthermore, great savings are possible in the amount of outside air needed in air-conditioning systems, which will enable engineers to specify lower capacity cooling units without sacrificing any cooling effect whatsoever.

A number of installations are discussed describing the various aspects of particular interest to motion picture engineers.

Color Television; PETER C. GOLDMARK, *Columbia Broadcasting System, Inc.*, New York, N. Y.

The paper will be introduced with a brief history of color television and the reasons leading up to the CBS color television System. A general theory for color television, including color, flicker, and electrical characteristics, will be given. Equipment designed and constructed for color television transmission and reception will be discussed. Slides illustrating circuits, equipment, and actual color pictures will be shown.

Synthetic Aged Developers by Analysis; R. M. EVANS, W. T. HANSON, JR., AND P. K. GLASOE, *Eastman Kodak Co.*, Rochester, N. Y.

The dropping mercury electrode is applied to the problem of analyzing aged photographic developers, and new tests are described for elon and hydroquinone. The question of suitable tests for bromide is discussed and it is shown that the bromide test must be independent of chloride. Such a test is described.

Using these new technics and others it is demonstrated that it is possible and practicable by chemical analysis alone to match exactly the photographic characteristics of an aged *MQ* developer. The only elements necessary for such an analysis are elon, hydroquinone, sulfite, salt concentration, *p*H, bromide, and iodide. The precision required for the proper analysis for each constitutent has been investigated and is reported for three developer-film combinations. In general the precision required is different for every combination.

Iodide Analysis in an MQ Developer; R. M. EVANS, W. T. HANSON, JR., AND P. K. GLASOE, *Eastman Kodak Co.*, Rochester, N. Y.

A method is described for the analysis of iodide in a developer, involving precipitation of the halide with silver nitrate and oxidation of the iodide while it is in the form of solid silver iodide to iodate with chlorine water. The iodate is then determined polarographically. Quantities of iodide from 2.5 to 10 milligrams of potassium iodide were analyzed with an accuracy of 2 to 4 per cent. Thiocyanate in the developer interferes but it can be removed by boiling with strong sulfuric acid before precipitation.

Using this method of analysis it was shown that an equilibrium amount of iodide is obtained in a developer. Curves are given showing the attainment of equilibrium for development of Eastman panchromatic negative motion picture film in Kodak *D-76* and in *D-16* developers, and Eastman panchromatic positive motion picture film in Kodak *D-16* developer. The equilibrium value depends upon the emulsion, the developer, the developed density, and perhaps other variables which will be investigated more thoroughly.

SOCIETY ANNOUNCEMENTS

FIFTIETH SEMI-ANNUAL CONVENTION
HOTEL PENNSYLVANIA, NEW YORK, N. Y.
OCTOBER 20–23, 1941

The 1941 Fall Meeting will be the Fiftieth Semi-Annual Convention of the Society commemorating the Silver Anniversary of the Society's founding. Members are urged to make every effort to be present, as the various Committees of the convention are endeavoring to make this convention an outstanding one. Details will be found in a preceding section of this JOURNAL.

PACIFIC COAST SECTION

A meeting of the Pacific Coast Section was held on Tuesday, September 23rd, at the Naval Reserve Armory at Los Angeles, Calif. The program of the meeting opened with the introduction of Capt. I. C. Johnson, Director of Naval Reserves, followed by two discussions by officers of the Unit. Lt. Comdr. John Ford, U. S. N. R., spoke on "The Organization of the U. S. Naval Reserve Photographic Unit," followed by Lt. Comdr. A. J. Bolton, U. S. N., Retired, who discussed "Personnel and Equipment Requirements of the Photographic Unit."

Following these presentations a number of demonstration films produced by the Photographic Unit were projected, and the meeting concluded with a discussion by Mr. Emery Huse, President of the Society, on "Photographic Materials for Military Purposes."

The meeting was arranged as a joint session of the Pacific Coast Section with the U. S. Naval Reserve Photographic Unit.

MID-WEST SECTION

The meeting of the Mid-West Section was held at the meeting rooms of the Western Society of Engineers, Chicago, on September 30th, at which engineers of the DeVry Corporation described "A New and Improved Theater Sound Projector." The presentation included an interesting demonstration of the equipment.

AMENDMENTS TO THE BY-LAWS

At the meeting of the Board of Governors on July 24, 1941, several amendments to the By-Laws were proposed and approved for submission to the Society membership at the next Business Meeting, to be held during the 1941 Fall Convention. These proposed amendments are as follows:

PROPOSED AMENDMENTS FOR STUDENT MEMBERSHIP

By-Law I

Membership

Sec. 1.—It is proposed that the first paragraph of this Section shall be changed to read as follows:

The membership of the Society shall consist of Honorary members, Fellows, Active members, Associate members, Sustaining members, and Student members.

It is proposed that a new paragraph *d* be added to Sec. 1 as follows:

(*d*) *A student member is any person registered as a student, graduate or undergraduate, in a college, university, or educational institution, pursuing a course of studies in science or engineering which evidences interest in motion picture technology. Membership in this grade shall not extend more than one (1) year beyond the termination of the student status described above. A student member shall have the same privileges as Associate members of the Society.*

Sec. 2.—It is proposed that a new paragraph *e* be added to the end of this Section as follows:

(*e*) *Applicants for student membership shall give as reference the head of the Department of the Institution he is attending; this faculty member not necessarily being a member of the Society.*

By-Law VIII

Dues and Indebtedness

Sec. 1.—It is proposed that the first sentence of this Section be changed to read as follows:

The annual dues shall be Fifteen ($15.00) Dollars for Fellow and Active members, Seven Dollars and Fifty Cents ($7.50) for Associate members, and Three ($3.00) Dollars for Student members, payable on or before January 1st of each year . . . . .

PROPOSED AMENDMENTS FOR FELLOW MEMBERSHIP

By-Law I

Membership

Sec. 3(b).—It is proposed that this Section be changed to read as follows:

Fellow Membership may be granted upon recommendation of the Fellow Award Committee, when confirmed by a three-fourths majority vote of the Board of Governors.

By-Law IV

Committees

Sec. 4(a).—It is proposed to add to the list of standing committees appointed by the president and confirmed by the Board of Governors a new *Fellow Membership Award Committee.*

PROPOSED AMENDMENT RELATING TO TECHNICAL COMMITTEES

By-Law IV

Committees

Sec. 4(b).—It is proposed that to the list of standing committees appointed by the engineering vice-president be added a new *Committee on Cinematography*.

JOURNAL

OF THE SOCIETY OF

MOTION PICTURE ENGINEERS

Volume XXXVII **November, 1941**

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(*The Society is not responsible for statements by authors.*)

JOURNAL
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MOTION PICTURE ENGINEERS

SYLVAN HARRIS, EDITOR

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RÉSUMÉ OF AN EXTEMPORANEOUS ADDRESS BY

HOWARD HANSON*

AT THE JOINT MEETING OF THE SOCIETY OF MOTION PICTURE ENGINEERS
AND THE ACOUSTICAL SOCIETY OF AMERICA AT
ROCHESTER, N. Y., MAY 5, 1941

I feel somewhat concerned in attempting to address this eminent group of scientists and technicians. I am under the impression that you may expect me to embark upon a technical discussion of problems in sound reproduction and an evaluation, from the standpoint of the musician, of the effectiveness of the solution of those problems. Perhaps I am even expected to make criticisms and to suggest directions in which the musician feels that sound reproduction may be improved.

Some years ago in speaking before this same body I had the temerity to attempt something of the sort. Today I feel quite unable to carry that discussion further. This reluctance is due to my conviction that you as scientists are already far beyond us, the musicians. You have progressed in the matter of sound reproduction to the point where the fidelity of the recorded sound to the original is remarkable. You have embraced in your recording, frequencies, both high and low, which formerly were lost. You have even solved to a startling degree the problem of gradations in intensity so that a dynamic range which gives an adequate representation of an actual orchestral performance is possible.

In fact in some respects you have gone beyond "natural" sound in such a way as to raise a question in my mind as to the validity of taking as our final criterion the direct comparison of recorded sound with "natural" sound. In certain experiments such as those which we are having the privilege of witnessing this week Doctor Fletcher and his colleagues of the Bell Laboratories are convincing us that the term "enhancement" seems quite justified. Scientists and technicians have for some time held before themselves the ideal of reproducing sound qualities which could not be distinguished from the original. This

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* Director, Eastman School of Music, University of Rochester.

they have accomplished to an amazing degree. It seemed to me as I listened to the results of Doctor Fletcher's experiments that the time has come when sound reproduction can itself become creative—that science may produce tonal beauty of a quality which has no counterpart in the sounds of the musical instruments and ensembles which we know today. This seems to me to be a legitimate goal.

But there is something else which is much closer to my heart today. I have the uncomfortable feeling that you as scientists are too good for us—that you have given us tools which are beyond our ability to understand and to use wisely. The terrible condition of the world today is all too vivid an illustration of what I am saying. Science gives us the airplane with which we can annihilate space and bring mankind closer together. We convert the airplane into a bomber and use it to kill our fellows. The sciences of chemistry and of medicine give us the blessed means of easing human pain. We divert the same scientific inventiveness to the production of gases which burn out men's lungs. Science puts into our hands magnificent tools but we are so spiritually unprepared for these miracles that we are quite likely to use them for the purpose of committing physical and spiritual suicide.

Does the scientist have any responsibility in all of this moral chaos? Is his task only to produce the tools and to allow us to misuse them as we will? I do not believe so. It seems to me that those of you who are creating the mechanisms which the rest of us are to use must be interested in the use to which they are put. You can not remain aloof to the manner in which these products of your hands and brain serve humanity for good or ill.

I have spoken with enthusiasm of the work which you have done in the field of sound and I say again, you have been too good for us. In the field of radio, for example, you must at times have the feeling that all of us—composers, performers, scientists, and technicians—are banded together for the high and noble cause of selling soap. Now I have nothing against the selling of soap. Certainly from the amount of time devoted to it we must be the cleanest nation in the world. The women of America must have the softest of hands and the whitest of teeth or our efforts have been in vain. All this is doubtless important but it was certainly not for this that you have labored.

In the field of the motion picture too often the same condition obtains. Magnificent invention is used to serve a cause which is too frequently unworthy. The creative brain of the scientist dreams a vision and labors to realize it only to find that his invention has been used for meretricious ends.

Certainly today we must pause and consider whither we are progressing. Today as seldom before in history the world needs spiritual awakening. It needs the quickening and sensitizing spirit of beauty. It demands the re-birth of man's soul. Of what good is it if all of our science, all of our material production, leads only to poverty of the mind and the heart? Of what merit is it if through the invention of man's mind we save our bodies but lose our souls?

ANALYSIS OF SOUND-FILM DRIVES*

W. J. ALBERSHEIM AND D. MACKENZIE**

Summary.—*In order to avoid audible flutter, the velocity of sound-films past the scanning light-beam must not vary more than about 0.1 per cent. Such precision can not be obtained solely by constant speed motors and high-quality gears. Mechanical filters must suppress the "drive side" disturbances originating in motor, gear-train, and sprocket-teeth, and the "load side" disturbances due to variations in the film and in the friction load.*

Early designs filtered only the drive-shaft rotation and steadied the film by recording on a large sprocket drum. Filtered sprockets in combination with fixed reproducer gates were not adaptable to modern requirements and were superseded by film-driven damped impedance drums(rotary stabilizers).

The recommended design avoids the troublesome inner flywheel bearings by a liquid stabilizer and overcomes the uncertain filtering properties of film compliance by means of elastic driving sprockets.

It has been stated that the main function of a film-driving mechanism is to pull the film out of the upper magazine into the lower magazine. This is true with the provision that the motion of the film must be uniform as it passes through the focal line of a beam of light. If the film speed varies, the frequency of every sound recorded on the film will vary in proportion, causing flutter. How small variations of speed or frequency can become noticeable is seen from Fig. 1 which shows the frequency variations of pure oscillator tones which were barely audible to trained observers in a live auditorium.[1] Some of the listeners were able to notice a rhythmical speed variation of† 0.005 per cent in a 3000-cycle tone at the rate of 1.5 cycles per second. What the ear hears under such conditions are not the frequency variations directly, because if the same tones are heard through headphones the frequency variations must be increased nearly one hundred-fold to become audible. What the observers actually noticed was an amplitude pulsation due to shifting of a standing-wave pat-

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* Presented at the 1940 Fall Meeting at Hollywood, Calif.; received June 12, 1941.

** Electrical Research Products, Inc., New York, N. Y.

† Above and below mean frequency is understood throughout the paper.

tern between parallel walls. Fortunately, under practical conditions, one does not have to listen to oscillator tones nor in empty straight walled halls, so that practical flutter tolerances are considerably higher, as indicated by Fig. 2. Curve *1* of this figure shows the flutter limits for the sound heard in the theater which we set for our own guidance as early as 1935. It amounted to 0.25 per cent at flutter rates above 25 cps, to 0.15 per cent at flutter rates between 25 and 1 cps and increased with the inverse square-root of the frequency for frequency "drift" below 1 cps.

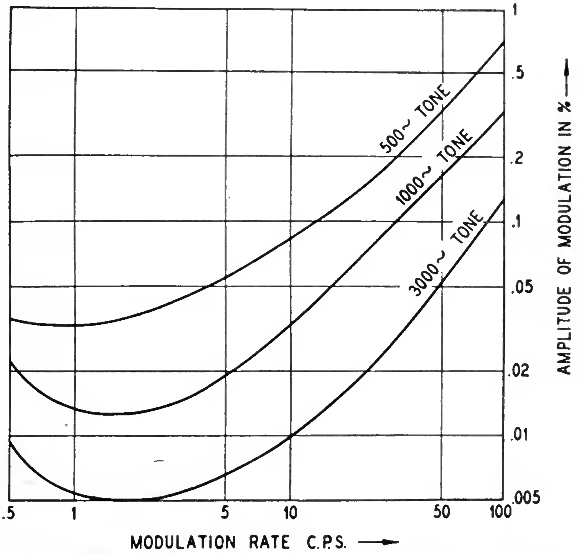

FIG. 1. Minimum perceptible frequency flutter (oscillator tones in live room).

The sound-film reproduction in the theater is the product of processes which involve generally at least three passages through film-driving mechanisms: the original recording process, the printing operation, and the reproduction. The number of cumulative speed distortions may be increased by re-recording operations. Assuming that the irregularities of the film motion are superimposed at random, one must take the total speed deviation as the root-sum-square of all contributory deviations. The irregularities of each step must therefore be held so far below the tolerance limit that they add up to a satisfactory total.

Economy requires us to impose the most lenient tolerances upon the apparatus used in the greatest quantity—that is, the theater reproducers—and to hold the recording and re-recording machines to closer limits. Accordingly, we allowed for the reproducer a high-frequency limit of 0.20 per cent, a low-frequency limit of 0.12 per cent, and drift limits increasing from 0.12 per cent as shown on Curve *2*. This left only a small margin for recording and re-recording flutter which were fixed at 0.10 per cent for high frequencies and 0.05 per cent for low frequencies (Curve *3*). In 1938 the Research Council of the Academy of Motion Picture Arts & Sciences recommended that the *total reproducer* flutter measured on our flutter bridge should not exceed 0.15 per cent (Curve *4*). This does not specify the frequency distribution. The bridge in its position for the measurement of "total flutter" has a flat output characteristic for flutter rates above 2 cps and a somewhat lower sensitivity for slow drift; it measures the power sum of individual flutter frequencies (rms addition). The Research Council requirement would therefore be satisfied by a 0.12 per cent 96-cycle flutter combined with a 0.08 per cent 3-cycle flutter and a 0.08 per cent $^1/_4$-cycle drift.

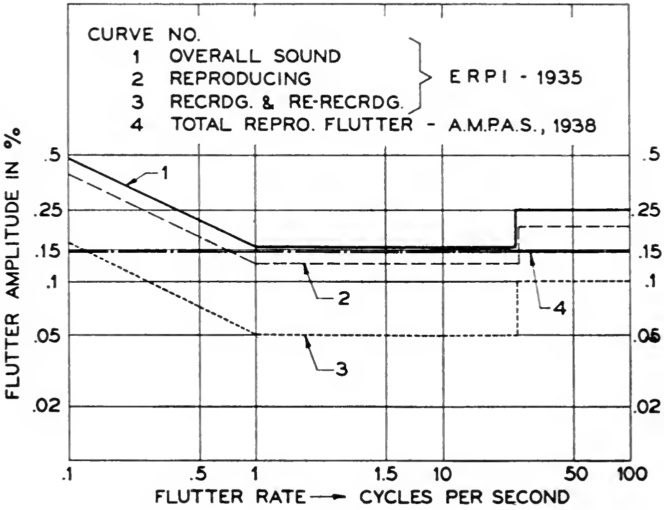

FIG. 2. Practical flutter tolerances.

Even these practical tolerances are by no means easily held. As the U. S. Circuit Court of Appeals stated in a well known decision:

The rapidly moving, flimsy, curling film must be uniform in its movements and so controlled that the position and motion of each fine line at the beam of light must be accurate within the thousandth of an inch.

Such precision requires high constancy of the motor speed, but it can not be attained by this means alone as will be seen from Fig. 3, which illustrates the flutter sources in unfiltered film drives. These are:

(*1*) *Drive-Side Disturbances* (irregularities in the force which pulls the film past the reference point).

(*a*) The motor supplies not only the steady (d-c) torque but it is subject to periodic power main surges and to vibrations at the high frequencies of the alternating current with its harmonics and at its own speed of revolution.

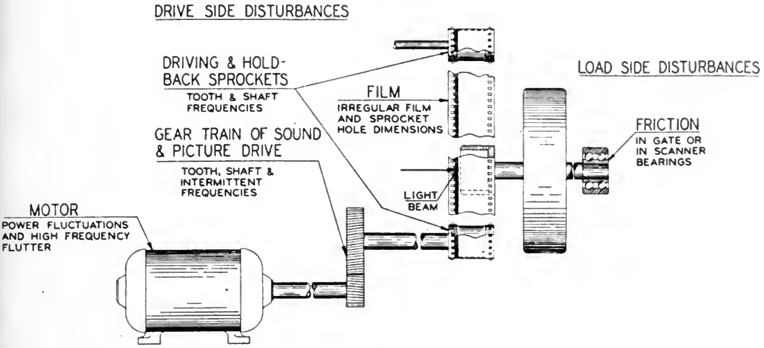

FIG. 3. Flutter sources in unfiltered film drives.

(*b*) The gear-trains needed for speed reduction and synchronization of picture and sound introduce the frequencies of their shafts and gear teeth—and their sums and differences. The most pronounced tooth frequency is that of the driving-sprocket teeth, 96 cps. Another disturbance impressed upon the gear-train of theater reproducers is the 24-cps intermittent frequency. This frequency may also be introduced by the variation of free loop length between the scanning point and the picture hold-back sprocket.

(*c*) The irregularities of the film intervene between the driving sprocket and the scanning light-beam.

(*2*) *Load-Side Disturbances* (irregularities in the mechanical impedance opposing film motion past the reference point).

(*a*) If scanned in a gate, the film is subject to irregular gate friction; if scanned on a rotating drum, to irregular bearing friction and to unbalance of rotating parts.

The requirement of passing without reduction the d-c motion and attenuating the unwanted a-c components can be met only by a type of structure which is the mechanical equivalent of a device well known in electrical transmission theory as a low-pass filter. A low-pass filter chain consists of series inductances L and of shunt capacities C. Taken by themselves these would resonate at a frequency $F_r = 1/(2\pi\sqrt{1/LC})$. Arrayed in a properly terminated filter they pass freely all frequencies below, and attenuate those above 2 F_r. The attenuation, increasing rapidly at first, asymptotically approaches

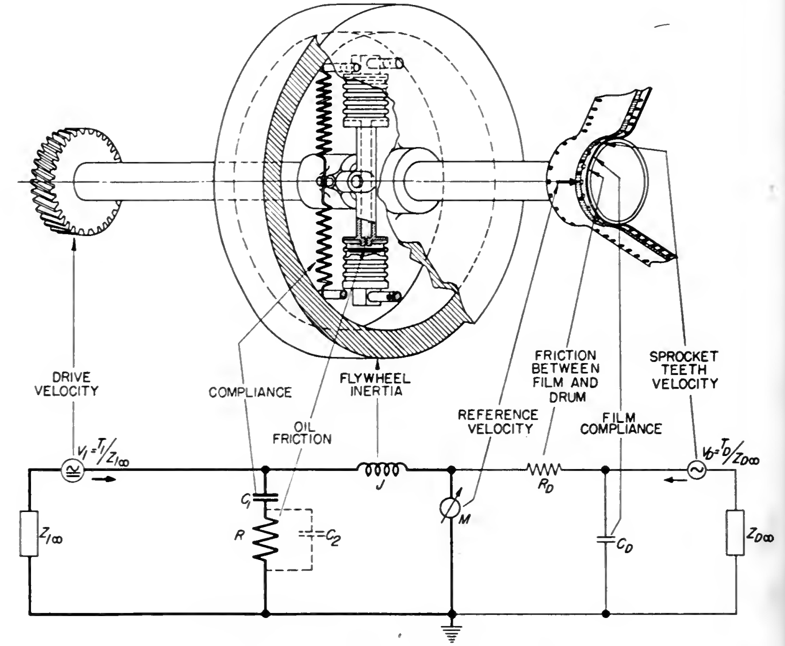

FIG. 4. Filtered sprocket drum.

a straight line through zero attenuation at F_r which slopes at the rate of 12 db per octave per filter section. This means that in each section the high-frequency amplitudes are reduced in proportion to the square of the frequency. In a mechanical filter, inertia takes the place of inductance, and compliance that of capacity. Since our ears remain sensitive to flutter rates even slower than one per second and since low-pass filters lose effect near their resonance frequency, one must either adjust the resonance to less than $^1/_4$ cps by heavy but very pliant filter structures, which tend to be unstable, or one must make the power source very constant at low frequencies. Neither of these objectives is easily attained and the elimination of audible film flutter has been a very gradual and difficult accomplishment as will be realized from the following short survey of some typical past and present film-driving mechanisms.

In recording, one of the oldest successful drives was the "filtered sprocket drum" (Fig. 4). This reduces the flutter components of motor and gear-train by a mechanical low-pass filter. In the preferred form of this filter, the motion of the drive shaft is coupled to the heavy flywheel by an arm which engages two spiral springs and two oil-filled sylphon bellows connected by a small aperture. Relative rotation between the drive shaft and the flywheel tensions the springs and forces oil through the friction aperture. The electrical analogy of this mechanism is shown in heavy lines on the left part of Fig. 4. V_1 is the sum of d-c and a-c angular velocity components impressed upon the flywheel shaft by the gear-train. Due to its great rigidity the gear-train approximates a constant-velocity generator, as symbolized in the analogy by an infinite impedance to ground, $Z_{1\infty}$ combined with an infinite torque $T = V_1 Z_{1\infty}$. In the simplest form of the analogy, a condenser represents the torsional compliance C_1 of the springs, a resistance the oil friction R, and an inductance the moment of inertia J, of the flywheel. The analysis of such a combination is given in the appendix. One sees that due to the absence of a heavy load the filter is not terminated and therefore resonant. The resonance peak is damped by a resistance in series with the condenser which cuts the high-frequency attenuation from 12 db per octave to 6 db per octave. (A more detailed analysis shows that the bellows themselves contain a small compliance which in the electrical analogy is shown in dotted lines as a second condenser in parallel with the resistance. This bellows compliance brings the high-frequency attenuation back to 12 db per octave and modifies the response characteristic in a manner discussed in the appendix.)

An advantage of the filtered flywheel drive is the absence of load-side trouble. It requires, however, careful matching of the sprocket-tooth pitch to the film length, and accommodates only the shrinkage range of reasonably fresh recording film stock. The residual sprocket-tooth impacts are reduced by providing simultaneous contact of the film with several teeth, a construction which requires a large sprocket drum, low angular speed and a large flywheel. In theater reproducers, the shrinkage difference between new and old films is uncontrollable, and a large sprocket drum can not be accommodated within the standard 15-inch distance between picture and sound scanning point. Consequently, the filtered sprocket drum has been used mainly in studio type recording and re-recording machines.

The first commercial reproducers in this country attempted to overcome drive-side disturbances by a filtered flywheel similar to that of Fig. 4. It was rigidly coupled to a small sprocket which pulled the film through a closely adjacent gate. Figs. 5(*a*) and 5(*b*) show two stages in the evolution of the gate. The straight gate of Fig. 5(*a*) was designed to insure that the film was held in the focal plane of the scanning-beam. Its sound quality was satisfactory at the time but the 96-cycle flutter exceeded the narrow tolerance limit later demanded and shown in Fig. 2. This flutter, originating at the mesh of sprocket-teeth and film, could not be reduced by the flywheel filter. The absence of flexibility between sprocket and gate impressed all irregularities directly upon the gate, where nothing but the solid friction of the gate shoes opposed them.

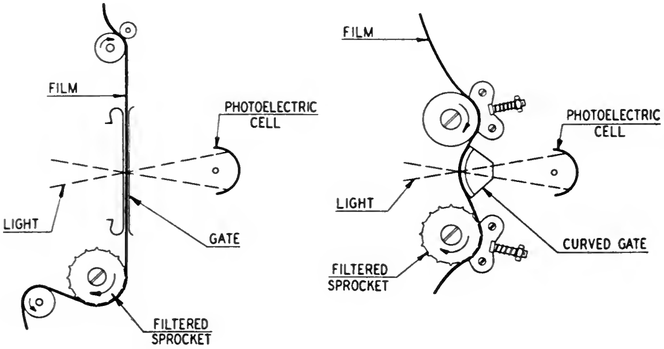

Fig. 5(*a*) Fig. 5(*b*)

Fig. 5(*a*). Reproducer straight sound gate with filtered sprocket.
(*b*). Reproducer curved sound gate with filtered sprocket.

The difficulties encountered in using solid friction as a damping means are explained by Fig. 6. The upper graph (*A*) shows the forces of viscous and solid friction as a function of velocity. While viscous friction force is proportional to velocity, indicated by a straight line through the origin, solid friction is high at rest, rapidly falling off to a minimum with increasing velocity in either direction and then slowly rising again. The lower graph (*B*) shows the frictional resistances derived from the above-illustrated forces. The viscous resistance is a constant, equal to the slope of the force-velocity line: $R = p/V$. The solid resistance depends on the magnitude and the starting velocity of the oscillatory motion. For periodic oscillations around zero velocity, the effective damping resistance is very high at small amplitudes and falls off with amplitude to a minimum, and then slowly increases again as shown by the upper (p/v) curve. For small vibrations superimposed on a d-c velocity, the resistance equals the gradient of the resistance forces and follows the lower (dp/dv) curve. At points remote from zero d-c velocity, it has a small value which in a certain range becomes negative, so that improperly used solid friction, instead of damping, may amplify external disturbances and even generate free vibrations like those of a violin string under the steady pull of the bow.

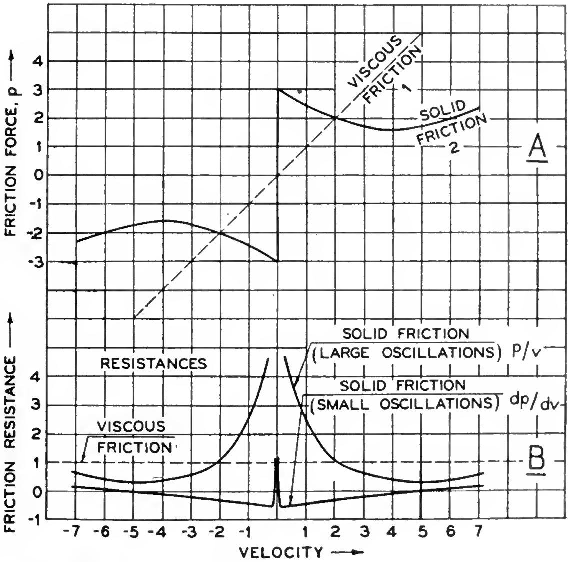

FIG. 6. Characteristics of viscous and solid friction.

A considerable improvement was brought about by the curved gate shown in Fig. 5(*b*). By reducing the film tension and introducing a short length of relatively loose film loop, the drive when well adjusted was capable of reducing the film flutter to about $^1/_4$ of 1 per cent.

It was found, however, that the best reproducing quality could be obtained by abandoning gates altogether and scanning the sound-track on a smooth impedance roller. The general nature of a typical impedance-roller drive is shown in Fig. 7. A sprocket wheel, usually unfiltered, pulls a loose film loop over a smooth drum rigidly coupled to a flywheel. The film loop supplies the shunt compliance, the flywheel the series inertia of a mechanical low-pass filter which, in this new location, attenuates sprocket-hole disturbances as well as motor and gear flutter. In order to act as a filter, this combination must be terminated by a proper load impedance. If left unterminated, it is a purely reactive structure which tends to oscillate at its resonance frequency, and therefore may increase rather than attenuate the film speed variations. The reactive elements must be damped in some fashion by resistive components. Experience has shown that such damping can be successfully incorporated, making the damped impedance drum the most economical and practicable sound-film drive for both recording and reproducing purposes.

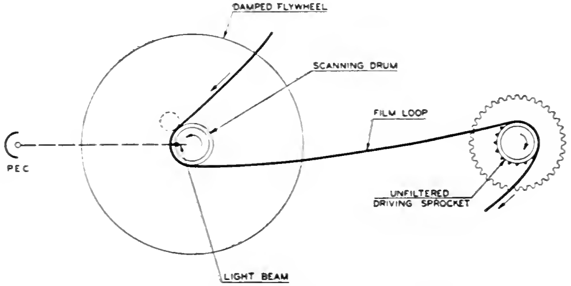

FIG. 7. Damped impedance drum.

It should be kept in mind that even a smooth recording drum introduces disturbances at sprocket-hole frequencies because the film bends more sharply in the regions weakened by the sprocket-holes. This bending stretches the sound-track, causing an increase of frequency in recording and a corresponding decrease in reproduction. The two effects neutralize each other if the same drum diameter can be used in recording and reproduction. Since the space available in theater reproducers limits the drum size to about 2 inches, and this diameter is too small for recording sprockets, the impedance drum is the only universally adaptable drive mechanism. Recording machines equipped with large sprockets are most useful if the films recorded on them are reproduced on mechanisms also using large scanning drums either with or without sprocket-teeth.

In providing damping for the impedance drums, the most obvious procedure is to add a straight resistance termination to the reactive filter elements. Fig. 8 shows schematically the mechanical arrangement of a resistance-terminated filter and its electrical equivalent.

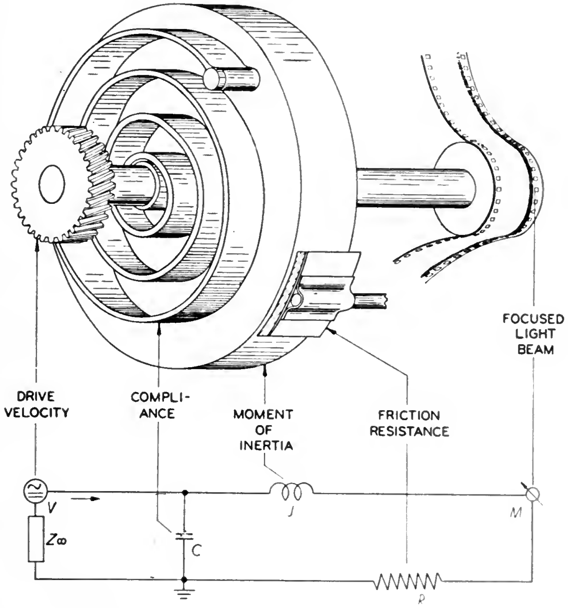

FIG. 8. Resistance-terminated filter.

Fig. 9 shows the response characteristics of such filter sections, as calculated in the Appendix. As a reminder, Curve *1* in this figure shows the ideal low-pass filter characteristic. The nearest approach for one resistance-terminated section is obtained with a torsional frictional resistance $R_c = 2\ J/C$, as shown by Curve *2*. This is a rather high resistance which opposes the steady rotation of the film drive as well as its speed fluctuations, causing unnecessary load on bearings and motor. If one reduces the resistance as shown in Curve *3*, the structure becomes resonant and amplifies some frequencies; if one desires to attenuate frequencies below the resonance frequency as shown in Curve *4*, the required damping resistance increases greatly, making the demands upon the drive even more impracticable.

A logical next step is to compensate for the resistance load of the film by supplying an auxiliary driving torque through the damping resistance. This leads to the resistance-coupled auxiliary drive schematically shown in Fig. 10, with its electrical equivalent. This type of drive has been successfully used. One recording mechanism now in the field uses eddy currents generated by electrodynamic induction to produce a friction drag between a copper drum and electromagnets mounted on a flywheel as shown on Fig. 10. A successful 16-mm reproducer uses the viscosity of an oil film to produce the drag between film-drum and auxiliary drive. As previously shown in Fig. 9, the resistance drive can be damped down to a peakless characteristic if the resistance is sufficiently high; but only at the price of a tight coupling between the film drive and the auxiliary drive. Naturally, the auxiliary drive is subject to speed variations of its own and one must therefore consider the response characteristics of resistance-coupled auxiliary drives to disturbances originating on the auxiliary drive or "load" side as well as on the film or "drive" side. In a recording mechanism previously described in the JOURNAL,[2] the

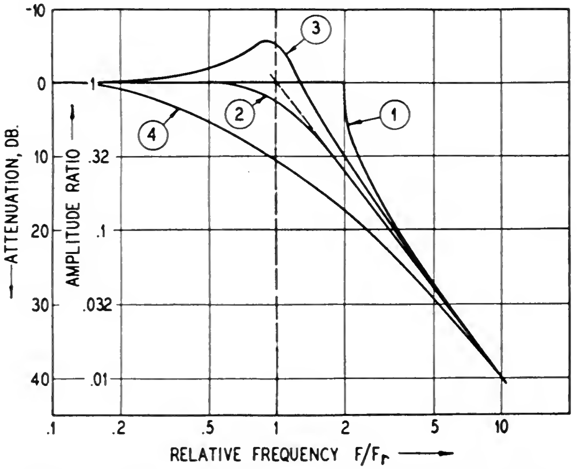

FIG. 9. Characteristics of resistance-terminated filters. (*1*) Ideal L. P. filter section. (*2*) Peakless damping $R = R_c = \sqrt{2L/C}$. (*3*) Underdamped $R = 0.4R_c$. (*4*) Overdamped $R = 2.5R_c$.

auxiliary drive moved with a 15 per cent higher angular velocity than the recording drum and supplied just about enough torque to neutralize the small friction in the ball bearings of the recording drum. This means that the effective coupling friction was only about seven times as large as the bearing friction, and in view of the fairly large moment of inertia of the magnetic flywheel, the film-side transmission characteristic showed a decided resonance peak.

Such a condition is illustrated in Fig. 11, which shows also the response to disturbances originating at the load side; the latter being computed in the Appendix under the favorable assumption that the auxiliary drive is free from shunt compliance. The film-side response has a 5-db peak near the resonance frequency, and at about the same frequency the load-side admittance has a maximum shown as 0-db attenuation to indicate that disturbances originating in the magnetic drive are freely passed on to the film. If the coupling resistance is further reduced, the peak of the film-side response becomes higher; that of the load-side response remains equally high but it becomes sharper so that a narrower range of drive-side disturbances affects the film motion. The load-side response peak means that at low frequencies near resonance the auxiliary drive must be of an excellence approaching that of the film drive; the broadness of the resonance demands that even at considerably higher frequencies up to about 6 cps, the magnetic drive and the coupling resistance must be

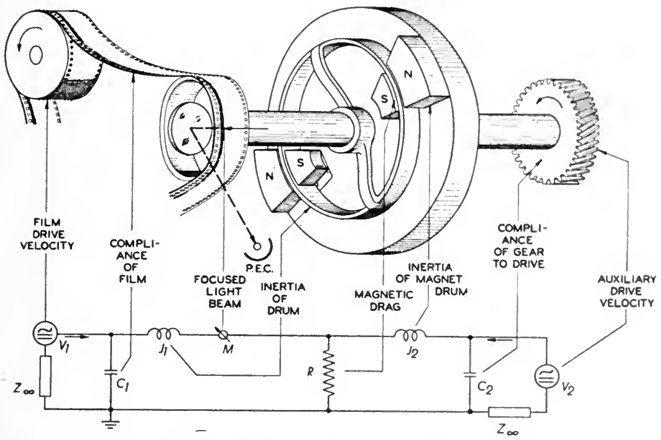

FIG. 10. Resistance-coupled auxiliary drive.

well balanced magnetically, mechanically, and electrically. These structural requirements are severe and lead to expensive construction. Before adopting this type of drive, it is therefore advisable to investigate whether its performance can not be matched or bettered by a simpler mechanism.

Such a simpler device does exist; it is known as the "stabilized flywheel." The main mechanical elements of a stabilized flywheel film drive are schematically shown in Fig. 12, with the equivalent electrical filter. This structure contains all the elements of the resistance-terminated low-pass filter but it eliminates the d-c resistance drag by shunting the damping resistance with a large inductance. Mechanically this means that the resistance operates not between the film-drum and a stationary friction pad as in Fig. 8, but between an outer flywheel shell and an inner flywheel mass which itself is free to rotate. The resistance may be supplied by the viscosity of an oil film in the small clearance between the flywheel and the shell. The greater the flywheel inertia compared to the inertia of the shell, the more the device resembles a resistance-terminated filter, and the lower becomes the resonance peak which is inherent in this design. The characteristics of stabilized flywheels are derived in the Appendix

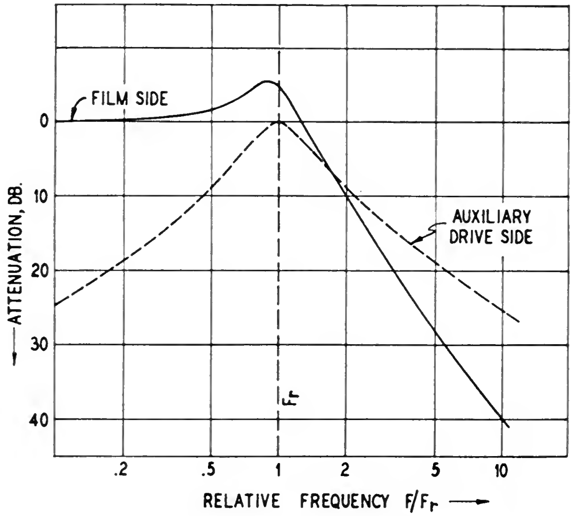

FIG. 11. Resistance-coupled auxiliary drive; attenuation of film and auxiliary drive disturbances.

and illustrated by Fig. 13 for a stabilized flywheel in which the inner flywheel inertia is only two and one-half times that of the shell, including the scanning drum and other moving parts. The drive-side impedance shows a peak of about 5 db and asymptotically approaches a straight 12-db-per-octave slope similar to the auxiliary drive characteristic shown in Fig. 11. In addition to this drive-side response, Fig. 13 also shows a load-side impedance characteristic. This takes into acount the eccentricities of flywheel load and the irregularities of bearing friction which may be transferred back to the light-scanning drum. In this respect, too, the stabilized flywheel drive is similar to the resistance-coupled auxiliary drive structure. Several successful film reproducers make use of this type of drive which incidentally is by no means a new development. It was invented by H. A. Rowland in 1899 for the damping of synchronous telegraph motors.[3]

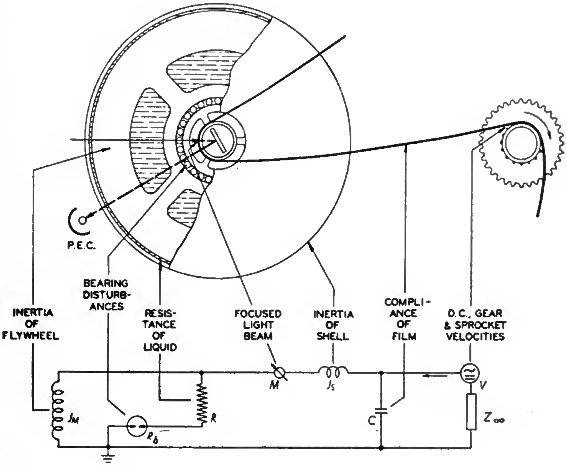

FIG. 12. Stabilized flywheel drive.

The damping properties of a stabilized flywheel are demonstrated by a simple experiment used some time ago in a court room; the flywheel is mounted on a shaft with two light cylindrical rollers and allowed to roll freely on two rails which are slightly higher at the ends than in the middle. In one flywheel the shell is locked to the inner flywheel by two small screws. When placed on the end of the rails it rolls back and forth for several minutes before it comes to rest.

Another wheel is identical with the first but the inner flywheel is permitted to rotate freely against the friction of the oil film. When placed on the rails, the wheel comes nearly completely to rest after one or two excursions. We say *nearly* because close observers may notice that sometimes the wheel continues to teeter back and forth at very small amplitudes as if the inner flywheel had become frozen to its shaft.

This actually can happen not only in this experiment but also under operating conditions. Remember that once the reproducer has come up to speed, the average rotational velocity of the flywheel equals that of the shell although there occur small cyclical speed differences between them. At least twice during each such cyclical variation, the relative velocity passes through zero and the friction coefficient of the inner flywheel bearing increases from rolling friction to the considerably greater static friction. The flywheel becomes locked to its shell and the mechanism becomes temporarily undamped until it exerts sufficient acceleration or deceleration torque upon the flywheel to break the friction lock. This effect, which is symbolized in the electrical analogy by a spark-gap or breakdown tube R_b in series with the damping resistance R, is the more pronounced the less high-frequency flutter components are there to maintain a rapid vibration

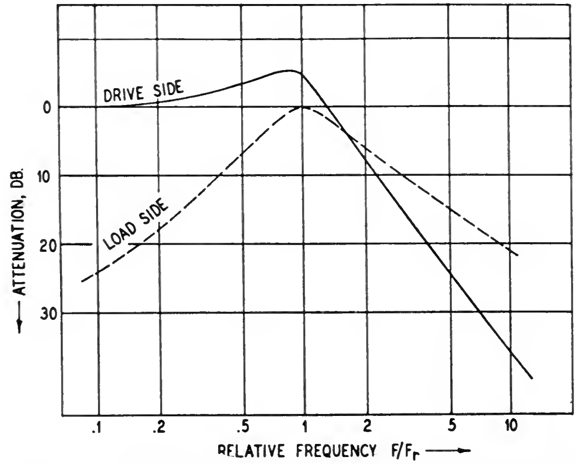

FIG. 13. Stabilized flywheel; response to drive and load-side disturbances.

between shell and flywheel. It causes hunting or drifting at the low resonance frequency of the locked flywheel.

This has been the main objection to the stabilized flywheel drive until it was recently overcome by a structure called the "liquid flywheel," used in the recording and reproducing machine designed by the Bell Telephone Laboratories for the stereophonic sound system which has been demonstrated in New York, Hollywood, and Rochester.

The new design replaces the solid flywheel by a heavy liquid of low viscosity which has to force its way through narrow channels within the flywheel shell. It thus eliminates the objectionable bearings and, incidentally, the very small clearance between flywheel and shell which contributed to the expense of the previous design. If the dimensions of liquid flywheel shell and friction channels are so chosen that the viscous resistance is concentrated at the channels and only slightly increased by friction on the surface of the shell walls, and if care is taken to avoid turbulence in the flow of the liquid, the new structure becomes equivalent to the solid stabilized flywheel previously discussed and its drive-side response characteristic identical with that of Fig. 13. The main source of load-side disturbance, however, is eliminated by the avoidance of inner flywheel bearings. The variations in the low resistance of the outer shaft precision ball bearings are superimposed on a high d-c velocity which according to Fig. 6(*B*) reduces the solid friction resistance. One may therefore greatly discount the influence of the load-side characteristic of Fig. 13.

The above design considerations were concerned with inertia and resistance components of the filter structures. Compliance, the third essential filter element, is supplied by the film itself in most damped impedance drives. In other words, the very flimsiness and the curling propensity of the film which the Court had stressed as the main obstacle to smooth film propulsion, is utilized to buff the irregular shocks of the gear drive. The more one reduces the d-c tension of the film by auxiliary drive torque or by precision ball bearings, the looser and more compliant becomes the film loop between sprocket drive and drum. While in highly resistive structures it resembles a straight line, the low tension film bends into a loop shaped like a *U* or preferably like an *S*. The compliance of such film loops has been determined by experiments[4] and by analysis (see Appendix). Its worst characteristic is that it is highly variable. It is approximately proportional to the 1.5 power of the film bending stiffness and inversely to the 2.5 power of the loop tension. The film stiffness and loop shape vary considerably according to weather condition, film age, and film pressure in the storage cans, and the film tension naturally depends on the conditions of the scanner bearings which also are subject to change. It is therefore impossible to determine and maintain a fixed resonance and cut-off frequency of the mechanical filter, and low-frequency flutter which is well suppressed at the time of installation may become noticeable after short use and require servicing. When uniformity and predictability of filtering performance are required, the objection of the Court to the "flimsy, curling film" must be sustained. The filtering can (and should) be made independent of the film loop by supplying an auxiliary compliance based on the more permanent properties of metallic springs. The most convenient method for the introduction of this compliance is an elastic sprocket in which a spiral spring is interposed between the drive shaft and the sprocket rim. Fig. 14 shows schematically the mechanical arrangement of a high-quality film drive which embodies the liquid stabilized flywheel and an elastic driving sprocket. The electrical equivalent looks rather complicated. The reason is that the small inertia of the sprocket rim must be depicted by an

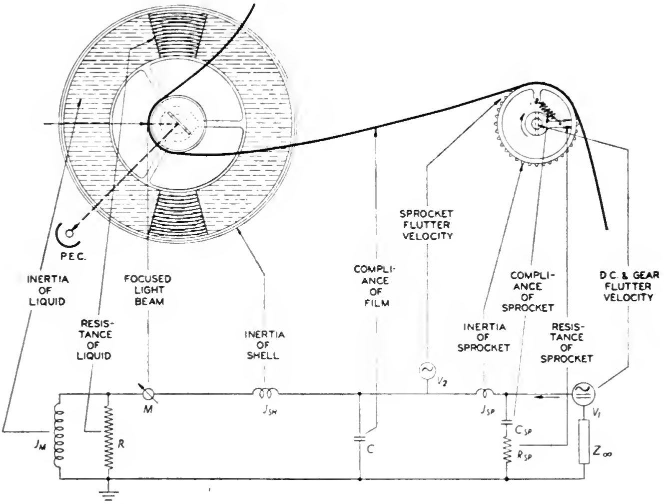

Fig. 14. High-quality drive with liquid flywheel and elastic sprocket.

additional small inductance and that the d-c and gear frequency velocity component V_1 is impressed at the sprocket shaft, the 96-cycle velocity component V_2 at the sprocket rim. At some relatively high frequency there is danger of resonance between the compliance of film loop and sprocket springs and the inertia of the sprocket rim. This will ordinarily be damped out by the internal viscosity of the film loop itself and by bearing friction, but in order to play doubly safe, the elastic sprocket is provided with a little internal damping by means of a small friction pad.

Summing up, the recommended film drive, which is schematically shown in Fig. 14, should contain the following elements:

(*1*) A motor which does not appreciably change speed with line variations; *i. e.*, an amply powered synchronous motor or a low-slip induction motor.

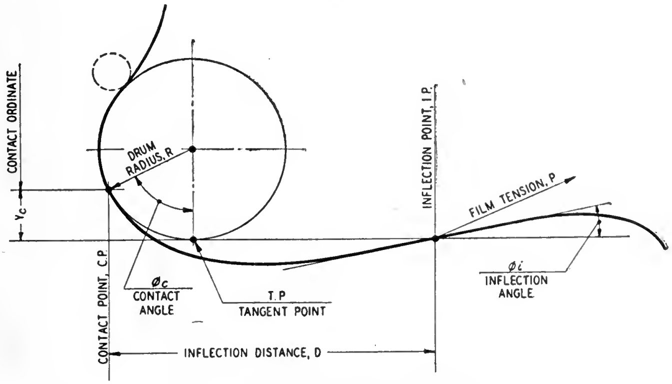

FIG. 15. Film loop compliance.

(*2*) A smooth recording or scanning drum of standardized diameter (between 1.5 and 2.5 inches).

(*3*) A mechanical low-pass filter attenuating high frequencies at least 12 db per octave with a cut-off below $^1/_4$ cps. The main shunt compliance of this filter should be independent of film and weather conditions and preferably consist of metal springs. The series inductance and damping resistance should be provided by a stabilized liquid flywheel.

A film drive based on these design principles should be able to perform consistently with the low flutter amplitudes now obtained only by frequent maintenance adjustments and reduce film speed variations to a level which is unnoticeable in the reproduction of sound-film records.

APPENDIX

(*1*) *Drive-Side Transmission Characteristic of Filtered Sprocket Drum* (*Fig. 4*).—Assuming that the motional impedance of the motor and gears is very high compared to that of the filters, one may regard the drive shaft as a constant-velocity source. If one calls the angular velocity of the drive shaft v_1, that of the drum v_2, then the transmission factor is

$$F = \frac{v_2}{v_1} = \frac{R + \dfrac{1}{C_1 j\omega}}{R + \dfrac{1}{C_1 j\omega} + Jj\omega}, \text{ with } \omega = 2\pi f \qquad (1)$$

The absolute value of F is

$$|F| = \sqrt{\frac{1 + nr}{1 + nr - 2n + n^2}} \qquad (2)$$

with

$$n = C_1 J\omega^2 \text{ (frequency factor)} \qquad (3)$$

and

$$r = R^2 C_1/J \text{ (damping factor)} \qquad (4)$$

The transmission factor for d-c is

$$|F_0| = 1 \qquad (5)$$

At high frequencies it approaches

$$|F_\infty| = \frac{r}{n} = \frac{R}{J\omega} \qquad (6)$$

which is inversely proportional to frequency, corresponding to an attenuation of 6 db per octave. The transmission factor has a peak at the frequency

$$f_p = \frac{1}{2\pi}\sqrt{\frac{n_p}{CJ}} = \frac{1}{2\pi RC}\sqrt{\sqrt{1 + 2R^2C/J} - 1} \qquad (7)$$

The peak transmission is

$$|F_p| = r/\sqrt{r^2 - 2(1 + r - \sqrt{1 + 2r})} \qquad (8)$$

The peak is always greater than one and depends only on the damping factor r.

(*2*) *Drive-Side Transmission as Modified by Bellows Compliance.*—By the addition of C_2 (dotted in Fig. 4) the transmission factor becomes

$$F = \frac{1 + Rj\omega(C_1 + C_2)}{1 - JC_1\omega^2 + Rj\omega(C_1 + C_2 - JC_1C_2\omega^2)} \tag{9}$$

Substituting the following symbols:

$$JC_1\omega^2 = n \tag{10}$$

$$\frac{C_2}{C_1 + C_2} = k \tag{11}$$

$$\frac{R^2(C_1 + C_2)^2}{JC_1} = r \tag{12}$$

one finds

$$\left|\frac{1}{F^2}\right| = (1 - kn)^2 + \frac{n^2(1 - k^2) - 2n(1 - k)}{1 + rn} \tag{13}$$

For a given coupling factor k, the transmission is a function of the frequency and damping factors, n and r. The influence of r is limited to the second term of (*13*) and is eliminated for

$$n_p = \frac{2}{1 + k} = \frac{2C_1 + 2C_2}{C_1 + 2C_2} \tag{14}$$

At this frequency the transmission has a gain determined solely by the coupling factor:

$$| F_p | = \frac{1 + k}{1 - k} = 1 + \frac{2\,C_2}{C_1} \tag{15}$$

$| F_p |$ may be called the peak factor because it becomes the absolute response maximum if one makes dF/dn equal to zero at n_p. This is achieved by the "optimum" choice of the resistance factor.

$$r_{opt} = \frac{1 + k}{2k} = 1 + \frac{C_1}{2C_2}, \tag{16}$$

or

$$R_{opt} = \sqrt{\frac{JC_1(C_1 + 2C_2)}{2C_2(C_1 + C_2)^2}} \tag{17}$$

The d-c transmission is

$$\mathrm{F}_0 = 1 \tag{18}$$

The high-frequency transmission approaches

$$F_\infty = \frac{C_1 + C_2}{JC_1C_2\omega^2} \tag{19}$$

which is inversely proportional to the square of the frequency with an attenuation of 12 db per octave.

(*3*) *Drive-Side Transmission Characteristic of Resistance-Terminated Filter* (*Fig. 8*).—The transmission factor is

$$F = \frac{1}{1 - JC\omega^2 + RCj\omega} \tag{20}$$

Using the symbols (*3*) and (*4*), the absolute value is

$$|F| = [(1 - n)^2 + rn]^{-0.5} \tag{21}$$

The d-c transmission is

$$F_0 = 1 \tag{22}$$

The high-frequency transmission approaches

$$F_\infty = -\frac{1}{JC\omega^2} \tag{23}$$

that is, 12 db per octave.
The shape of the characteristic depends on r.

$$r_c = 2 \left(R_c = \sqrt{\frac{2J}{C}} \right) \tag{24}$$

is the critical value.
For

$$r < r_c \tag{25}$$

the transmission has a peak

$$F_p = \frac{1}{r - 0.25r^2} = \frac{4J^2}{4R^2CJ - R^4C^2} \tag{26}$$

which it reaches at the frequency

$$n_p = 1 - \frac{r}{2} \left(\omega = \sqrt{\frac{1}{JC} - \frac{R^2}{2J^2}} \right) \tag{27}$$

This condition is shown as Curve *3* in Fig. 9.
For

$$r > r_c \tag{28}$$

$$F_c = \sqrt{\frac{1}{1 + n^2}} = \sqrt{\frac{1}{1 + C^2J^2\omega^4}} \tag{29}$$

This curve is flat at low frequencies and droops smoothly near resonance frequency as shown in Curve *2*, Fig. 9.
For

$$r > r_c \tag{30}$$

the transmission begins to droop at low frequencies in accordance with Curve *4*. Fig. 9.

(4) *Resistance-Coupled Auxiliary Drive* (*Fig. 10*).—(*a*) Transmission of film-side disturbances: Assuming that the compliance C_2 of the auxiliary gear drive is negligible, the transmission becomes identical with the "drive-side" characteristic of the resistance-terminated filter (Fig. 9, Curve 3).

(*b*) Transmission of disturbances from auxiliary drive ("load-side" disturbances): For negligible C_2 the transmission factor is

$$F = \frac{RCj\omega}{RCj\omega + 1 - LC\omega^2} \tag{31}$$

Using the symbols (3) and (4) the absolute value of transmission becomes

$$|F| = \sqrt{\frac{rn}{rn + (1 - n)^2}} = \sqrt{\frac{r/n}{r/n + (1 - 1/n)^2}} \tag{32}$$

The peak value of transmission occurs at

$$n_p = 1 \tag{33}$$

and equals

$$F_p = 1 \tag{34}$$

At low frequencies F approaches

$$|F_0| \doteq RC\omega \tag{35}$$

which increases 6 db per octave.

At high frequencies F approaches

$$|F_\infty| \doteq \frac{R}{L\omega} \tag{36}$$

which decreases 6 db per octave.

The two forms of (32) show that when plotted on a logarithmic frequency scale the curve is symmetrical with regard to $n = 1$.

(5) *Stabilized Flywheel* (*Fig. 12*).—(*a*) Transmission of drive-side disturbances:

$$F = \frac{1}{1 + Cj\omega\left(J_s j\omega + \frac{J_m j\omega R}{J_m j\omega + R}\right)} \tag{37}$$

Introducing the symbols

$$J = J_s + J_m \tag{38}$$

$$n = JC\omega^2 \tag{39}$$

$$k = \frac{Js}{J} \tag{40}$$

$$r = \frac{R^2CJ}{Jm^2} \tag{41}$$

one finds

$$\left|\frac{1}{F^2}\right| = (n-1)^2 + n^2(1-k)\,\frac{2-n(1+k)}{n+r} \tag{42}$$

The d-c transmission is

$$F_0 = 1 \tag{43}$$

At high frequencies it approaches

$$F_\infty = \frac{1}{CJ_s\omega^2} = \frac{1}{kn} \tag{44}$$

The attenuation increases 12 db per octave.
At the frequency

$$n_p = \frac{2}{1+k} = \frac{2J_s + 2J_m}{2J + J_m} \tag{45}$$

the second term on the right side of (39) vanishes, leaving F_p independent of r and equal to

$$F_p = \frac{1}{n_p - 1} = 1 + 2\frac{J_s}{J_m} \tag{46}$$

This value is the peak of the whole response characteristic if one adjusts r to make the value of (42) an extreme for $n = n_p$. One finds for the "optimum drive-side" resistance r_d the equation

$$2(n_p - 1) - n_p^2\,\frac{1-k^2}{n_p + r_d} = 0 \tag{47}$$

and

$$r_d = \frac{2k}{1+k} = \frac{2J_s}{J_m + 2J_s} \tag{48}$$

$$R_d = \sqrt{\frac{2J_sJ_m^2}{C(J_s + J_m)(2J_s + J_m)}} \tag{49}$$

(*b*) Admittance to load-side disturbances: The impedance is

$$Z = \frac{1}{Cj\omega} + J_sj\omega + \frac{RJ_mj\omega}{R + J_mj\omega} = \frac{1}{FCj\omega} \tag{50}$$

At low frequencies the admittance approaches

$$G_0 = \frac{1}{Z_0} \doteq Cj\omega \tag{51}$$

increasing 6 db per octave. At high frequencies the admittance approaches

$$G_\infty = \frac{1}{J_sj\omega}, \tag{52}$$

decreasing 6 db per octave. Introducing the symbol

$$Z_k = \sqrt{\frac{J}{C}} \tag{53}$$

one finds

$$\left|\frac{Z^2}{Z_k^2}\right| = \frac{(n-1)^2}{n} + n(1-k)\,\frac{2-n(1+k)}{n+r} \tag{54}$$

This is independent of r at the common point frequency n_p defined by (*45*). The "common" value of admittance is

$$G_c = \frac{\sqrt{n_p}}{(n_p-1)Z_k} = \sqrt{2C(J_m+2J_s)}/J_m \tag{55}$$

It is the "peak admittance" if one adjusts r to make the value of (*53*) an extreme for $n = n_p$. One finds for this "optimum load-side" resistance r_L the equation:

$$1 - \frac{1}{{n_p}^2} = \frac{n_p(1-k^2)}{n_p + r_L} \tag{56}$$

and

$$r_L = \frac{2}{1+k}\cdot\frac{1+3k}{3+k} = \frac{2J_m+2J_s}{J_m+2J_s}\cdot\frac{J_m+4J_s}{3J_m+4J_s} \tag{57}$$

$$R_L = \sqrt{\frac{2{J_m}^2(J_m+4J_s)}{C(J_m+2J_s)(3J_m+4J_s}} \tag{58}$$

R_L is always larger than R_d but for most practical designs the difference is small enough to allow a compromise which only slightly increases the peak values per (*46*) and (*55*).

(*6*) *Compliance of Film Loop* (*Fig. 15*).—

If E is the modulus of elasticity of the film,
J the moment of inertia of its cross section,
P the longitudinal loop tension,
Q the curvature,
s the length of film loop and

$$B = \sqrt{\frac{EI}{P}} \tag{59}$$

one finds the "Loop equation"

$$\frac{d^2Q}{{d_s}^2} = \frac{O}{B^2} \tag{60}$$

which has the general solution

$$O = \frac{1}{A_1}\sinh\frac{s}{B} + \frac{1}{A_2}\cosh\frac{s}{B} \tag{61}$$

If the film is wound around two drums or sprockets in opposite directions, forming an S, the loop contains an inflection point which we choose as origin of coordinates. If one calls R the drum radius and ϕ the angle between film and abscissa,

$$\phi_s = \phi_0 + \frac{B(\cosh s/B - 1)}{R\sinh s/B} \tag{62}$$

For *flat* loops one may use the approximations

$$\begin{aligned} \phi_s &\ll 1 \\ y'' &\doteq 0 \\ x &\doteq s \\ y' &\doteq \phi; \end{aligned} \tag{63}$$

then

$$y'' = \frac{\sinh x/B}{R \sinh f} \tag{64}$$

where

$$f = D/B$$

and

$$D = \text{inflection length per Fig. 15}$$

Based on (*64*) it can be shown that the increase of film length due to looping is

$$\Delta S = \frac{B^3}{12R^2}[6a^2f - 12a + 2(a - \coth f)^3 + 3f/\sinh^2 f + 3 \coth f] \tag{65}$$

in which

$$a = \coth f - f + \sqrt{f^2 - 2f \coth f + 2} \tag{66}$$

For large f (long flat loops) one can expand (*65*) into a power series in $1/f$:

$$\Delta S \doteq \frac{B^3}{12R^2}\,[1 - 1.5/f + \ldots] = \frac{B^3}{12R^2} - \frac{B^4}{8R^2D} + \ldots \tag{67}$$

one finds

$$C \doteq d\Delta S/dP = d\Delta S/dB\,\frac{dB}{dP} \tag{68}$$

$$C \doteq -\left[\frac{B^2}{4R^2} - \frac{B^3}{2R^2D} + \ldots\right]\left[-\frac{B^3}{2EJ}\right] \tag{69}$$

$$C \doteq \frac{(EJ)^{1.5}}{8R^2P^{2.5}} - \frac{(EJ)^2}{4R^2P^3D} + \ldots \tag{70}$$

REFERENCES

[1] SHEA, T. E., MACNAIR, W. A., AND SUBRIZI, V.: "Flutter in Sound Records," *J. Soc. Mot. Pict. Eng.*, **XXV** (Nov., 1935), p. 403.

[2] DREW, R. O., AND KELLOGG, E. W.: "Filtering Factors of the Magnetic Drive," *J. Soc. Mot. Pict. Eng.*, **XXXV** (Aug., 1940), p. 138.

[3] ROWLAND, H. A.: U. S. Pat. No. 691,667 (1899).

[4] COOK, E. D.: "The Technical Aspects of the High-Fidelity Reproducer," *J. Soc. Mot. Pict. Eng.*, **XXV** (Oct., 1935), p. 289.

DISCUSSION

MR. KELLOGG:* This paper is a valuable contribution to the theory of mechanical filters and their application to sound-film drive, and the expedient to which the authors have resorted to eliminate the last vestige of solid friction in a stabilized flywheel is of much interest. There are several matters, however, concerning which I feel that something further should be said in justification of the types of constructions that my associates have adopted for our recording and reproducing machines.

The damping coefficient for the magnetic drive was calculated on the basis of its supplying only enough forward torque to overcome bearing friction. Since in all magnetic drive applications, the drum is overdriven and the film is pulling back on the drum, the magnets are supplying considerably more torque than that which just balances bearing friction. In view of this, and the fact that ball bearings have not been employed, but sleeve bearings with small clearance, the magnetic coupling, and therefore the damping is much greater than the assumption made in the paper would indicate. Sleeve bearings have been employed for the reason that they have been found to give a smoother action than any ball bearings, despite the low average friction of the latter.

I have, in several publications, recognized non-uniformity in magnet rotation as a conceivable source of disturbance in drum motion. In prolonged experience with this system and in numerous tests, we have found this to be a negligible factor, and the reason, I believe, may be explained in terms of Fig. 11. This figure shows that the full amplitude of speed variation of the magnets can be transmitted to the drum provided that the magnet speed irregularity is of exactly the resonance frequency established by the inertia of the flywheel and the stiffness of the film loop. This zero attenuation at a single frequency is simply one aspect of the fact that a resonant system with zero resistance has zero impedance. Fig. 13 shows the same characteristic. There is no possibility, it will be noted, that the magnetic coupling will cause a greater amplitude of drum disturbance than that which is in the magnet-drive itself, and actually it would be less because of some damping in bearings. At all frequencies except that at which the elastic and inertia reactances cancel, there is substantial attenuation. It is characteristic of a system of gears that there are no disturbances of lower fundamental frequency than the rotation frequency of the slowest gear in the train. (No difference frequency or beat effects are produced.) There is thus no occasion for any irregularity in magnet speed or for lower frequency than the rotation of the magnets themselves, or about $3^1/_2$ revolutions per second. As compared with this, the natural frequency of the drum and flywheel is of the order of $^1/_4$ cycle per second. According to Fig. 11, there would be something like 27 db attenuation of the lowest frequency magnet disturbance. Components of higher frequency would be attenuated still more.

As compared with an internally damped flywheel, the auxiliary drive makes it practicable to employ a much greater directly connected mass on the drum shaft and still provide adequate damping. The weight on the drum bearings, however, is not materially increased. The greater mass, with corresponding damping,

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*Communicated.

means a higher mechanical impedance to resist "load-side" disturbances, due, for example, to bearing irregularities.

The *S*-shaped loop is mentioned as preferable to a *U*-shaped film loop. This does not agree with our experience, although the *S*-shaped loop can serve very well in a filtering system, and may often be chosen for the sake of simplicity in design.

Turning next to the oil-damped wheel, which has sometimes been called a "rotary stabilizer" and sometimes a "kinetic scanner," the friction in the ball bearing within the stabilizer should not be included as a disturbing force. When the drum is up to speed, there is no continuous rotation on this bearing. It is acknowledged that bearing friction, if it locks the inner flywheel to the drum shaft, can prevent damping. Oscillations, however, must be extremely small in order not to cause some relative motion, and when there is any relative motion there is damping. Some tests and demonstrations have been given that indicate a loss of damping for very small oscillations, but these tests were made without the wheel turning over, and not with the oscillation superimposed on continuous rotation, as would be the condition in actual operation. With continuous rotation, the direction of gravity on the bearing is always changing and goes through several revolutions in a single period ot the natural oscillation. With this changing gravitational force, the probability of locking so as to prevent all relative motion is reduced to almost zero.

Since in any system with flywheel damping without an auxiliary drive, the film must accelerate the entire rotating system, it is not feasible to employ as heavy elements as with an auxiliary drive, nor is it practicable to get as high a directly connected moment of inertia. In view of this, it is difficult for me to see how the very low natural frequency mentioned near the end of the paper ($^1/_4$ cycle per second) can be obtained without an extremely flexible spring. I should expect that a spring with sufficient flexibility to accomplish this would be wound up through a large angle by the frictional torque, and since friction varies with temperature and other factors, there would be considerable departures from synchronism.

For the benefit of those who may wish to refer to earlier publications relating to sound-film drives, the following list is submitted.

KELLOGG, E. W.: "A New Recorder for Variable-Area Recording," *J. Soc. Mot. Pict. Eng.*, **XV** (Nov., 1930), p. 653.
COOK, E. D.: "The Technical Aspects of the High-Fidelity Sound-Head," *J. Soc. Mot. Pict. Eng.*, **XXV** (Oct., 1935), p. 289.
KELLOGG, E. W.: U. S. Pat. Re. 19,270.
HANNA, C. R.: U. S. Pat. No. 2,003,048.
KELLOGG, E. W., AND DREW, R. O.: "Filtering Factors of the Magnetic Drive," *J. Soc. Mot. Pict. Eng.*, **XXXV** (Aug., 1940), pp. 138–164.
KELLOGG, E. W.: "A Review of the Quest for Constant Speed," *J. Soc. Mot. Pict. Eng.*, **XXVIII** (April, 1937), p. 337.

MR. ALBERSHEIM:* In our survey of resistance-coupled auxiliary drives, such

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*Communicated.

as the magnetic drive, we made the most favorable assumptions. These include a loose film loop. If in Mr. Kellogg's design the pull of the film loop increases the required magnet torque considerably, its stiffness must be greater, and its filtering properties less than we estimated. However, from the paper, "Filtering Factors of the Magnetic Drive" by Messrs. Kellogg and Drew, it appears that the average torque needed to overcome the film loop pull is only about one inch-ounce.

We can not agree that in a system of gears there are no disturbances of lower fundamental frequency than that of the slowest gear in the train. A disturbance caused by the meshing of two high teeth has a period determined by the smallest common multiple of the numbers of teeth in all the gears. Assuming, for instance, that a 20-tooth gear drives a 25-tooth gear, the same teeth will not mesh until 100 teeth have passed the line of contact, *i. e.*, until after five revolutions of the smaller gear and four revolutions of the larger gear. Unless special precautions are taken it is therefore always possible that the auxiliary drive may generate disturbances in resonance with the flywheel-loop system. With regard to the shape of the film loop, Mr. Kellogg appears to prefer the *U* loop. In an actual drive, these distinctions are not always sharp. Fig. 5 on p. 146 of the paper by Kellogg and Drew, for instance, shows *S* bends on each side of the main *U* loop, so that the filter combines properties of both loop shapes. Such structural details are, of course, a matter of design choice, and we have already stated in the text of the paper that auxiliary overdrives have been successful. Our own preference for damped flywheels was based on economy of design.

The locking of inner ball bearings in damped flywheels or "kinetic scanners," which the liquid flywheel avoids, does not occur radially between balls and shaft but laterally between balls that are wedged together. This locking action has been verified, even during rotation of the flywheel, by quantitative tests of the Bell Telephone Laboratories. Experience has shown that introduction of the liquid flywheel reduced the flutter content, compared to previous designs, and eliminated the occasional jumps of flutter amplitude which we attribute to locking.

As in this case, practical success is the ultimate test in the design of elastic flywheel sprockets. A recently built re-recording machine embodying this feature obtains the low natural frequency recommended in the paper and has been found to have consistently low flutter, to require less maintenance than previous designs, and to be free from any observable asynchronism.

A SUGGESTED CLARIFICATION OF CARBON ARC TERMINOLOGY AS APPLIED TO THE MOTION PICTURE INDUSTRY*

H. G. MacPHERSON**

Summary.—*This paper presents definitions of the three general types of carbon arcs used in the motion picture industry, the distinction between them being based upon the origin and the character of the radiation in each case. In the low-intensity arc, the principal light-source is incandescent solid carbon at or near its sublimation temperature; in the flame arc, the entire arc stream, made luminescent by the addition of flame materials, is used as the light-source; while the high-intensity arc is one in which, in addition to the light from the incandescent carbon, there is a significant amount of light originating in the gaseous region immediately in front of the carbon. With these concepts as a basis, the theory of light generation in each case is presented with the object of further clarifying the distinction between the three types of carbon arcs.*

The carbon arcs used in the motion picture industry are of three general types—the low-intensity arc, the flame arc, and the high-intensity arc. The low and high-intensity arcs have been used in both motion picture photography and in projection, although the former is now obsolete in photography and is steadily being replaced by the more efficient high-intensity type in the projection field as well. The most important use of the flame arc in the motion picture industry is in photography, where it provides a broad beam of suitable color quality for general set illumination. The system of nomenclature that has grown up with the industry is more descriptive of certain types of lamp than of the character of the arc. Names such as "mirror arc," "Hi-Lo," "Simplified High-Intensity," "M. P. Studio," "Baby Spot," and "Sun-Arc" are in common usage, but some of these terms are not descriptive of either the arc itself, the mechanism, the optics, or the service. It is the purpose of this paper to define the arc itself, irrespective of the other factors just mentioned, so that a given trim may be readily classified as to whether it is a low-intensity, a flame, or a high-intensity arc.

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received May 1, 1941.

** National Carbon Company, Cleveland, Ohio.

As a basis for classification, the physical nature of the light-source offers the most logical distinction. Therefore the definitions have been phrased from this standpoint, followed in each case by descriptive material in their support.

The Low-Intensity Carbon Arc.—The low-intensity carbon arc is one in which the principal light-source is incandescent solid carbon at or near its sublimation temperature.

In the vast majority of cases, this arc is operated on direct current, although a few carbons are still sold for alternating-current service. The direct-current arc uses neutral cored positive electrodes and either solid or cored negative electrodes. A neutral cored carbon contains a core consisting predominantly of carbon, less dense than the surrounding shell, and incorporating a small percentage of an arc-supporting material such as a potassium salt, which does not contribute significantly to the light. "White Flame A.C." carbons are used in the alternating-current, low-intensity arc. The core of these carbons contains flame-supporting material the function of which is to steady the arc, quiet the hum, and whiten the light. In the direct-current arc, the crater face of the positive electrode is used as the light-source for projection, since it operates at a much higher temperature than the negative electrode and so provides about 90 per cent of the total light from the arc. The bright spot on the end of this positive carbon has a rather sharply delineated boundary which is called the anode spot or the positive crater. This crater marks the region within which most of the electric current passes between the anode and the arc stream.

The surface of the crater is heated to its high temperature as the result of the absorption of energy from electrons discharged there, and the absorption of energy from the gaseous region known as the anode layer directly in front of the anode. The arc gas in the major part of the arc stream is very hot, having a temperature of 6000°C or more, and is therefore highly ionized. In its highly ionized condition, it can carry the current with a fairly low voltage drop per unit length, amounting to about 20 volts per centimeter. In the anode layer, however, the gas is cooled by the proximity of the anode to such an extent that its degree of ionization, and therefore its electrical conductivity, is very low. Because of its low electrical conductivity and because of space-charge effects, a high voltage drop must be concentrated in the region of this anode layer in order to force electrons through it and thus conduct the arc current. This voltage is called the anode drop, and is of the order of magnitude of 35 volts for a low-intensity arc.

This energy dissipated at the anode heats it to incandescence, the maximum temperature obtained being limited by the sublimation temperature of carbon. This limits the maximum brilliancy of the low-intensity arc to a value of about 175 candles per square-millimeter. The area of the anode spot or crater adjusts itself for a given current so that the heat input is sufficient to bring the crater to a value near this sublimation temperature. An increase in current in the low-intensity arc will, therefore, not increase appreciably the maximum brightness, but will increase the area of the crater surface. Compared to a high-intensity arc, the current-density of a low-intensity arc is quite low. For the familiar commercial lamps, the current-density in the positive carbon ranges from approximately 50 to 200 amperes per square-inch.

It is interesting to observe that carbon is an ideal material for use as an electrode in such an arc, because it remains a solid at a higher temperature than any other substance of suitable electrical and thermal conductivity, so that a more brilliant light may be produced; while its property of volatilizing directly from a solid to a gaseous state permits convenient disposal of the consumed portion without danger to the associated mechanism.

The Flame Arc.—A flame arc is one in which the entire arc stream, made luminescent by the addition of flame materials, is used as a light-source.

The flame arc was a natural development from the low-intensity arc, obtained by enlarging the core in the electrodes and replacing part of the carbon there by chemical compounds capable of radiating efficiently in a highly heated gaseous form. These compounds are vaporized along with the carbon and diffuse throughout the arc flame, rendering it luminescent. The high concentration of flame materials in the core reduces the area and brilliance of the anode spot so that, at the low current-densities used in flame arcs, the contribution of the electrode incandescence to the total light becomes unimportant. The evaporation of flame materials is slow relative to that obtained in a high-intensity arc, and the resulting concentration of flame elements in the arc stream is low so that a high brilliance does not result. Since the whole flame is made luminous, however, the light-source is one of large area and the radiating efficiency is high.

The radiation emitted by the flame arc consists chiefly of the haracteristic line spectra of the elements in the flame material, and n the band spectra of the compounds formed. The rare earth metals f the cerium group are used as flame materials where, as in most ases, a white light is desired, while calcium salts are used to give a ellow light and strontium salts red.

The High-Intensity Carbon Arc.—The high-intensity carbon arc as sed for projection is one in which, in addition to the light from the ncandescent crater surface, there is a significant amount of light riginating in the gaseous region immediately in front of the carbons s the result of the combination of a high current-density and an tmosphere rich in flame materials.

To produce a direct-current high-intensity arc, the positive carbon ust be cored with chemical compounds similar to those used in flame rc electrodes. The current-density, however, is much higher, so hat the anode spot spreads over the entire tip of the carbon, result- ng in the rapid evaporation of flame material as well as carbon from e core. Since the flame material is more easily ionized than car- on, its presence in the anode layer results in a lower anode drop at e core area than at the shell of the carbon. This tends to concen- ate the current at the core surface, resulting in the hollowing out of crater as the current is increased. The rapid evaporation of the ame material produces a high concentration of this efficiently radi- ting gas in the crater and immediately in front of it. This gas, of ourse, radiates in all directions, even back toward the crater surface, nd consequently tends to serve as a blanket preventing the radiative ooling of the crater face. The heat liberated at the crater face must hen be dissipated entirely through evaporation of more flame ma- erial and through conduction back along the positive carbon. This, f course, tends to increase the evaporation of material within the rater and aids in the tendency for crater formation. Thus in a igh-intensity arc there is a close correlation between the crater depth nd the brilliancy of the arc gas within and immediatey in front of the rater; for a given type of positive carbon, there is a linear relation- hip between the crater depth and the excess brightness over that of low-intensity arc.

An increase of current in a high-intensity arc increases the crater rea only slightly, but produces a marked increase in brilliancy. he maximum brilliancy of the crater obtained in various types of rect-current high-intensity arcs used in common commercial lamps anges from 350 to 1200 candles per square-millimeter with current-densities in the positive carbon ranging from 400 to well over 1000 amperes per square-inch. Experimental carbons have been produced with brilliancies in excess of 1500 candles per square-millimeter.

The increased brilliancy of a high-intensity over that of a low-intensity arc is produced by radiation from the high concentration of flame materials within the confines of the crater. The thermal energy supplied by the electrical power input to the arc continually excites the atoms of the flame materials to higher energy states, and the excess energy of these atoms is being continually released in the form of radiation. The high density of radiation results in the production of a strong continuous spectrum in addition to the line spectrum of the flame elements. Since radiation in the visual range of wavelength from 4000 to 7000 Angstroms is required in motion picture services, the most efficient compounds to use as flame materials are those producing the most radiation in this spectral band. Nothing better than the rare earth metals, of which cerium, lanthanum, neodymium and praesodymium are typical examples, has ever been found for this purpose. With complex atoms having many electrons, countless opportunities for the energy exchanges that give rise to radiation in the visual region are provided, so that no one part of the spectrum is unduly exaggerated, and a white light is naturally produced.

The alternating-current high-intensity arc is also a true high-intensity arc within the meaning of the definition proposed. The high current-density and the high concentration of flame materials combine to produce light both from the incandescent electrode and from the gaseous region immediately adjacent, as they do on direct current.

Summary.—The fundamental distinction between the different types of arc is based upon the origin and character of the radiation The chief contributing factors associated with this are composition of carbon, current-density, and brilliancy. The low-intensity arc is one in which the principal light-source is incandescent solid carbon at or near its sublimation temperature. The high-intensity arc is one in which in addition to the light from the incandescent crater surface there is a significant amount of light originating in the gaseous region immediately in front of the carbon. In the flame arc the entire arc stream, made luminescent by the addition of flame materials, is used as the light-source.

Many members of the Cleveland and Fostoria laboratories, and of the Carbon Sales Division of National Carbon Company have contributed to the material presented here, and the author gratefully acknowledges their assistance in this connection.

IMPROVED METHODS OF CONTROLLING CARBON ARC POSITION*

D. J. ZAFFARANO, W. W. LOZIER, AND D. B. JOY**

Summary.—*This paper shows, both from previous data and fundamental considerations, the close control of carbon position necessary to obtain constant light on the proiection screen, particularly with reflector-type high-intensity carbon arc lamps. Review of the characteristics of this type of lamp and optical system reveals that in order to obtain constant light on the screen it is necessary to avoid variation of carbon position and changes in arc current due to line-voltage fluctuations. Methods of arc control employing photoelectric cells and bimetallic thermostats directly responsive to carbon position have been analyzed with regard to their applicability for this purpose. Some examples of these have been constructed and have demonstrated that automatic devices of simple construction are capable of maintaining constant the intensity, distribution, and color of the light on the projection screen.*

Recent years have seen great advances in the carbon arc light-sources used for motion picture projection. The "Suprex" type of arc and the more recent "One Kilowatt" arcs have brought to both the medium and small-size theaters much-needed increases in screen brightness, a more favorable color quality, and improvement in efficiency. The fundamental factors important to the operation of these reflector-type high-intensity arc lamps have been described in several publications in this JOURNAL.[1,2,3] One of the important requirements for uniform light is the fact that the arc must be accurately maintained at the proper distance from the reflector. The purpose of this paper is to show how automatic devices can be employed with these lamps to position the arc and deliver a more constant light to the screen.

The necessity of accurate positioning of the arc is made clear by examination of the geometry of the optical system of the reflector type lamp. Fig. 1(*A*) shows the essentials of the optical system commonly employed. The light-source and the film aperture are placed at the two foci *F* and *F'* of the elliptical reflector, which gathers

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received May 10, 1941.

** National Carbon Company, Fostoria, Ohio.

the light from the crater of the positive carbon and directs it to the film aperture, which in turn is imaged on the screen by the projection lens. Fig. 1(A) shows the path of a ray from one focal point, F, to the margin of the mirror and to the center of the aperture, F'. It can be seen that if the crater of the positive carbon is positioned at Q, the light from the center of the crater is focused at the center of the film aperture. If the positive carbon is moved ahead to position P, the ray travelling to the center of the aperture originates from the cooler portion of the carbon back of the crater which results in a change in color and intensity of the light at the center of the aperture and projection screen. Similarly, if the carbon recedes to position R,

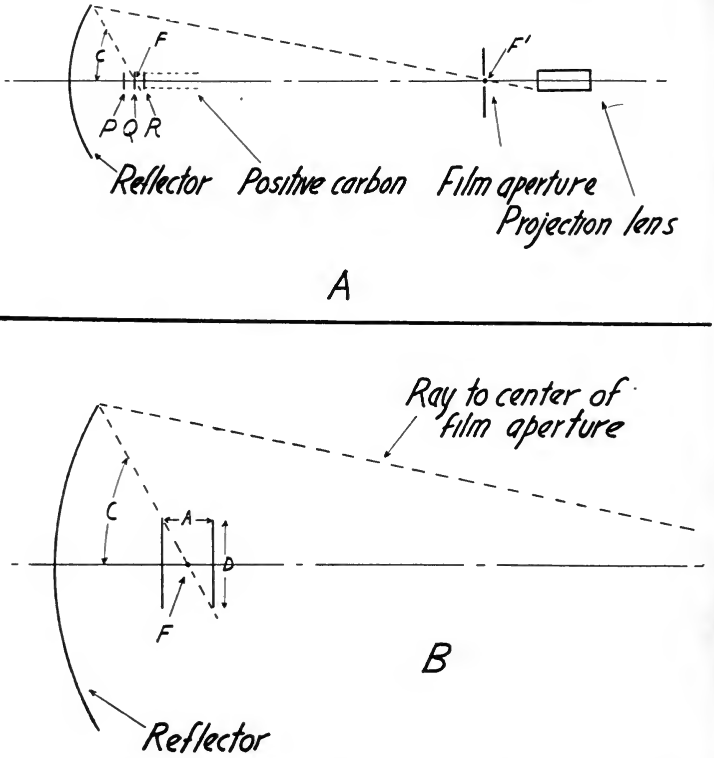

FIG. 1(A). Optical system of reflector-type projection lamp, showing relation of position of positive carbon to the light-ray travelling to the center of the film aperture. 1(B). Showing movement A within which light-ray to center of film aperture will originate on light-source of diameter D.

the ray travelling to F' originates from the arc stream in front of the crater, which is blue in color.

Fig. 1(B) shows the movement A of the light-source of diameter D within which the ray passing to the center of the film aperture F' will originate on the light-source. The two quantities A and D are related to the angle C by the equation:

$$\tan C = \frac{D}{A} \tag{1}$$

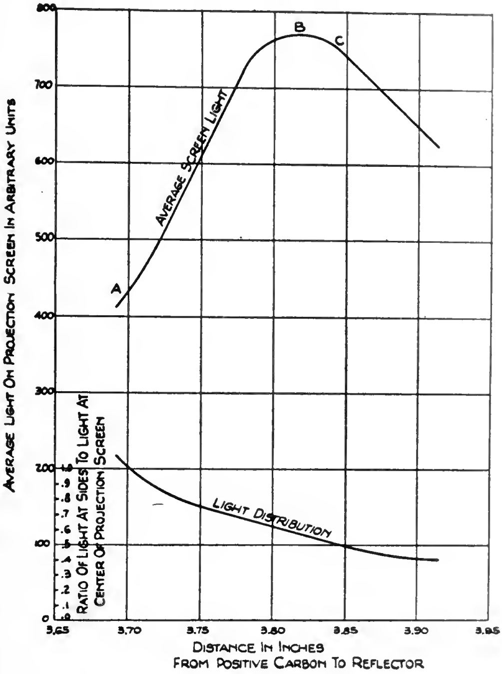

FIG. 2. Light on projection screen *vs.* position of arc: 7-mm positive, 6-mm negative carbons; 45 amperes; $^5/_{16}$-inch arc length.

With lamp and carbon combinations in use today, angle C may be as great as 70 to 75 degrees, for which the tangent is approximately three, indicating from equation *1* that the movement A would be about one-third the useful diameter D of the light-source. The useful diameter of the light-source in some examples may be as small as 0.15 inch in which case equation *1* would indicate a movement A of

0.05 inch. Although the basic considerations used in deriving equation *1* are greatly simplified compared with those that actually exist, the values calculated for the movement *A* roughly agree with laboratory determinations of the allowable arc movement for satisfactory screen color, especially with carbons burned at low current-densities, where the light-source has limited depth. Equation *1* suggests that the allowable arc movement can be increased by limiting the collecting angle *C* to a smaller value and by increasing the diameter of the light-source. Combinations of these two factors can be chosen so that there is no decrease in speed or relative aperture of the optical system and therefore no loss in light on this account. Under these circumstances greater allowable arc movement is observed. Examples are the condenser-type high-intensity lamp and some of the earlier low-intensity reflector arc lamps. However, the smaller

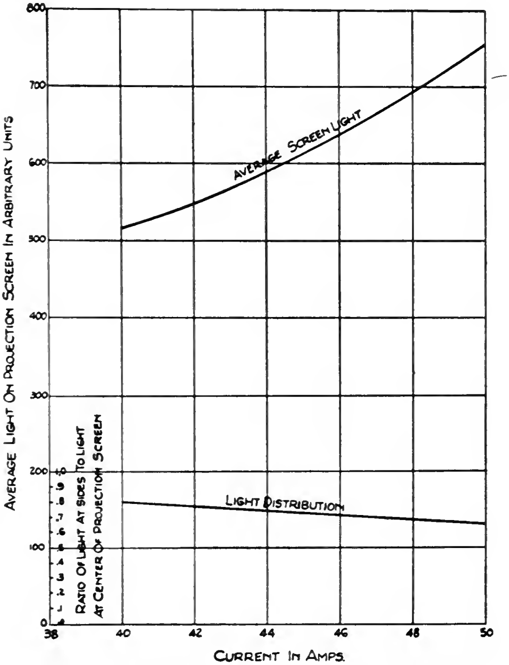

FIG. 3. Light on projection screen *vs.* current: 7-mm positive, 6-mm negative carbons; $^5/_{16}$-inch arc length; positive carbon 3.76 inches from reflector.

collecting angle results in incomplete utilization of the available cone of light, and the increase in light-source size necessitates larger carbons and higher currents to cover the film aperture and maintain the same brilliancy and light on the screen. Both these result in an undesirable reduction of efficiency.

Even within the range of allowable movement of the positive carbon for satisfactory screen color, there are changes in total screen light and in the distribution of light over the screen. The relations between screen light, screen distribution, arc length, current, and arc position have been previously published[2] and are reproduced in Figs. 2, 3, and 4. Fig. 2 shows the variation in total screen light and distribution with change in the arc position, at constant arc length and current, for one of the popular "Suprex"-type reflector lamp combinations. This clearly indicates that to hold the variation in screen intensity to a few per cent would require that the arc position be held within 0.01 to 0.02 inch.

The above discussion shows the necessity for accurate positioning of the arc. The degree to which this is accomplished with most of the present lamps depends to a large extent upon a favorable combination of the stability of the power source, the speed characteristics of the electrical feeding motor, the uniformity of burning characteristics of the carbons, and the attentiveness of the projectionist. When it is realized that high-intensity reflector lamps may consume from 2 to 4 inches of positive carbon during a 20-minute reel, and that a movement of the crater position of 0.01 inch would amount to only $^1/_4$ to $^1/_2$ per cent of the total length of carbon consumed, it can be seen that this degree of control is probably beyond the capabilities of any control system except one that is directly responsive to the position of the positive carbon.

Automatic methods of arc control responsive to the position of the carbons offer practicable means of holding the light on the screen constant and maintaining optimum burning conditions at all times. Some of what will be described in this paper is not new. Patents exist covering various embodiments of controls, and to insure freedom from infringement in adopting arc controls for specific lamp apparatus, the active patent art on the subject should be examined. Automatic devices responsive to carbon position have been employed to a limited extent with condenser-type projection lamps and to a greater extent on searchlights. They have not, however, found appreciable usage as yet on reflector-type projection lamps.

Requirements for Constant Screen Light.—Figs. 2, 3, and 4, giving the fundamental characteristics of high-intensity reflector lamps, point out essential requirements for constant light on the screen. As already discussed, Fig. 2 shows that movement of the arc position greatly changes both the intensity and the distribution of the screen light. Fig. 3 demonstrates that an increase in arc current increases the screen light. Fig. 4 shows that the arc length may be varied considerably without affecting screen light so long as the arc current and positive crater position are held constant.

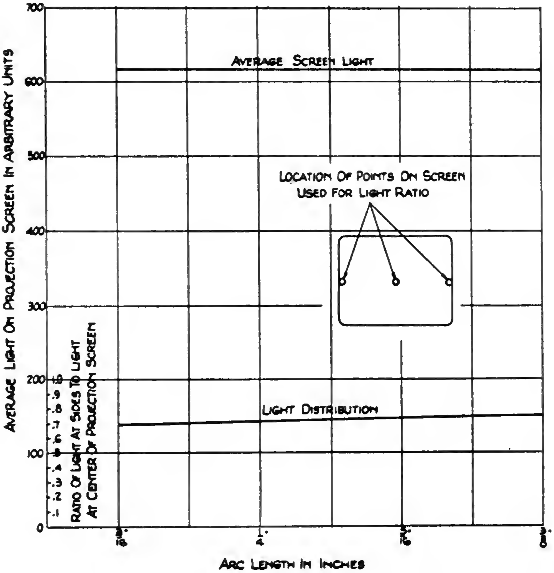

FIG. 4. Light on projection screen *vs.* arc length: 7-mm positive, 6-mm negative carbons; positive carbon 3.76 inches from reflector; constant current, 45 amperes.

Fixing the positions of both the positive crater and the tip of the negative carbon with respect to the reflector will result in constant light on the screen if all other conditions of the arc remain constant. However, with some types of power supply, line-voltage changes produce corresponding changes in arc current which, as shown in Fig. 3, would result in changes in screen light even when the positions of both carbons are fixed.

Where changes in power supply do occur, their effect upon the screen light can be avoided through the use of a method of arc control in which the position of the positive crater is fixed and the negative carbon position is controlled by a current-responsive device that changes the arc length so as to keep the current constant. This latter method is particularly effective with the low-voltage power sources commonly employed with "Suprex" and "One Kilowatt" d-c arcs with which small changes in arc length result in relatively large changes in arc current.

Methods for Controlling Arc Position.—One approach to the problem of controlling the positions of the burning electrodes in the arc is to use the intense radiation emitted by the arc to actuate sensitive receivers. Such devices include photoelectric cells, which convert radiation directly into electrical energy; or thermocouples, resistance thermometers, and thermostats, which function indirectly through conversion of the radiation into heat. A simple method of using this radiant energy for arc control is to project a side image of the arc by a fixed lens as shown in Fig. 5. As the arc moves, the image will also move, and a fixed receiver at the image will be subjected to changes in radiation intensity as a direct result of the displacement of the burning electrodes.

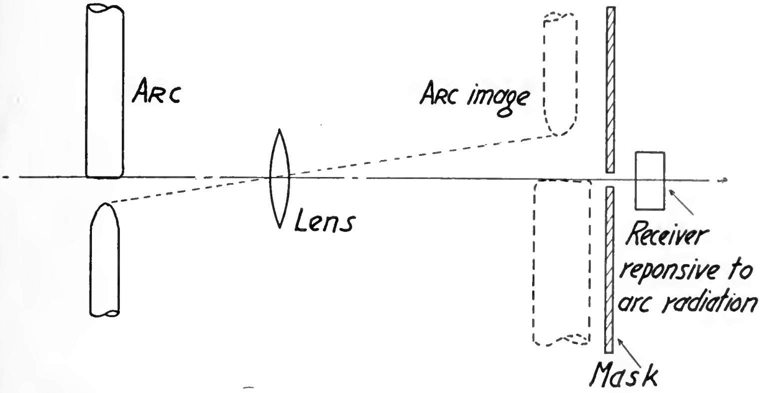

FIG. 5. Optical system for arc controls, showing image of arc focused on the receiver.

The relative intensity of radiant energy emitted along the axis XX' (Fig. 6) of the arc as detected by a thermopile and galvanometer

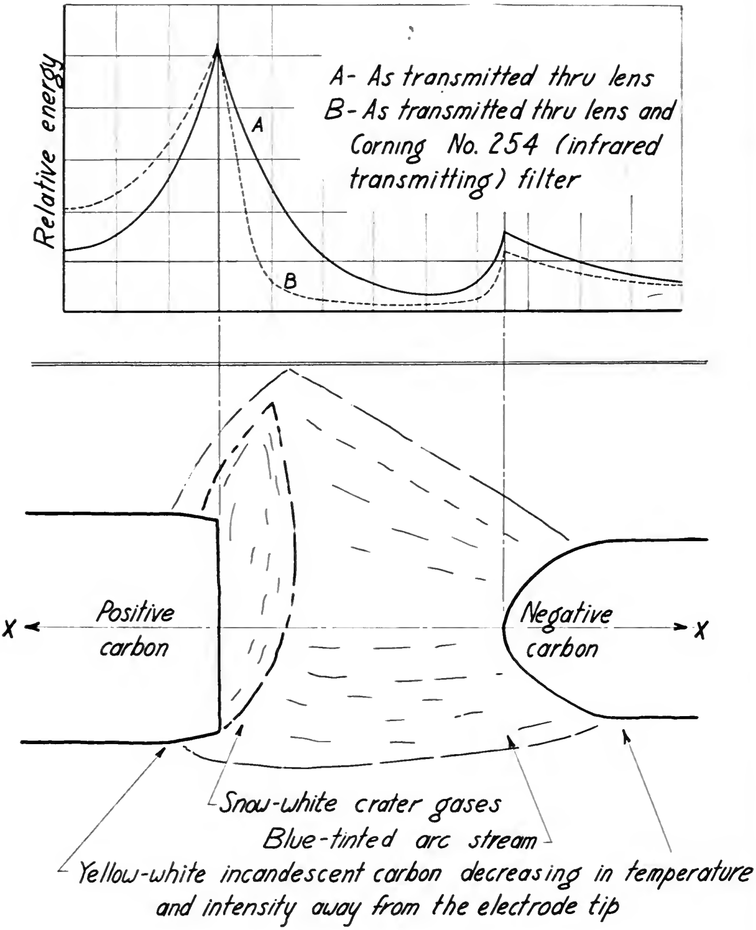

FIG. 6. Image of arc and distribution of intensity of radiant energy across carbons and arc stream. The ordinates of Curve *B* would need to be reduced by a factor of 2.5 to express them in correct proportion relative to Curve *A*.

is plotted in Curve *A* of Fig. 6, where the various features can be correlated with the portions of the arc from which they originate. The intensity of emitted radiant energy exhibits maxima at both the positive and negative electrode tips and decreases rapidly a short distance away. The intensity at the positive carbon tip is about three times as great as at the negative tip. Variation of the arc current results principally in changes in the intensity along the arc stream but does not destroy the essential features shown in Fig. 6 or result in much displacement of the positions of the maxima. The visual appearance of the arc reveals at a glance that the spectral energy distribution of the radiation originating from the various portions of the arc varies markedly. This is further borne out by the Curve *B* in Fig. 6, obtained after passing the radiation through a 5-mm thickness of Corning No. 254 infrared-transmitting filter which absorbs the visible light. This shows that the arc stream is rich in visible light while the incandescent carbons are relatively richer in infrared radiation. By means of this filter, the radiant energy gradient between the positive carbon and the arc stream can be made much more abrupt.

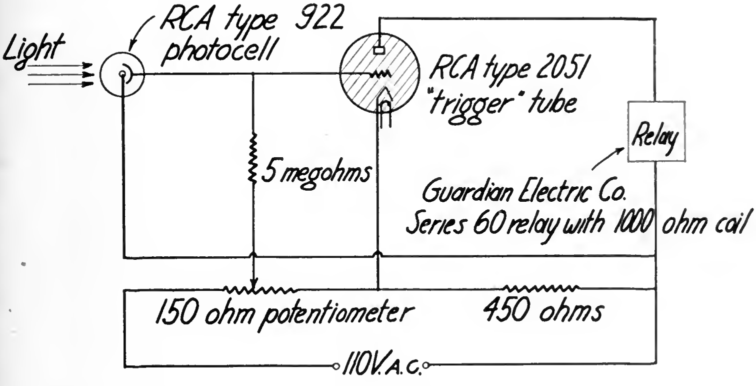

FIG. 7. Circuit of photocell and amplifier.

There are further marked differences in the radiation within the visible wavelengths originating from the different portions of the arc though these are not illustrated by the energy measurements of Fig. 6. How the marked change in energy along the carbons and arc stream can be used to operate arc control devices will be explained.

Arc Control with Photoelectric Cells.—A vacuum-type photoelectric cell was used as a receiver behind a slit 1/4 inch wide at an enlarged arc image, as shown in Fig. 5, and was made to operate a relay through an electronic amplifier in response to changes in the light-intensity associated with movement of the arc and its image. With the arc burning, the amplifier was biased so that the relay was inoperative when the light from the positive carbon just behind the crater struck the photocell. The lamp-feeding motor was adjusted to advance the carbons at a rate slower than their consumption rate, and was connected to the photocell-actuated relay so that it would run at high speed when the relay was energized. When the positive carbon burned back, the more intense light from the vicinity of the carbon tip struck the photocell, tripping the relay which allowed the carbon to feed up until the light at the photocell was reduced to its original level, at which point the relay again became inoperative and the feed-motor returned to its normal speed.

The photocell control circuit used is shown in Fig. 7, and employs a single gas-discharge "trigger" tube. The speed of the feeding motor is controlled as shown in Fig. 8 by means of a resistor in the motor field circuit which is short-circuited by the relay when the motor is running at low speed.

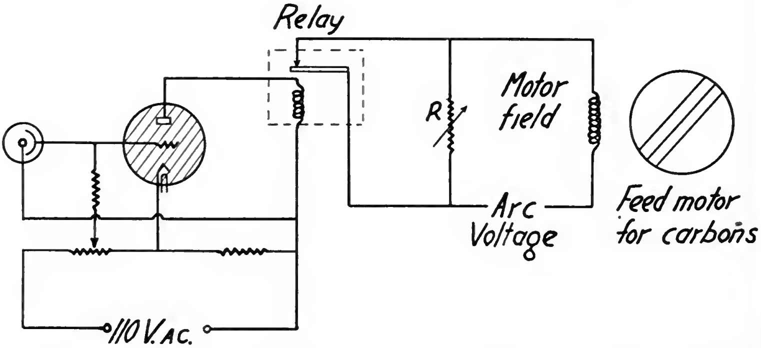

FIG. 8. Method of connecting photocell and amplifier to control the speed of the motor feeding the carbons.

Since a variation in light-intensity exists also at the negative carbon tip, a double photoelectric control was constructed for controlling both positive and negative carbons by means of two photocells and associated amplifiers, giving constant arc length as well as constant arc position. This control was used in conjunction with a "Suprex" type of lamp modified to employ separate feed-motors for the positive and negative carbons. A photocell circuit essentially similar to that of Figs. 7 and 8 was provided for each of the carbons. A side image of the arc was focused on the photocells placed outside the lamp-house. The light emitted from the vicinity of the two carbon tips was admitted to the respective photocells through a double slit placed at the arc image in front of the photocells. Performance data on this combination are given in a later section of this paper.

Arc Controls with Thermostats.—It has been found possible to make bimetal arc controls which possess sufficient sensitivity and are capable of carrying the current necessary to change the speed of the lamp-feeding motor, and which therefore do not require amplifying equipment.

Since the Curve A in Fig. 6 is a plot of the variation in total energy across an arc image, a curve of the deflection of a blackened bimetal strip *versus* the position across the image would be expected to have a similar shape with the maximum deflection occurring at the positions of the peaks on the curve. The simplest thermostat would consist of a single bimetal strip with one end fixed and the other end free to deflect and make or break a circuit to a fixed electrical contact in response to changes of temperature of the bimetal caused by movements of the arc image. Such a thermostat, however, would be unable to differentiate between the radiant energy received from the arc and the heat received from the adjacent surroundings which may vary during the "warm-up" period of the arc lamp or because of room temperature changes. Compensation can be made for the variable heat received from extraneous sources by replacing the fixed electrical contact point by one mounted upon a "dummy" or compensating piece of bimetal which is free to respond to the heat received from the surroundings but which is shielded from the direct radiation from the arc. This compensating member eliminates the effect of the surroundings and leaves the relative motion of the contact points dependent only upon the direct radiation from the arc. Such

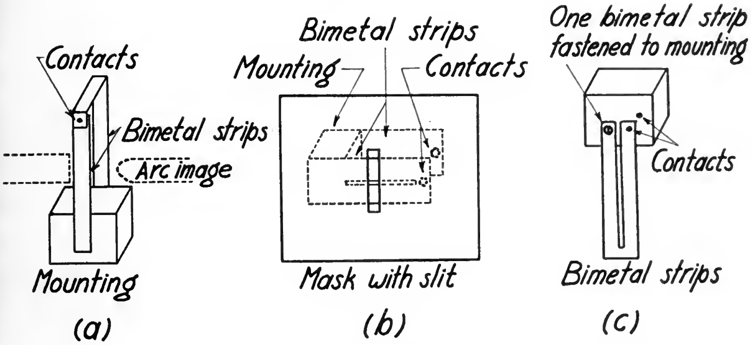

FIG. 9. (*a* and *b*) Singly compensated thermostats; (*c*) doubly compensated thermostat.

a thermostat is shown in Fig. 9(*a*), in which the "dummy" bimetal strip is placed behind the "active" strip and thereby shielded from the direct radiation of the arc. For purposes of discussion, we have chosen to call this type of thermostat a "singly compensated" one. Another example of a singly compensated thermostat is shown in Fig. 9(*b*). This differs from the one of Fig. 9(*a*) in that the lengthwise direction of the bimetal strip is placed parallel to the axis of the carbons instead of perpendicular. Another difference is the use of a mask with a narrow vertical slit to restrict the portion of the arc image admitted to the bimetal. With the thermostat of Fig. 9(*a*), the orientation and narrow width of the bimetal strips effectively perform this function of a slit. In this arrangement of Fig. 9(*b*), wider and thinner, and more sensitive pieces of bimetal have been employed. A lengthwise slot in the center of each strip was used to avoid "cross-buckling."

Singly Compensated Thermostat.—With the singly compensated thermostat, the initial setting of the positions of the electrical contacts determines the amount of radiation the bimetal must receive from the arc to effect interruption or completion of the electrical circuit. This type of thermostat can be utilized as follows for control of carbon position. The thermostat contacts are connected to short-circuit a resistance in the field circuit of the motor that feeds the carbons, giving a high speed when the contacts are open and a low speed when they are closed. The thermostat contacts can be set to close at a point on the arc image on the falling part of the energy curves of Fig. 6 in the arc stream just in front of the positive carbon. If the carbon burns back, less energy will be received by the thermostat, which can be arranged to open its contacts and speed up the motor, feeding the carbon forward and increasing the energy on the thermostat until the contacts close and reduce the speed of the motor. The gradient of the energy *vs.* position curve along the arc, such as *A* in Fig. 6, determines the sensitivity to arc position with which such a thermostat will function. Therefore, any procedure that increases this gradient, such as the use of a filter described in connection with Curve *B* of Fig. 6, will improve the sensitivity of the types of thermostat shown in Figs. 9(*a*) and (*b*). Changes in the overall level of intensity of radiation received at the arc image would tend to result in a shift along the arc image of the point at which the singly compensated thermostat closes its contacts due to its inherent property of requiring a fixed amount of radiant energy. The gradient in intensity from carbon to arc stream as shown in Curve B of Fig. 6 is sufficiently abrupt, so that the point along the arc stream where the contacts of the thermostat close will not shift appreciably. With energy distribution curves along the arc such as shown in Fig. 6, there will necessarily be two points, one on either side of the maximum, at which the thermostat will close. If one of these is used for arc control as described above, the other will affect the feed motor in a sense opposite to what is required. The possibility of the thermostat's being displaced out of its operating range will be lessened if the two points at which the thermostat closes are separated as widely as possible on the arc image which, as can be seen from Fig. 6, means operating the thermostat at as low energy as practicable. This is more feasible with Curve B than Curve A of Fig. 6 because the gradient, which has been shown above to be important to sensitivity, can be kept abrupt at low values of energy.

Doubly Compensated Thermostats.—Another form of thermostat is well adapted to the type of energy distribution along the arc shown in Fig. 6. An example is shown in Fig. 9(*c*). Two adjacent strips of bimetal are employed, rigidly linked together at one end. With the thermostat illustrated in Fig. 9(*c*), mounting is accomplished at one of the unlinked ends of the strips, leaving the other unlinked adjacent end free to move and make contact with a fixed point. Both bimetal strips receive radiation from the arc and bend in the same direction when heated. They are placed with respect to the arc image so that one is on either side of the maximum of intensity at the positive carbon shown in Fig 6; thus both strips are approximately equally heated. If the arc image is displaced in either direction, due to movement of the carbon, one strip becomes heated more strongly than the other, resulting in opening or closing of the contacts, which can be made to control the feed-motor in the same manner as previously described. Such a thermostat has two degrees of compensation. In the first place, as with the singly compensated type described above, it is compensated for heat received from the surroundings, since this causes equal deflection of both strips which leaves the separation of the contacts unchanged. Second, it responds only to displacements of the position of maximum intensity on the arc image and is unaffected by general overall increases or decreases of the level of the curves of Fig. 6, such as would occur with increase or decrease of arc current. We have called this a "doubly-compensated" thermostat because of this twofold degree of compensation.

The various examples of singly and doubly compensated thermostats shown in Fig. 9 have been constructed and tested. A simple bracket mounting the lens and thermostat was fastened to one window of a "Suprex"-type lamp. The lens was supported about four inches from the arc, giving an image on the thermostat just outside the window. The thermostats were constructed of W. M. Chace Co.'s Type *2400* bimetal,[4] heat treated by the manufacturer to a temperature of 700°F. The thickness of the bimetal was 0.010 inch except for the thermostat of Fig. 9(*b*) which was 0.005 inch thick. The material was used in the form of strips about 1 inch long and 0.1 to 0.2 inch wide. Platinum-faced contact points obtained from the H. A. Wilson Co. were employed.[4]

PERFORMANCE OF ARC CONTROLS

Double-Photocell System.—To evaluate the performance of the double-photocell control previously described, "Suprex" trims were burned for 20 minutes each and the positions of both carbons were read on an enlarged side image. Readings were begun two minutes after the arc was struck, and no adjustments were made on the lamp, photocells, or amplifiers during the test. The observations on the accuracy with which the carbon positions were maintained have been reduced to the statistical basis shown in Table I, giving the per cent of the total time that the carbons were held at various distances from the original arc position.

TABLE I

Tests of Accuracy of Carbon Position Control with Double Photocell

	Per Cent of Time Held within Limits Specified	
	0.000 In. to 0.015 In.	Greater than 0.015 In.
Positive carbon	80	20
Negative carbon	90	10

This shows that the double-photocell control was capable of limiting the variation of carbon position for the most part to less than 0.015 inch, with a few excursions greater than this. Since the photocells are biased so as to respond to departures from light levels determined at the time of the initial adjustment, any change from the initial conditions that causes light variations, such as line-voltage fluctuations, results in a change of the positions at which the carbons are held. This is probably the reason for the few cases in which the change in position exceeded 0.015 inch.

Performance Tests on Thermostats.—Performance tests were made on a "Suprex"-type lamp adapted to accommodate various examples of the singly and doubly compensated thermostats described above. These were used to control the position of the positive carbon.

The feeding of the negative carbon was accomplished through a separate motor which was controlled by a magnetic relay responsive to the arc current. In this manner the negative carbon was advanced by just the amount necessary to maintain the arc current constant. This combination is designed to eliminate the effect upon screen light of movement of the arc crater and variations in power supply.

A considerable number of trims of "Suprex" carbons were tested and observed as described in connection with the photocell evaluation. The data on the accuracy of positioning the positive carbon are shown n Table II on the same statistical basis as used for Table I.

TABLE II

Tests of Thermostats Shown in Fig. 9 in Conjunction with Constant-Current Control

	Per Cent of Time Positive Carbon Held within Limits Specified	
Type of Thermostat	0.000 In. to 0.015 In.	Greater than 0.015 In.
Singly compensated (Fig. 9*a*)		
Without heat filter	78	22
With heat filter	85	15
Singly compensated (Fig. 9*b*)	96	4
Doubly compensated (Fig. 9*c*)	99	1

The data in Table II show that all the thermostats restricted the position of the positive carbon most of the time to within 0.015 inch of the correct position. The use of the heat filter described in connection with Fig. 6 improved the accuracy of control obtained with the singly compensated thermostat of Fig. 9*a*. The superior performance of the singly compensated thermostat of the type shown in Fig. 9(*b*) may be due to its differences in construction and method of application as discussed in an earlier portion of this paper. The best performance of all in Table II is shown by the doubly compensated thermostat. This can probably be attributed to its different principles of operation and inherently greater degree of compensation. It must not be assumed that these data in Table II represent the ultimate in performance. Further improvements may bring the performance of the singly compensated thermostats up to that shown by the doubly compensated one.

While comparison of Tables I and II indicates that the double-photocell control was not quite as effective as the thermostat devices, refinements are, however, possible for the photocell that can improve the precision of arc control obtainable with it. For example, the use of the constant-current relay for the negative carbon and one photocell to fix the positive carbon position would no doubt result in more precise control. Furthermore, just as a filter was used to increase the gradient in radiation between the positive carbon and arc stream as shown in Curve *B* of Fig. 6, suitable filters may be employed to increase the sensitivity of photoelectric cells to movement of the arc image. It is possible also to devise photoelectric means utilizing one of the important principles of the doubly compensated thermostat—namely, the property of responding only to the position of maximum intensity on the arc image and not to the level of intensity. This can be achieved through the use of a special photocell consisting of two adjacent cathodes placed one on each side of the maximum of intensity in the arc image.

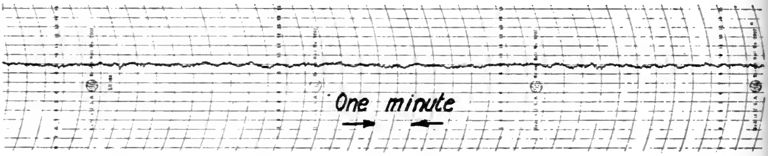

FIG. 10. Record of light at center of screen over 20 minutes, using doubly compensated thermostat plus constant-current relay.

These control devices have been used in connection with commercial reflector-type lamps in the experimental work described above. Some modification of the mechanism and method of operation of these lamps is necessary in order to obtain independent control over both the positive and negative carbons. While the emphasis in this paper has been chiefly on the application of these methods of arc control to reflector-type high-intensity lamps, they can be used also with other types of carbon arc lamps to effect automatic control.

The primary aim of all these arc-control devices is to maintain constant light on the projection screen. The chart shown in Fig. 10 is a record of the light-intensity at the center of the screen over a 20-minute period without the projector shutter running, using the doubly-compensated thermostat whose performance is given in Table II. This thermostat plus the constant-current control was used with a "Suprex"-type lamp burning the 8-mm—7-mm "Suprex" trim at 62 amperes. The trace shows that over a 20-minute period, the average light level remained constant within about two per cent and the extreme variation from this level was only about four per cent. This demonstrates that these automatic controls can effectively maintain constant light on the screen. The employment of such methods of arc positioning, therefore, makes possible significant advances in the quality of motion picture projection.

REFERENCES

[1] 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.

[2] JOY, D. B., AND GEIB, E. R.: "The Non-Rotating High Intensity D-C Arc for Projection," *J. Soc. Mot. Pict. Eng.*, **XXIV** (Jan., 1935), No. 1, p. 47.

[3] LOZIER, W. W., JOY, D. B., AND SIMON, R. W.: "A New Negative Carbon for Low-Amperage Trims," *J. Soc. Mot. Pict. Eng.*, **XXXV** (Oct., 1940), No. 4, p. 349.

[4] We wish to acknowledge the generosity of the W. M. Chace Co. of Detroit, Mich., and the H. A. Wilson Co. of Newark, N. J., in furnishing us thermostatic bimetal and platinum-faced contacts for our experimental work.

SYMPOSIUM ON PROJECTION*

PREPARED FOR THE PROJECTION PRACTICE COMMITTEE AND PRESENTED AT THE ROCHESTER CONVENTION

***Summary.**—This symposium on projection comprises three parts: (1) Projection Room Equipment Requirements; (2) The Projection Room—Its Location and Contents; and (3) Factors Affecting Sound Quality in Theaters.*

PROJECTION ROOM EQUIPMENT REQUIREMENTS

J. J. SEFING

What is installed in a modern projection room is of great importance to all connected with the motion picture industry. A projection room may possess all the requirements for a safe and efficient layout and still remain equipped with obsolete or inadequate apparatus. To set a 100 per cent workable standard is quite impossible, but from every-day practical experience, much knowledge has been gained that tells us quite accurately just what a piece of equipment will do and how the equipment can best be applied.

In the old "magic-lantern" days, a projector was bought haphazardly, not as a matter of choice but because of the limitations of the infant industry. At the present time, there is no legitimate excuse for not knowing what is best and most efficient in motion picture equipment, as nearly everyone is "picture conscious" and is clamoring for good screen performance. A good projection room layout has well planned and sufficient working space around the various pieces of equipment for the convenience of the projectionist, and the equipment installed therein is adequate for the needs of the particular theater. However, in many instances, projection rooms in theaters are not provided with adequate and suitably planned space for the workers and the equipment, and it is for the designers of such rooms that reliable information should be available as to the most practicable methods and procedures.

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.

In purchasing and installing projectors, several important items should be carefully considered. The pedestal or base should be sufficiently strong and steady to support properly the heavy load of the lamp house, magazines, and mechanisms in order to produce a steady picture on the screen. An old-type, obsolete pedestal, even with makeshift braces, can not be as steady and reliable as a pedestal especially designed to carry the load of the modern projector and sound mechanisms. A lamp house should be selected that will be adequate for the size of the picture and the auditorium. At present, there are three arc lamps on the market that are widely used, each having its advantages and specific applications. Theaters having an average-size picture of 14 × 18 feet should have at least a "1-kw" arc, thus providing a *minimal* screen brightness of 9 foot-lamberts; with a picture size up to 17 × 22 feet the "Suprex"-type arc will produce *minimal* brightness; for pictures wider than 24 feet, high-amperage condenser type arc should be used.

With regard to the upper and lower magazines on the projector, there is nothing special about them except that the 2000 and 3000-foot types are quite regularly used. The take-ups at the lower magazine are of several types: the friction type, the friction even-tension type, and the fluid drive. There are three methods of driving—belt, bicycle chain, and silent chain.

The selection of the projector mechanism is of prime importance, as its operation is very delicate and the parts must be precision-made, with a high degree of accuracy. The average projector mechanism must operate about twelve hours a day, over a period of one to two years, pulling a 35-mm film intermittently at a rate of 90 feet per minute, or 24 pictures a second and magnifying a frame area of about $^1/_2$ square-inch to about a screen area of 350 square-feet. It can be seen that the proper selection of the projector mechanism is of great importance in assuring trouble-free operation and screen results as fine as it is possible for modern mechanisms to produce.

For picture change-over from one projector to another, a good type of electrical device should be used. A projectionist can not make a good change-over when he has to manipulate a home-made device. Everything in the projection room is timed so precisely that anything that disrupts or hinders the timing will show itself quickly on the screen.

Regarding the sound equipment, a choice of several well known systems can be had today. The amplifier, monitor, volume controls, and change-over device should be installed as near to the projectionist as is practicable, within the available working area, for convenience of manipulation. The dials, switches, and pilot-lights should be so arranged in the sound equipment as to be easily distinguishable.

In planning the projection facilities, three separate rooms should be provided: one for the two projectors, the spotlight or third projector, the sound equipment, and, in the larger theaters, the dimmer bank; a second room, for the rewind equipment, and a third room for the d-c generating equipment. A separate toilet and wash room should be provided near the projection room proper; in some states this is compulsory. The walls of the rooms must be fire-proof, with metal access doors and two main metal doors on opposite sides of the projection room. Two port-holes should be provided for each projector, one for projection and the other for viewing the screen. If a spotlight is included in the equipment, a port somewhat larger than the projection port should be provided as well as another observation port of the same size as the projector observation port in the rewind room. Over these various port-holes, approved metal fire-shutters must be installed and so arranged by a master trip system that the shutters will drop and cover the openings in case of fire, automatically, by the melting of fusible links, or manually, by the projectionist. For exhausting the hot, stale air from the various rooms, a mechanical blower with a metal duct system and grille-taps into the rooms should be installed. The blower may be controlled electrically by a snap-switch and by a special switch connected to the master trip arrangement on the fire-shutter apparatus, which will automatically turn on the blower in case of a fire. Another blower with a metal duct system and taps into the arc lamp houses should be provided for exhausting the heat, gas, and ash of the arc. This blower should also be mechanically electrically controlled and of sufficient capacity to exhaust the arc lamp house properly and yet not affect the burning of the arc.

For sound-proofing the projection room or for cutting down noise transmission to a minimum, a good practice is to use cement plaster up to a height of 5 feet from the floor, all around the room, and above this height acoustone *D* or other approved material of equal acoustical properties. The port-holes in the projection room may be sound-proofed by glass in a separate track over the shutters or by installing acoustical baffles inside the openings. If glass is used in the projection ports, it should be special "optical" glass.

The projection room floor should be coated with a good grade of paint to stand the wear and tear and the penetration of oil or, better, it should be covered with a good grade of "battleship" linoleum. A popular color scheme is olive-green on the floor and walls, up to a height of 5 feet all around the room, and buff or gray on the upper walls and ceiling. The complete fire-shutter apparatus should be painted a flat green color instead of the former black enamel finish.

The projection room proper should be so planned that the horizontal center-line of the auditorium and screen is midway between the two projector lenses, which latter should be 5 feet apart. If the projection room is located an appreciable distance off this screen and auditorium center-line, due to disadvantageous structural conditions, a definite and noticeable "keystone" will result on the screen. The edge of the screen image farther from the lens will be longer than the opposite edge, and so the screen picture will not be rectangular. The "keystone" effect will likewise occur if the projector lenses are too high above the center of the screen, necessitating a steep projection angle. There are two ways to help overcome the "keystone" effect; one is to use dark, heavy velour masking around the picture to absorb light falling upon the screen outside the required rectangular area, and the other is to file a blank aperture plate to the proper dimensions required for a rectangular screen picture. This method is quite critical as the filing must be quite precise.

A safe working area around the projector and other equipment in the projection room can not be stressed too strongly. At least 30 inches of clear space should be provided at the sides and rear of each piece of equipment in the projection room. The projection room, rewind room, and generator room must be constructed of substantial, approved, fire-proof materials. In all cases, before proceeding with the construction, approval of the design should be obtained from the local, state, or city authorities having jurisdiction. This will avoid any costly revisions or penalties after the work is done.

The architect, engineer, or even the theater owner can obtain reliable, up-to-date information from the Society of Motion Picture Engineers' specifications on projection room planning, prepared by the Projection Practice Committee, which provides all the important and desirable dimensions.

THE PROJECTION ROOM—ITS LOCATION AND CONTENTS*

J. R. PRATER

Before selecting the location for the projection room, let us consider the individual factors involved.

(*1*) *Effect on Screen Image.*—The primary purpose of the projection room is to provide a place from which the screen image can be projected to the best advantage. This requires that:

(*a*) The projection angle be kept as small as possible, both laterally and vertically. The depth of focus of the projection lens is taxed severely to maintain a sharply defined image over the entire screen area under working conditions. Add to this the buckling of the film at the projector aperture, plus any uneven wear of the aperture tracks and tension shoes, plus the unavoidable lateral projection angle imposed by the spacing necessary between projectors, and the best we can hope for in theater practice falls considerably short of the ideal. Now if we add a vertical projection angle to the already difficult situation, the screen image definition suffers visibly with only a very small vertical angle. Long before the maximum approved limit of 15 degrees is reached, the screen image suffers visibly from distortion as well as from loss of definition. The added depth of focus of the longer E.F. lenses may hold the definition within tolerable limits, but the distortion is unavoidable.

(*b*) The projection distance should be such that a projection lens with an equivalent focus within normal limits will produce the desired size screen image. The lens must have a speed of $f/2.0$ to match that of modern arc lamp optical systems. Such projection lenses are available in focal lengths from 2 to 5 inches to fit existing projectors. Although $f/2.0$ lenses are also available in focal lengths of 6, 7, and 8 inches, they are too large for standard projectors to accommodate. If longer than 5-inch E.F. lenses are used with standard projectors, speed must be sacrificed, with resultant loss of light efficiency. On the other hand, fast lenses of extremely short E.F. have a lesser depth of focus, and the lateral spacing between projectors at the necessarily short projection distances imposes an undesirably heavy lateral projection angle. For example, a 2-inch E.F. lens will form a screen image 20.5 feet wide at a projection distance of only 50 feet. At this short projection distance, with the recommended spacing of 60 inches between projectors, the lateral projection angle is approximately $2^1/_2$ degrees for each projector where two are used; 5 degrees for both outside projectors where 3 are used. Lateral angle is more serious than the same amount of vertical angle, because of the 4 to 3 proportion of the image width to its height. Also, it is impossible to cancel any of the lateral projection angle by tilting the screen. This brings our ideal projection distance to that which will give the desired picture size with an *f*/2.0 projection lens of 5 inch E.F.

(*c*) The lowest point of the light-beam projected to the screen must have a clearance of at least 6 feet 4 inches above any seating or traffic floor area to prevent interference with the picture. The highest point of the light-beam must be sufficiently below any ceiling obstruction to afford a clear view by the projectionist.

(*2*) *Accessibility.*—The projection room should be easily accessible from outside the theater without passing through the seating area or other public areas. Under no conditions should the projection room open directly into an audience area without double doors so arranged as to prevent any patron from seeing into the projection room at any time.

(*3*) *Fire Hazard.*—To reduce the fire and audience panic hazard, and consequently the insurance rates, the projection room should be located outside the fire wall of the theater or within a fire wall of its own.

(*4*) *Heating and Ventilating.*—Provision must be made for a non-combustible vent duct of ample capacity leading to the open air; also for fresh air in-take not connected with the main air-conditioning system. If unit heaters or steam radiators are placed directly in the projection room they must be covered with wire mesh. A much more satisfactory plan is to place heating coils or radiators in the projection room supply ducts.

(*5*) *Plumbing.*—Plumbing facilities must be extended to the projection room location, space being allowed immediately adjoining.

(*6*) *Noise Isolation.*—The projection room noise and mechanical vibration must be kept from the audience area of the theater. While it is possible to do so by employing massive construction and acoustical materials, regardless of the location, the task can be accomplished much less expensively if only the front wall of the projection room is directly exposed to the auditorium.

(*7*) *Additional Space Immediately Adjoining.*—It is highly desirable that motor-generators, rheostats, rectifiers, and other apparatus necessary to projection, as well as supplies, spare parts, test equipment, tools used only occasionally, and clothes lockers be located as conveniently as possible to the projection room without being placed directly therein.

Considering all these factors, it is obvious that the location of the projection room will necessarily be a compromise in many respects. In making the compromise, it is well to remember that the screen image is what the theater has to sell. The requirements for excellent projection should come first and foremost, even at an added initial cost.

The contents of any projection room should be limited strictly to what is necessary for carrying on the performance with safety, dependability, and excellence. The following should be within the projection room proper:

(*1*) Fire-proof shutters on all ports, with both automatic and manual controls as described in the SMPE approved plans. (Also NBFU* Pamphlet 40, Sec. 191*e*.)

(*2*) A switch controlling the auditorium lights. Provision must be made also for turning these lights on from at least one other convenient point in the building. (NBFU, Sec. 191*j*.)

(*3*) Fire extinguishers of types using water or water solutions, such as soda and acid, calcium chloride, pump tank, and loaded stream. (NBFU, Sec. 144.) It seems that there is room for argument on this point. Water extinguishers are dangerous to use on electrical equipment, besides being themselves a source of extensive damage to such equipment. Carbon tetrachloride or compressed carbon dioxide extinguishers would seem much more appropriate for location inside the projection room. If the water types must be provided, it is the author's opinion that they should be located just outside the projection room, and be used only after the projectionist is outside. If such procedure does not satisfy local fire authorities, however, it can not, of course, be followed.

An interesting fact is that the NBFU does not recommend the use of fire extinguishers by the projectionist at all. Section 218 of NBFU Pamphlet 40 states: "*Procedure in Case of Fire.*—In the event of film fire in a projector or elsewhere in a projection or rewind room, the projectionist should immediately shut down the projection machine and arc lamps, operate the shutter release at the nearest point to him, turn on the auditorium lights, leave the pro-

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* National Board of Fire Underwriters.

jection room, and notify the manager of the theater or building." If such procedure is followed, why should there be any hand extinguishers at all inside the projection room?

(*4*) *Waste Receptacles.*—(*a*) A suitable container for keeping scrap film under water, separate from waste paper and other rubbish. (NBFU, Sec. 183.)

(*b*) A metal container for hot carbon stubs. This should have a funnel-shaped cover with an opening only large enough to admit the largest diameter carbon used.

(*c*) If we adhere strictly to regulations, there would be no need for a receptacle for other waste material, because in Sec. 191*f* the NBFU states: "No combustible material of any sort whatever shall be permitted or allowed to be within such enclosure (projection room), except the films used in the operation of the machine, and film cement." Such a condition would indeed be ideal from a fire-hazard standpoint, if it could be maintained; but in actual practice there will almost inevitably be waste material of various sorts to be disposed of. There are available on the market cans suitable for such material.

(*5*) A work-table or bench of metal or other non-combustible material, *not* provided with racks or shelves underneath, which might be used for keeping film or other materials. (NBFU, Sec. 117.)

(*6*) Such tools as are necessary for changing carbons and making minor adjustments or repairs during the performance. These should be permanently located as conveniently as possible to the place where they will be most frequently used.

(*7*) Two good flashlights. One may burn out when needed in a hurry, or may be in use in an adjoining room. An approved portable trouble-lamp with metal guard, such as a "Reel-Lite," is good for long repair jobs, but should never be used around machinery in operation, and should not take the place of the flashlights.

(*8*) Two or more projectors and arc lamps. Sound equipment including a double-channel amplifier, all of NBFU approved design and manufacture.

(*9*) An enclosed metal cabinet for supplies and spare parts most likely to be needed during a performance.

(*10*) All controls necessary to operate the projection equipment, including associated apparatus not located in the projection room proper, such as rectifying equipment, ventilating fans, effect lighting, stage curtains used for motion picture presentation, *etc.*

(*11*) A house phone or other means of communication between projection room, auditorium, and manager's office.

(*12*) No film other than that actually in projectors or being threaded. This requires, of course, that there be an adjoining room for rewinding, inspection, and storage.

(*13*) One or more qualified projectionists, who shall not be minors. (NBFU, Sec. 217.) To operate a projection room with minimum fire hazard and first-class screen results requires that at least two projectionists be on duty at all times. Large theaters using more than two projectors, spotlights, effect machines, *etc.*, in the projection room must have more men in proportion to the additional equipment.

This outline covers only what must be in the projection room proper. Even for the one-man room, there is need for adjoining space to accommodate rectifying equipment, shipping cans, a complete stock of supplies and spare parts, oil cans, tools and test equipment not ordinarily used during a performance, a work-bench with vise, clothes lockers, books, records, and any other items necessary to the operation of the projection room, but which need not and should not be inside the projection room proper.

FACTORS AFFECTING SOUND QUALITY IN THEATERS

ADOLPH GOODMAN

During the past ten years a great deal of technical progress has been achieved in recording technic, and in recording and reproducing apparatus, so that today these advances should be reflected in greater entertainment value of the motion picture. In spite of such improvements there is much to be desired in the final presentation in theaters, mainly because there is a lack of proper coördination between the various phases that go to make up the ultimate sound as heard by the audience.

In this discussion, we shall point out the factors that must be considered and how they affect each other from the standpoint of the presentation in the theater. Assuming that the sound-track on the film is a faithful record of the original sounds, final results that the theater patrons hear depend upon the following five important, closely related factors:

(*1*) The sound-reproducing system.
(*2*) The theater acoustic condition.
(*3*) The screen.
(*4*) The adjustments of the sound system.
(*5*) The operation and maintenance of the sound system.

The Sound-Reproducing System.—It is fundamentally important that the sound-reproducing system be adequate, since it is through this medium that the audience is expected to hear sounds as the studio directors and technicians originally conceived them. It is well known that inadequate sound reproduction can ruin an otherwise excellent picture, while sound properly reproduced adds greatly to the entertainment value of the motion picture action.

In the early days, equipments having output power up to 10 or 12 watts were considered satisfactory, while in many instances the power available was as low as 1 or 2 watts. Modern presentation of sound motion pictures requires considerably increased power for proper dramatic effects, and it is not unusual for the larger theaters to use as much as 150 watts of undistorted power. Even greater power is needed for showing pictures such as Disney's *Fantasia* for creation of effects designed to stimulate the audience.

Realism in sound effects adds tremendously to the appeal of the screen action. Earthquake and warfare scenes must have sound accompaniment loud enough to make the audience feel that they are actual spectators at the scene of action. Thus, the small theaters as well as the large ones need apparatus having many times the power considered adequate in the past.

The Society of Motion Picture Engineers and the Academy of Motion Picture Arts and Sciences have studied the requirements for adequate theater sound equipment to meet the needs of modern pictures, and the following specifications represent the results of these studies:

(*1*) Volume range of 50 to 60 db.

(*2*) Amplifier capacity in accordance with recommendations of Academy of Motion Picture Arts and Sciences. (See *Research Council Bull.*, June 19, 1940.)

(*3*) Frequency response of 50 to at least 8000 cycles, with provision for extension to 10,000 cycles.

(*4*) Stage loud speaker system should have a high degree of efficiency, so that the required amplifier capacity need not be too great. The loud speaker system should have proper angular distribution so that all frequencies can be properly distributed throughout the theater.

(*5*) The sound-head should have a "flutter" content imperceptible to the ear.

(6) The equipment should be easy to install and operate. Necessary operating controls should be accessible.

(7) Components of apparatus should be easily accessible for maintenance and service operations.

(8) Adequate emergency provisions should be incorporated.

(9) Provision should be made for addition of apparatus that may be required in the future due to advancements in the art.

Theater Acoustics.—Regardless of how well sound is reproduced by the stage speakers, the theater acoustics greatly influence the final result. If a theater is properly designed acoustically, it will allow the sound to arrive at the listeners' ears with naturalness and realism. If the theater has any acoustic defects, the sound may be so changed in character that it arrives at the listeners' ears harsh, distorted, and very unsatisfactory.

In view of the technical progress that has been made in both recording and reproducing apparatus, it is more important than ever before that careful consideration be given to the acoustic design of the theater. This is necessary in order to take full advantage of the ability of modern equipment to give a faithful reproduction of the original sound.

Some of the more common defects found in auditoriums that are detrimental to good reproduction are high reverberation-time, echo, resonance, and extraneous noise from auxiliary equipment, or noises from sources outside the theater. Many of these can be overcome or eliminated by proper consideration of such problems in the original design. Specifically, attention should be given to the shape and size of the theater, the location and frequency characteristics of absorbent materials, and the insulation of walls and air-conditioning ducts to minimize the transmission of noise to the auditorium proper.

Fortunately, the present trend is toward coördination between acoustic treatment and the other functions of the auditorium such as lighting, decoration, air conditioning, *etc.* Thus the theater architect can carry out a definite decorative scheme and at the same time incorporate the necessary provisions to make the theater suitable from an acoustic standpoint.

Screen.—After the sound leaves the loud speaker system it must pass through the screen before reaching the audience. Just as the acoustic condition of the theater plays an important part in the final result, so does the screen influence the sound as heard by the listeners.

One of the improvements made in modern sound equipment is the extension of the upper audio-frequency range. A poor screen will not allow the high-frequency tones to be transmitted with the proper intensity, resulting in a loss of brilliance of the music and lack of intelligibility of speech.

The sound-transmission properties of a screen depend upon several factors, the most important of which are the size and number of perforations per square-inch and the thickness of the screen material. If the holes are too small or the material is too thick, then the screen presents too high an acoustic impedance to permit good sound transmission.

Even though a screen may be satisfactory when first installed, it may adversely affect the sound transmission after a period of use. The perforations will gather dust, and eventually the hole diameters will be restricted, causing a reduction in high-frequency transmission. More frequently loss of transmission qualities are due to resurfacing the screen, in an attempt to improve the light-reflecting qualities. Any attempt to overcome such adverse conditions of the screen by recompensating the sound system to accentuate certain frequency bands results in ragged response and uncomfortable hearing conditions as far as the audience is concerned.

Adjustments of the Sound System.—While present-day theater sound apparatus is capable of reproducing with greater fidelity, the various components must be more carefully installed and adjusted than has heretofore been necessary. Low-level circuits should be carefully shielded and grounded to prevent the introduction of extraneous noises into the system. Correct power-transformer taps should be used, depending upon the line voltage. Voltages and currents in tubes, exciter lamps, and loud speaker fields should be checked to be sure they conform to specifications. In addition, the mechanical apparatus should be carefully inspected, oiled, and adjusted before any film is run. After these preliminary adjustments have been made, then the amplifier system should be set to conform to the frequency response characteristic set up for that particular system. Experience with a large number of installations has shown that the standard electrical characteristic will prove to be satisfactory in the vast majority of theaters.

To secure uniform frequency balance, proper distribution of high-frequency tones, and equalized volume levels in the various parts of the theater, it is necessary to pay special attention to the installation and adjustment of the stage loud speaker system. One of the most satisfactory speaker set-ups is that in which the high frequencies are reproduced by a cellular type of horn and the low frequencies by some type of folded horn, with a suitable cross-over network to separate the two frequency bands properly. Since frequencies above 300 cycles become directional and beyond 2000 cycles have a beam effect, the positioning of the high-frequency horn is extremely critical in arriving at the best setting for uniform sound distribution. Also, the high-frequency horn must be properly set with respect to the low-frequency unit to obtain the correct phase relation between the sounds emanating from both sources. Usually, this dimension is specified by the manufacturer, but the actual relative positions are subject to slight variation in practice and must be checked during the tune-up process.

At present, the most satisfactory means for adjusting the balance and distribution in the auditorium is by use of the Academy Research Council Theater Sound Test-Reel and by careful listening tests in all parts of the theater. Since the test-reel contains selections of regular release prints from the various major Hollywood studios, once the equipment has been adjusted properly, it will reproduce the product of all studios with uniformly good quality.

Operation and Maintenance of the Sound System.—The preceding discussion pointed out how the condition of the theater and the equipment affects the sound reproduction. Of equal importance are the operation and maintenance of the sound system. Since the apparatus consists of delicate mechanical parts and sensitive electrical circuits, it must be kept in good condition at all times.

An important point in practical operation is the setting of the sound volume level for the auditorium to allow the audience to hear comfortably. It must be remembered that the frequency response of the human ear changes for different sound levels. When the response of the sound system is adjusted for proper balance between high and low frequencies for a certain optimal level in the auditorium, the pictures reproduced at this level are natural and pleasing. However, if the average level is increased or decreased, the sound quality changes appreciably and the balance is destroyed. Generally, if the level is set too low, the sound loses "screen presence," giving the impression that the actors are far behind the screen. If the level is too high, certain features of voice reproduction are over-accentuated and the sound becomes extremely irritating, (*e. g.*, excessively strong sibilants). Projectionists can determine the average gain setting for their theaters that will give the most pleasing and understandable sound. Once this has been determined, there should be no necessity for "riding" the gain control during the showing of a picture.

Because of the many delicate adjustments that must be maintained it is extremely important that the equipment be inspected periodically. Quite often the quality of the sound will deteriorate slowly, but not enough to be noticed immediately. Such a condition can be checked quickly, provided the system is regularly adjusted, to be sure that it performs in accordance with the standards originally set for that particular type. Such inspections require the use of proper tools and test equipment, including electrical meters specially designed for the purpose, flutter indicator, and special test-films. Worn parts in the sound-heads should be replaced before they adversely affect the sound reproduction.

PROGRESS IN THREE-DIMENSIONAL PICTURES*

J. A. NORLING**

Summary.—*Recent years have seen improvements in still and movie stereoscopy that have given impetus to their commercial exploitation. The developments that have resulted in their commercial acceptance have been in the nature of refinements rather than in radically new devices. Experimental work on many such new devices has received notice in the public press and in technical journals.*

Some of the problems encountered in the production of three-dimensional motion pictures and the methods suggested for exhibiting them have been reviewed in a previous article.[1] The present paper is in reality a supplement to the earlier one, and, in addition, will deal with some of the problems of projected three-dimensional still pictures.

The first commercial application of Polaroid to three-dimensional pictures was in 1939, when a 35-mm black-and-white three-dimensional production was used as a featured attraction at the Chrysler Corporation's exhibit at the New York World's Fair.

During the year 1940, two other 35-mm three-dimensional films were made and exhibited. One was a new film entitled *New Dimensions*, for Chrysler's 1940 New York World's Fair Exhibit and was produced in Technicolor; the other was a 35-mm black-and-white film called *Thrills for You*, which was the major attraction in the Pennsylvania Railroad's exhibit at the Golden Gate International Exposition in San Francisco.

About four million persons have viewed these three films, so it is probably safe to say that real three-dimensional motion pictures have emerged from the experimental and novelty stage.

The success of three-dimensional motion pictures both with Polaroid as a projecting and viewing means as well as the earlier anaglyphs[2] using red-and-green spectacles, has stimulated great interest in further exploration of the possibilities of projected stereo-

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received May 1, 1941.

** Loucks & Norling Studios, New York, N. Y.

scopic pictures. Still stereograms as well as cine stereograms have received attention, and a few recent improvements have been made, particularly in projectors. Most of the projection devices presented have employed polarized light. The "eclipse" system has been experimented with for motion pictures, and a still picture projector utilizing this method was put on the market recently. This method requires a shutter on the still projector, synchronized with shutters on individual viewing devices. Another method[3] uses prism viewing spectacles fitted with a baffle for each eye to block the unwanted images.

All these methods and devices have interesting possibilities, but at present the polarized-light system is the only one that provides simplicity and economy *together with a satisfactory quality in the projected picture.*

CAMERA EQUIPMENT

To photograph three-dimensional pictures requires cameras having twin lenses or some other provision for obtaining pictures from spaced viewpoints. When two lenses are used, it is recognized that they must be very closely matched. For practical reasons there must be some tolerance in matching. Lenses that match each other within one-half of one per cent in focal length will be satisfactory. It is advisable to keep the two images to the same size within a tolerance of not more than one-half per cent.

Definition is more important in stereoscopic picture making than in ordinary photography. Three-dimensional images should be crisp, clear, and as sharp as possible throughout the whole scene depth. Lenses should be highly corrected and capable of being operated at small apertures. Surface-treated lenses are particularly advantageous since they are capable of producing images of superior quality.

Matched lenses in sets of various focal lengths are required to extend the operating range of the camera. However, it is questionable whether extreme long-focus lenses are ever going to be widely used, if at all. In my judgment, the useful range of focal lengths is from the shortest (widest angle) that can be used up to a focal length of about four times the diagonal of the picture.

The mounting of the lenses is important. The ordinary stereoscopic camera has its lenses mounted so that the axes are parallel and extend perpendicularly from the center of the picture plane. This is acceptable and good practice for most subjects but it may be desirable to change the axes so that the image centers will converge at some point in the scene. It is therefore advantageous to have the lenses mounted so they can be rotated or shifted or both.

Most stereoscopic cameras have the lenses mounted at a fixed interocular distance. In many cases it is desirable to use less than the normal $2^1/_2$-inch spacing, and in some cases it is desirable to extend the spacing to many times the normal. A versatile stereo camera will, therefore, have provision for changing the lens interocular.

There are on the market many types of stereoscopic still cameras. They range in size from those using 35-mm film up to such cameras as the "StereoGraphic" which makes the pair of pictures on one 5 × 7-inch plate. There are also several attachments employing prisms or mirrors. These are made to fit on a single-lens camera and produce two images on the plate or film within the space occupied by the single image when using the lens without the attachment.

These cameras and attachments are adequate for making stereograms that are to be looked at through a lens or prism-type stereoscopic viewer, but are lacking in versatility for the production of stereograms to be projected on a screen.

To obtain results beyond the capacity of the standard stereo still camera it is necessary, at present, to have the desired features built into existing models.

In order to obtain pictures with proper "borders" the operator has to be able to shift the lenses in relation to the centers of the plates (or to shift the plates in relation to the optical axes). To obtain the best three-dimensional effect he has to be able to select a narrow interocular for close-up work and a wide interocular for distant scenes. In the ordinary stereoscopic camera with parallel lens axes the "border" is at infinity. Under these conditions there is no actual stereoscopic "border," or stereoscopic "window" at all. It is generally conceded that the most pleasing projected stereogram results when the spectator sees it as if looking through a window—when the scene seems to exist behind the window or screen frame.

For still-life subjects a single camera may be used, the exposures being made successively. The camera is mounted on a slide-board and the interocular may be any selected value from zero to as great as the capacity of the slide-board. For action shots or exposures of short duration the two pictures must be made simultaneously.

Apparatus for action shots may be made up of two cameras mounted on a common base and so arranged that the interocular may be varied by moving one or both cameras The shutters must be accurately synchronized and the timing of the shutters closely matched.

The requirements for making still stereograms apply also to motion picture stereoscopy. For instance, in scientific films it may be necessary to photograph a very small object, such as an insect, quite close to the camera. This demands a very narrow interocular. On the other hand, some scenic shots are vastly improved by spreading the lenses apart, thus obtaining a greater three-dimensional effect.

Obviously it is difficult, if not impossible, to build one camera with such a wide range. Several cameras may be required to cover a wide variety of subjects.

Since photoplay production does not demand the photography of minute objects, it seems reasonable to assume that only a limited interocular range will be needed. A range of interocular from $1^1/_2$ inches for close-ups up to 4 inches for long shots should be adequate for the average photoplay. It is possible to provide this range in one camera.

The same desirable features regarding convergence of the picture centers in making stereo movies, because "bordering," that is, establishing the proper margins at right and left, must be done, and can be done, only in the camera.

The finder on a stereoscopic motion picture camera is an important accessory, and its functions differ in some important respects from standard practice. It is desirable to view the scene in three dimensions and to see both images so that proper alignment for convergence and bordering can readily be effected. Naturally the finder images must be right side up and not reversed left for right. A binocular finder of the right kind enables the cameraman and director to determine by visual means the lens interocular considered best for any given scene. Of course, general rules must be established for interocular spacing depending upon distance of principal object and magnification of the lenses employed, but occasionally it may be desirable to increase the depth of a scene to enhance its dramatic effectiveness.

No data are included in the present paper on interocular spacing *versus* distances and magnifications because there is little agreement among research men and operators as to recommendations. Everybody agrees that "excessive" interocular spacing creates distortion. The controversial point is to define the words "excessive" and "distortion" as applied to the problem. Broadly, the whole matter of interocular spacing and magnification in the taking of the scene should be influenced by the conditions of projection under which the picture will be shown. Therefore, it is of great value to know beforehand what will be the average conditions of screen angles, seating arrangement, *etc.*

John T. Rule, of Massachusetts Institute of Technology, has contributed valuable data on the geometry of stereoscopic projection in a recent paper.[4]

PROJECTION

The projection of the Polaroid three-dimensional 35-mm motion pictures that have been mentioned has been done through two synchronized projectors. In one case synchronism was obtained by electrical interlock; in the other, by mechanical means. Both systems worked excellently. Since projection of the pictures was on a "grind" basis, with very short periods between shows, and there were no breakdowns, it is evident that either method is satisfactory.

Considerable experimental work has been done with 16-mm projection but no actual use has been made of 16-mm stereograms for commercial purposes. The indications are that such equipment will be available sometime this year.

Several types of stereoscopic still projectors have been introduced, and the three-dimensional projected still picture is coming into wide use for display and advertising purposes.

At present there are on the market two types of projectors using Polaroid and one using the "eclipse" system. One of those using the Polaroid method projects stereograms consisting of pairs of standard 3 × 4-inch lantern-slides; the other is equipped for both 2 × 2-inch slides and 35-mm slide-films.

All these projectors employ dual optical systems. One type uses two lamps, and the projector for slide-films uses a special lamp containing two filaments.

These new projection facilities should be of interest to the scientist as well as the advertiser. The medical profession can utilize them for many purposes. Gross specimens, operations, and radiographs may be enlarged in three-dimensional form and may be viewed by large groups. Engineers can obtain photoelastic records obtained by polarized light in three-dimensional form to facilitate the study of stresses and strains in the various planes of the plastic model. Any number of other interesting possibilities present themselves.

The projection of polarized-light stereograms demands a screen that will not affect the angles of polarization of the projected images. A metallic surface, preferably aluminum unadulterated by the admixture of white or gray pigment, is indicated. Several screens now on the market meet these requirements.

The angles of polarization recommended by the Polaroid Corporation and adopted as standard practice is a 45-degree slant upward to the right for the right-eye picture and a 45-degree slant upward to the left for the left-eye picture. Arranged this way it does not matter whether the viewers are turned left for right or not. The earlier vertical-horizontal polarization axes required of the user that he face the viewers in one selected direction. The new arrangement requires no special instruction to the audience.

THE VECTOGRAPH

No review of progress in three-dimensional photography would be complete without a mention of E. H. Land's remarkable process for combining the two disparate images on one film. The vectograph, as this new type of print has been called, was reported at a meeting of the Optical Society of America held at Rochester last year, and those interested in its technical features may refer to that valuable paper.[5] At present the vectograph is available for stills, either as slides or mounted on aluminum-surfaced paper. When this new method becomes available for motion picture printing it will simplify enormously the present projection difficulties. Ordinary projectors, without any changes at all, will be used for the projection of vectograph films.

OTHER METHODS RECENTLY PROPOSED FOR PRODUCTION OF THREE-DIMENSIONAL MOVIES

S. J. Ivanov is credited with having developed a new method of projecting stereoscopic movies.[6] From the description of the Ivanov method it appears that the cost of the special screen required must be rather high. Projection is from two projectors, but it is claimed no viewing accessories are required. It is not apparent that the Ivanov method differs essentially from other systems employing grids in front of, or behind, the screen. Many variations of the principle have been proposed during the last thirty years or so.

Another grid device, recently patented by Suzanne Carre,[7] is an interesting variation on the grid principle. The grid is composed of thin rods or wires spaced apart a distance equal to their width. A motor synchronized with the projector reciprocates the grid back and forth across the screen. Rear projection is employed, the grid being between the audience and the screen. It is claimed that in this manner the grid will select the pictures for the left eye and then for the right eye in such a manner that each eye sees only the picture intended for it.

William Alder, of Pasadena, Calif., has devised a method for which much is claimed. The Alder method requires an attachment that fits on the lens of an ordinary movie camera. It consists of a group of mirrors revolved at high speed. By this means part of both sides as well as the front of an object are recorded on the same film—three images altogether. It is claimed that projection of the print, through an ordinary projector and on any standard screen, results in a three-dimensional effect without the necessity for using individual viewers.

The Alder method is evidently capable of giving the screen image of some subjects a certain plasticity absent in the ordinary two-dimensional picture.

Since Mr. Alder's theories were expounded in a newspaper article,[8] I think it only fair to quote from that article:

"I have found," Alder said, "that the stereopticon photography creates a false illusion of too much depth. I am trying to attain 'natural vision.' I want to show the human being and the landscape with the same amount of depth it shows to the naked eye."

This broad statement does not explain that "too much depth" in stereograms is the result of faulty technics in the use of the twin-lens camera. Too much depth results when too wide an interocular is employed. Varying the interocular controls the apparent depth and for natural results it is often necessary to reduce the interocular to less than the normal $2^1/_2$ inches, as pointed out previously.

Quoting Mr. Alder from the same article again: "I have played around with double lenses on a camera and with double rows of film, attempting to equal the parlor type of stereopticon still photographs. But while from one section of the theater there is the illusion of depth and three dimensions, nevertheless any move from this limited area means that the illusion vanishes and you have two pictures, in two dimensions, running side by side on the screen."

Actually, when the proper conditions exist in the theater and the spectators are furnished with proper means for viewing the three-dimensional picture it will remain a three-dimensional picture from every point in the house, with the qualification that a view from a great angle will introduce marked distortion. But serious distortion is present in any two-dimensional picture viewed from the same unfavorable angle.

TRICKS OF THE NEW ART

Three-dimensional photography offers rare opportunities for special stunts and startling effects. The possibilities are almost limitless.

First, we can change the depth of the scene—lengthen it excessively or compress it if we so desire.

Second, it is possible to change the apparent size and shapes of objects and in that manner create startling and often amusing effects.

Third, it is possible to combine elements of one scene into another to achieve striking effects.

CONCLUSION

John T. Rule stated, in the paper referred to above,[4] "The present stereoscopic movie, when intelligently taken and projected, is a very good product, acceptable to even a critical observer."

That is the state of the art today. What it will be in the future, with all the refinements that will be developed as the stereoscopic movie becomes more widely used, can best be left to the imagination.

GLOSSARY OF TERMS

Anaglyphs. Stereograms in which one image of a stereoscopic pair is printed in one color and the other in another color.

Angular Distortion. The apparent distortion resulting from viewing a three-dimensional picture from an unfavorable angle.

Bordering. The manipulation resulting in creating the "stereoscopic window," through which a three-dimensional picture seems to be seen.

Convergence Point. The point on the scene at which the optical axes cross.

Depth Distortion. The apparent distortion in the depth of a three-dimensional picture.

Eclipse Stereoscopy. Methods of producing projected stereograms by intermittent projection. One image of the pair is projected while the other image is eclipsed; then the other image is projected while the first is eclipsed.

In-Front-of-the-Window. Term applied when objects apparently exist between the stereoscopic window and the spectator.

Interocular. The distance between the optical centers of twin lenses or attachments for single lenses.

Marginal Cut-Off. The effect at the side margins of the stereogram when objects in front of the "stereoscopic window" are cut off by the "window."

Polaroid. The material most commonly used in making projection and viewing filters for polarized-light stereograms.

Polarization Angle. The angle from the horizontal at which the axes of the polarizing filters are set.

Stereoscopic Window. The border or frame around the stereogram and behind which the three-dimensional scene appears to be.

Through-the-Window View. Applied to the stereogram when it appears as if seen through a window.

REFERENCES

[1] NORLING, J. A.: "Three-Dimensional Motion Pictures," *J. Soc. Mot. Pict. Eng.*, **XXXIII** (Dec., 1939), No. 12, p. 612.

[2] LEVENTHAL-NORLING *Audioscopiks,* motion pictures released by Metro-Goldwyn-Mayer since 1936.

[3] WITHEROW, G.: "An Experiment in Three-Dimensional Movies," *Home Movies* (April, 1941), p. 170.

[4] RULE, J. T.: "The Geometry of Stereoscopic Projection," *J. Opt. Soc. Amer.*, **31** (April, 1941), p. 325.

[5] LAND, E. H.: "Vectographs: Images in Terms of Vectorial Inequality and Their Application in Three-Dimensional Representation," *J. Opt. Soc. Amer.*, **30** (June, 1940), p. 230.

[6] *Moscow Pravda* (March 7, 1940), and New York *Times* (Jan. 25, 1941).

[7] U. S. Pat. No. 2,240,131, assigned to La Chronostereoscopic, Paris, France.

[8] Gregg Toland, New York *Times* (Apr. 20, 1941).

SOLVING ACOUSTIC AND NOISE PROBLEMS ENCOUNTERED IN RECORDING FOR MOTION PICTURES*

WILLIAM L. THAYER**

Summary.—*More and more attention is being given to the naturalness and clarity of reproduction of sound in motion picture theaters. To accomplish these it is necessary to improve not only the equipment in both the theater and the studio, but also the acoustics, and to reduce noise in both the theater and in the sets where the sound is recorded.*

It is the purpose of this paper to describe the acoustic and noise problems encountered in recording, and to describe ways in which these problems have been met. This includes a discussion of the ways of minimizing reverberation in outdoor scenes on a sound-stage; of reducing sound resonance between ceiling and floor, and between parallel walls of sets; of reducing reflection from concave surfaces, nearby hard walls, windows, table and desk tops; of reducing resonance in small rooms such as telephone booths, boat and train interiors. Also included is a discussion of the progress recently made in reducing equipment noises such as those from cameras, background projection machines, arc lamps, wind machines, treadmills, etc., and ways of reducing noises caused by actors and horses on hardwood floors, gravel walks, and on raised structures, such as artificial hills built of wood; and of noise created by artificial rain. The control of outside noises such as those of traffic, aeroplanes, and wind is discussed.

When looking at a motion picture one is interested mainly in the story and thinks of the sound only when it is hard to understand or is unnatural in quality; and then he becomes only slightly irritated If this irritation keeps up throughout the picture he will not enjoy the picture nearly as much as if the sound were so good that he would not think about it. Surely no one in a motion picture audience is ever consistently aware of the varying acoustic and noise problems that confront the sound-recording engineers as the actors move about the "set" and from one type of "set" to another. Neither are they aware of the fact that when the picture was made a microphone was continually moved about just above the frame line of the camera and in

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** Paramount Pictures, Inc., Hollywood, Calif.

front of each actor as he spoke, in order to record as much direct sound as possible and consequently to minimize the acoustic and noise problems that might become irritating to the listener.

Because of the necessity of maintaining beauty or realism in the picture it often becomes impossible to build sets having good acoustics; but through experience the sound engineers, working with the set designers, have found numerous ways of avoiding poor acoustic conditions without destroying the beauty or naturalness of the set. It is the purpose of this paper to describe ways in which acoustic and noise problems have been met, perhaps not perfectly in every case, but adequately.

FIG. 1. Typical exterior set on motion picture sound-stage.

ACOUSTIC PROBLEMS

There is an endless number of types of sets encountered in making motion pictures. They may be classed into exterior and interior sets. The exterior sets are either natural outdoor settings or exterior sets within a building or stage. The interior sets range from large rooms or groups of large rooms to very small rooms, such as the interiors of trains, aeroplanes, automobiles, boats, or even telephone booths.

The general problem in exteriors on stages is to keep the reverberation sufficiently low to give the audience the impression that the recording has actually been made outdoors in accordance with the illusion established in the picture. Fig. 1 is a typical exterior set on a motion picture sound-stage. On sets of this type, even though the stage is relatively dead acoustically, the painted sky backing, which usually covers about three-fourths of the stage wall area, is rather hard and normally reflects enough sound to spoil the illusion of an exterior scene. In recording scenes on such a set it is difficult to avoid reverberation in the "long shots" where the camera shows the entire set; but in "medium shots" and "close ups" reflections and reverberation can be reduced by acoustic treatment on the portions not shown in the picture. This is usually accomplished by hanging large drapes or "sound blankets" (20 × 30 ft), to partition off the portion of the stage not in use, or in hanging the "blankets" a short distance in front of all "sky backing" not in the picture. Also, improvement is sometimes obtained by hanging "blankets" overhead horizontally just above the elevation of the lights. Considerable improvement can be obtained by using a directional microphone such as the cardioid or ribbon microphone. Jungle and forest scenes are less difficult than

FIG. 2. A set requiring reduction of reflections.

the set shown in Fig. 1 because the shrubbery and trees help to absorb the sound, while ocean or lake scenes are more difficult because of sound reflections from the water's surface.

In interior scenes one expects to hear reverberation, and therefore the presence of recorded reverberation is not disturbing to an audience so long as the reverberation is not greater than what would be expected from the interior pictured on the screen. However, excessive reverberation, sound-wave resonance, or reflection from nearby hard surfaces can distort the amplitude or phase of sound picked up by a microphone to such an extent that dialog may become very difficult to understand.

FIG. 3. Set with ceiling of acoustical board simulating concrete.

Fig. 2 shows a round set in which no resonance or long-period reverberation occurred, but because of the hard materials and the concave surfaces severe reflections occurred near the center of the room. Luckily the set designer placed a round table in the center of the room and a baffle between the piano and the glass tile. Further reduction of the reflections was achieved by hanging heavy drapes over the entire portions of the walls not included in the camera angles.

Parallel hard walls often set up undesirable resonance that is just as objectionable as the direct concentrated reflections from concave surfaces. Good quality in small rooms such as telephone booths, boat cabins, train interiors, *etc.*, can be obtained by the removal or draping of one of the two opposite walls. Sometimes sufficiently good quality can be achieved by building the room so that one wall is broken by an open door or window or with sufficient other irregularities to avoid resonance. Often the glass in windows may be completely removed without being detrimental to the picture.

Where it is necessary to have ceilings in the sets, considerable care in design is necessary in order to avoid resonance between the ceiling and the floor. Figs. 3 and 4 show ceilings that simulate concrete, but were constructed of removable sections of soft acoustic board that had been "aged" with a light water-color spray coat. Resonance and reflections were avoided in the air-raid shelter by removing all ceiling sections not included in the camera angle, which in most cases included the section immediately over the actors' heads. The acoustic conditions in the cafe shown in Fig. 3 were sufficiently good to make it unnecessary to remove ceiling pieces other than those over the table of the principal actors.

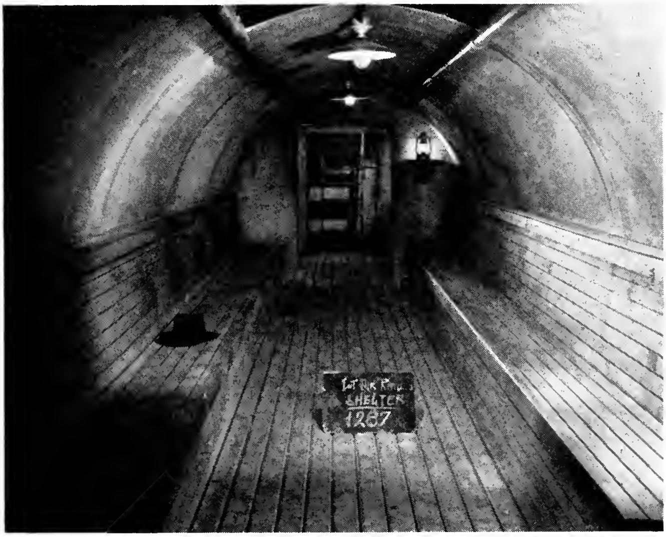

FIG. 4. Set using removable sections of acoustic board for ceiling.

An acoustically good ceiling that simulates a plaster ceiling can be made by using a roll of muslin. Fig. 5 shows (at top of picture) a muslin ceiling which can be rolled back to facilitate lighting and placement of the microphone. When necessary a fair grade of recording can be made through this ceiling, but such practice is not recommended unless a much more porous cloth than muslin is used.

When hard ceilings are necessary, such as when the ceiling is the under side of the upper deck of a steamer, acoustic improvement and satisfactory appearance have been obtained by applying a layer of sound-absorbing material covered with tightly stretched muslin.

NOISE PROBLEMS

Noises incident to the making of motion pictures may be classed into equipment noises, noises created by actors and equipment in scenes being photographed, and outside noises such as those from aeroplanes, automobiles, industrial machines, wind, rain, people, animals, and insects.

Equipment noises consist of noises made by cameras, background projection machines, arc lamps, treadmills, vehicles for moving shots, and effects-making equipment such as wave machines, wind machines, lightning-making devices, artificial rain systems, artificial cloud, fog, and snow-dispensing devices, and devices for jiggling, rocking, or turning boats, aeroplanes, or vehicles.

Most of the camera and background projection machines now in use require noise-absorbing enclosures. However, both cameras and background projection machines have been developed that are sufficiently quiet to be used without a "blimp" or "booth."

Arc lamps have been quieted considerably, but they are still noisy enough to cause trouble when used in large numbers. It has been found that arc "sing" or "whistle" can be almost entirely eliminated by a line filter consisting of a series choke-coil ($L = 0.15\ \mu h$) with shunt electrolytic condensers of 2500 μf across the generator side of the choke and 5000 μf across the line side. Arc motor noise has been diminished by using a rubber motor mounting. Arc "boiling" noise has been reduced by lining all lamp houses with woven asbestos and by using an improved type of carbon. Tests are under way to reduce further the "boiling" noise by baffling the lamp vents.

Treadmills are now available that are sufficiently quiet for normal dialog recording. They are constructed with an endless rubber-on-fabric belt, about 6 ft wide and 18 ft in total length, running on large rollers driven by a variable-speed motor and variable-ratio belt transmission system, both of which are enclosed in a "sound-proofed box."

In making moving shots on stages it is often necessary to use "camera booms." Recently the largest-size booms have been equipped with a motor-drive system made "silent" by enclosing it in a heavy steel case lined with several layers of soft sound-absorbing material.

Effects-making equipment is often extremely noisy and its use makes it impossible to record satisfactory sound. Among these is the high-velocity wind machine consisting of an aeroplane engine and propeller, and the lightning-making device which consists of a handful of arc carbons mounted on each of the two points of a pair of wooden scissors. The noise occurs when an arc is drawn between the two groups of carbons. Relatively quiet flares are sometimes used but the effect is not as good as that from the arc.

FIG. 5. Set using muslin ceiling that can be rolled back.

Effects-making machines that cause some disturbance but which when run at moderate speed are tolerable, are wind "blowers," "silent fans," wave machines, and hydraulic or motor-driven rocking and jiggling devices. The "blower" or "wind tunnel" consists of a large ventilation-type centrifugal blower which is usually placed outside the stage or at some distance from the set, and wind is delivered to the set through a canvas pipe about three to four feet in diameter. The most satisfactory fan in use is the 48-inch diameter fan having from three to eight wide overlapping blades. Fans 24 inches in diameter are useful where a fan must be small enough to be hidden behind shrubbery, but fans smaller than that usually make too much noise because of having to be run fast to deliver sufficient breeze.

Artificial rain systems are normally very quiet except for the falling of the rain against the set and on the stage floor, or on hats or umbrellas. Rain effects seen through the window of a room can be kept quiet by putting a 6-inch layer of excelsior or rubberized hair on the floor where the rain falls. Where heavy rain must strike window panes the noise can be reduced considerably by placing a large piece of glass on the outside of each window against the back of the set, leaving a dead air-space of about 2 inches between the window and the exterior glass. A layer of felt is often tacked to the outside of the set to reduce the noise further when low-level dialog is to be recorded. Thin metal roofs are usually avoided, but when they are necessary for the correct pictorial effect they can be quieted some by coating with tar. Umbrellas usually cause considerable noise because they are so close to the microphone. The new type transparent umbrellas cause more noise than cloth umbrellas and for that reason are usually avoided where dialog is to be recorded.

Noises created by actors usually consist of footsteps on bare floors, sidewalks, and gravel walks. Good substantial construction is necessary on floors, stairways, and raised platforms in order to avoid squeaks and drumminess. Dance floors must have a smooth lacquer finish in order to keep foot-shuffle noise sufficiently low for recording dialog. In close-up shots where the feet do not show, the dancers wear window-dressing socks over their shoes to reduce the noise. Sidewalks of cement sound natural, but when a sidewalk is built of wood the surface is usually covered with a soft acoustic board to avoid an unnatural sound. Noise of footsteps on gravel walks on stage floors is lessened by spreading a thin layer of gravel on about one inch of moist dirt. Gravel walks are sometimes constructed of chipped cork, but this has the disadvantage of being dusty, and consequently of being detrimental to photography. When artificial hills are built, similar to that shown in Fig. 1, very sturdy construction and a layer of dirt is necessary in order to prevent drumminess. When horses are to be ridden on the hills it is usually necessary to cover the woodwork with four to six inches of moist dirt.

Outside noises are usually of little concern on a sound-stage inasmuch as the stages usually have from 40 to 60 db of attenuation in the walls and from 10 to 30 db in the roof. Occasionally aeroplanes and large trucks close to the stages cause some interference. When shooting outside on the studio lot usually 6 to 12 "flagmen" are employed to keep down local noises. Some of the studios use an orange-colored captive balloon about 400 feet in the air as a signal to aeroplane pilots to keep away. A local ordinance specifies that pilots seeing the balloon should avoid flying near it.

When choosing shooting locations a "noise check" is made in advance to make sure that there are no noises that can not be controlled. Locations on boulevards are avoided unless heavy traffic noise can be tolerated. In residential areas city traffic officers stop or re-route traffic during "takes." No attempt is made to control aeroplanes on locations; consequently areas where planes frequently fly overhead must be avoided. The noise of ocean waves is generally too high for satisfactory dialog recording, and it is nearly always desirable to shoot beach scenes on the stage, using background projection. The noise of the wind in the trees, the croaking of frogs, and the chirping of crickets, and other similar noises of nature are detrimental to good recording, mainly because the amount of noise varies from "take" to "take," and when the takes are cut together the sudden jumps in the volume of the noise become very distracting. Some success in controlling the noises of locusts, crickets, and frogs has been obtained by hiring boys to disturb them just prior to the start of each take.

Each problem that arises is somewhat different and each has to be handled individually, but the problems discussed in this paper are typical and of the type that the set designers and the construction and operating crews have become familiar with to the extent that in nearly every case steps are taken to eliminate possible acoustic or noise troubles before commencing to "shoot" in the set.

The recent reduction in film background noise through the use of fine grain films exposes recorded set noises and set reverberation to an even greater extent than in the past, and efforts will be continued to reduce them further. In order to gain full advantage of improvements in the theater, the studios, through the Research Council of the Academy of Motion Picture Arts and Sciences, are making an effort to familiarize theater architects with the common acoustic and noise troubles that are evident in existing theaters, and to point out ways in which these problems may be solved in existing theaters and avoided in designing new theaters.

BIBLIOGRAPHY

"Recommendations for Reducing Acoustic Difficulties on Motion Picture Sets," *Acad. Mot. Pict. Arts & Sciences Tech. Bull.* (May 19, 1941).

"Theater Acoustic Recommendations," *J. Soc. Mot. Pict. Eng.*, **XXXVI** (Mar., 1941), p. 267 (reprinted from Acad. Mot. Pict. Arts & Sciences Tech. Bull.).

"Report on Arc Lamp Noise Tests," *J. Soc. Mot. Pict. Eng.*, **XXXVI** (May, 1941), p. 559 (reprinted from Acad. Mot. Pict. & Sciences Tech. Bull.).

HILLIARD, J. K.: "Theater Standardization Activities of the Research Council of the Academy of Motion Picture Arts & Sciences," *J. Soc. Mot. Pict. Eng.*, **XXXV** (Oct., 1940), p. 388.

REPORT OF THE STANDARDS COMMITTEE

Summary.—*Letter ballots taken by the SMPE Standards Committee recently gave approval to two projects, viz., (1) the designation of the direction of winding 16-mm film perforated along one edge, and (2) the method of edge-numbering 16-mm motion picture film. These projects have been approved by the Board of Governors and are published here in accordance with the Standardization Procedure adopted recently by the Board.*

On two following pages are shown two SMPE Recommended Practices recently approved by letter-ballot of the SMPE Standards Committee, as follows:

(*1*) *Designation of Direction of Winding 16-Mm Film Perforated along One Edge.*—For a long time there has been some divergence of practice among the various companies of the industry in designating the direction of winding of 16-mm film, and it is the intent of this SMPE Recommended Practice to establish a uniform method of making such designations. The specification given on the following page has been adopted by the large film manufacturing companies in addition to approval by letter ballot of the SMPE Standards Committee, and subsequent ratification by the SMPE Board of Governors.

(*2*) *Edge-Numbering Interval for 16-Mm Motion Picture Film.*—Quite a number of proposals for edge-numbering 16-mm film have come from various parts of the industry. One of the proposals was to place numbers on the film at 16-frame intervals corresponding to one-foot intervals on 35-mm film; at one-foot intervals; and at intervals corresponding to seconds of screen time. After considerable study and discussion with various companies of the industry, the Committee arrived at the specification shown on the following page. It has been ratified by the SMPE Board of Governors.

These specifications are published in accordance with the Standardization Procedure for the Standards Committee adopted by the Board of Governors. If after thirty days from the date of publication of this issue of the JOURNAL, no adverse comments are received by the Chairman of the Standards Committee from the membership of the Society with regard to these two items, the specifications described herein will be referred to the Board of Governors of the Society for action upon them as proposals for either American Standards or American Recommended Practices. Comments on these proposals are invited from readers of the Journal.

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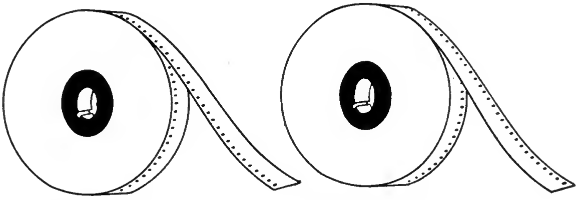
SMPE RECOMMENDED PRACTICE
For 16-mm Motion Picture Film

DESIGNATION OF DIRECTION OF WINDING OF FILM PERFORATED ALONG ONE EDGE

SMPE
July, 1941

When a roll of 16-mm film, perforated along one edge, is held so that the outside end of the film leaves the roll at the top and toward the right, winding *A* shall have the perforations on the edge of the film toward the observer; and winding *B* shall have the perforations on the edge away from the observer. In both cases the emulsion surface shall face inward on the roll.

The following sketch illustrates these definitions:



Winding *A*
Emulsion side in

Winding *B*
Emulsion side in

The above-given sketch shows reels having round holes on both sides. When the film is wound on a reel having a square hole on one side and a round hole on the other, the square holes in the illustrations shall be understood to be on the side away from the observer.

	SMPE RECOMMENDED PRACTICE For 16-mm Motion Picture Film EDGE-NUMBERING INTERVAL	SMPE July, 1941

If 16-mm film is edge-numbered, the interval between consecutive footage numbers shall be 40 frames.

NEW MOTION PICTURE APPARATUS

During the Conventions of the Society, symposiums on new motion picture apparatus are held in which various manufacturers of equipment describe and demonstrate their new products and developments. Some of this equipment is described in the following pages; the remainder will be published in subsequent issues of the Journal.

A NEW 13.6-MM HIGH-INTENSITY PROJECTOR CARBON*

M. T. JONES, W. W. LOZIER, AND D. B. JOY**

The condenser-type high-intensity carbon arc lamp, using 13.6-mm high-intensity carbons at 125 amperes, has been used for a number of years by many of the largest theaters in this country as the light-source for projection.[1] On account of the large screens in such theaters, a 13.6-mm super-high-intensity carbon for 180-ampere operation was developed about five years ago,[2] providing at least 30 per cent more light than was obtainable from the regular 125-ampere carbon. This "super" carbon has found usage in some of the largest theaters, and also for background projection in process motion picture photography.[3] However, the necessary revisions in lamp and power-supply characteristics have prevented its use in many applications where increased light is desirable.

Research and development work in the laboratories of National Carbon Company, Inc., has recently produced a new 13.6-mm high-intensity projector carbon to fill this need. The new carbon, in most cases, can be directly substituted in the present condenser-type lamps and operated with present auxiliary equipment, although in a few instances minor changes may be necessary if the higher current is used. This new carbon gives a substantial increase in light over the regular 125-ampere carbon with considerably lower current than necessary for the 13.6-mm super-high-intensity carbon. It also has other advantages of lower consumption rate, greater latitude of carbon position, and improved resistance to the shocks encountered when striking the arc. The spectral composition and color of the light on the screen is the same as with the regular and super-high-intensity carbons.

The new carbon has the same core size and outside diameter as the regular 13.6-mm H.I. projector carbon. However, its design and composition allow it to be burned equally well at the 125-ampere rating of the regular projector carbon and

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received May 1, 1941.

** National Carbon Company, Fostoria, Ohio.

at higher currents ranging up to 150 amperes. In the higher part of the usable current range of the new carbon, it is desirable that a $^1/_2$-inch "Orotip" carbon be used for the negative carbon since the $^7/_{16}$-inch "Orotip" commonly employed with the regular carbon will be overloaded.

The burning characteristics of this new H.I. projector carbon are shown in Table I in comparison with the regular and super H.I. projector carbons. The new carbon at 150 amperes delivers a slightly higher crater candle-power than the super carbon at the higher current of 180 amperes, while the consumption rate of the new carbon is only little more than one-half that of the super carbon. In comparison with the regular carbon at 125 amperes, the new carbon at 150 amperes delivers 45 per cent higher crater candle-power with only 20 per cent more current and 15 per cent increase in consumption rate. When both the new and regular carbons are burned at 125 amperes, they give the same candle-power but the consumption rate of the new carbon is 35 per cent lower.

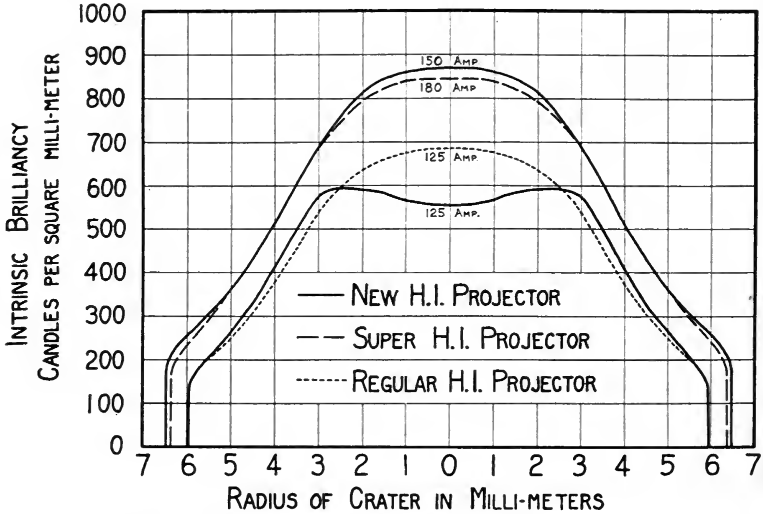

FIG. 1. Distribution of intrinsic brilliancy across crater face of 13.6-mm high-intensity carbons.

Fig. 1 shows the distribution of intrinsic brilliancy across the crater face of the above carbons at the currents given in Table I. The new carbon at 150 amperes, despite a 40 per cent slower burning rate, has an intrinsic brilliancy of 870 candles per sq-mm, which is slightly higher than that of the super carbon at 180 amperes. At 125 amperes the new carbon has a lower intrinsic brilliancy in the center of the crater than the regular carbon at the same current, but an essentially uniform distribution over a much larger area, the importance of which will be discussed later.

The data presented above indicate that in a motion picture projection system the new carbon at 150 amperes would be expected to yield a considerable increase in screen light, compared with the regular carbon at 125 amperes, and should in fact equal that from the super carbon at 180 amperes. Comparative tests show that this expected improvement is realized in practice. The performance of the new carbon has been compared with that of the regular and super carbons in several projection lamps and optical systems commonly used in theaters. The importance of making screen-light comparisons at the same distribution of light over the screen has been demonstrated in an earlier publication.[2] Accordingly, all measurements were made with the intensity at the sides of the screen 80 per cent of that at the center. In order to place the measurements with the various lamps and optical systems on a comparable basis, the screen light and efficiency values for the various carbons and currents have all been expressed in Table I and Fig. 2 on a relative basis, assuming the regular carbon at 125 amperes with the same optical system to be 100.

TABLE I

Characteristics of 13.6-Mm H.I. Projector Carbons under Typical Operating Conditions

Carbon	Regular H.I. Projector	New H.I. Projector		Super H.I. Projector
Arc amperes	125	125	150	180
Arc volts	68	68	78	75
Positive consumption rate (inches per hour)	13	8.5	15	25
Crater candle-power	43,000	43,000	63,000	60,000
Relative screen light at 80 per cent side-to-center distribution ratio*	100	98–103*	128–147*	122–136*

*The ranges given are due to variations between different conventional optical systems employed.

The gain in screen light obtained with the new carbon at 150 amperes compared to the regular carbon at 125 amperes ranges from 28 to 47 per cent, depending upon the type of optical system employed. Similarly, at 180 amperes the super carbon gives from 22 to 36 per cent more screen light than the regular at 125 amperes. It is therefore apparent that the new carbon at 150 amperes delivers slightly more screen light than the super carbon at 180 amperes. The new carbon and the regular carbon produce essentially the same amount of screen light when both are operated at 125 amperes. This may at first glance appear to contradict the brilliancy data shown in Fig. 1, where it is seen that at 125 amperes the new carbon has a lower center brilliancy than the regular carbon. This is explained by the fact that the new carbon, with its larger area of uniform brilliancy, can be operated closer to the true focus in an optical system than can the regular carbon.

As shown in previous publications,[4,5] if the amount of screen light is divided by the length of carbon consumed in unit time, there is obtained a measure of the efficiency of utilization of carbon in terms of the total light energy derived from a unit length of carbon. This efficiency is shown in Fig. 2. While the super carbon gave higher light than the regular, this was accompanied by an efficiency of carbon utilization only 63 to 71 per cent as great as with the regular carbon.

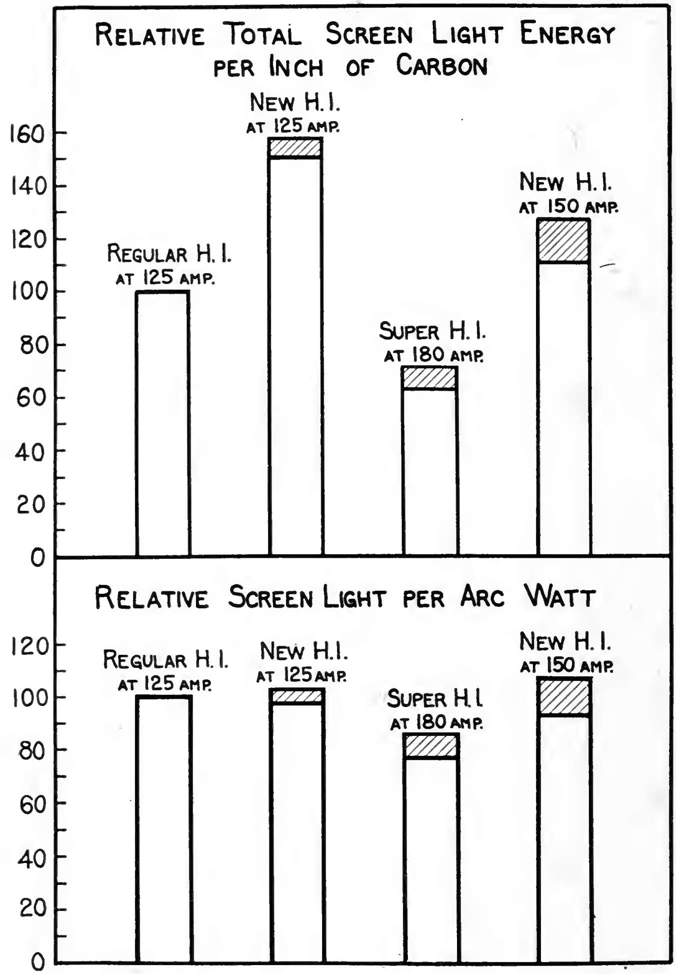

FIG. 2. Efficiency of utilization of carbon and electrical power with 13.6-mm high-intensity carbons. The ranges shown are due to variations between the different conventional optical systems employed.

One of the outstanding advantages of the new carbon is its greatly increased efficiency which at 150 amperes results in about 75 per cent more light energy per inch of carbon than the super carbon at 180 amperes, and in fact is 11 to 27 per cent better in this respect than the regular carbon at 125 amperes. In common with past experience the new carbon has a higher efficiency at 125 amperes than at 150 amperes, so that at the lower current it produces 50 to 57 per cent more light energy per inch of carbon than the regular carbon at this same current.

Fig. 2 gives also the relative efficiency of power utilization in terms of relative screen light per arc watt. This shows that the new carbon at 150 amperes delivers about 20 per cent more screen light per unit of power consumed at the arc than the super carbon at 180 amperes. At both 150 and 125 amperes, the new carbon produces approximately the same amount of screen light per arc watt as the regular carbon at 125 amperes. This new carbon offers a favorable combination of high light output and efficiency of utilization of carbon and power.

In addition to the advantages described above, the new carbon has greater latitude in relative carbon positions at which steady burning may be attained. In order to maintain steady operation with the regular carbon, a certain minimum protrusion of the positive carbon from the jaws is required.[1] The new carbon will give a steady light at the optimum protrusion of the regular carbon and also with the positive protrusion shortened by as much as about 0.1 inch. Carbon efficiency, light, and life are slightly improved at the shortened protrusion possible with the new carbon. This reduction in positive protrusion increases the distance from the crater to the condenser lenses, requiring a corresponding adjustment of the condenser position toward the arc to maintain the desired screen-light distribution. Maximum efficiency has been found when the arc length between the centers of the carbons is between $^3/_4$ and $^7/_8$ inch. Table I and Fig. 2 were obtained with the optimum positive protrusion and arc length.

When an arc is struck, the positive crater is subjected to both thermal and mechanical shock, particularly if the arc is struck at full current. Occasionally this shock causes the lip of the crater to be cracked or a chip broken away so that the burn-in period is increased by the time necessary to form a symmetrical crater. This will occur more frequently when the contact is made on the lip of the crater. The new carbon has improved resistance to these shocks and gives greater assurance of freedom from chipping in case unfavorable conditions are encountered during the striking of the arc.

The new H.I. projector carbon possesses all the advantages of the super H.I. carbon from the standpoint of light without requiring the high current and consumption rate necessary for the super carbon, and in fact with very little increase in consumption rate over the regular carbon. This new carbon therefore brings to the great majority of the theaters now using the regular carbon an extremely practicable means of increasing their screen brightness to give better projection.

REFERENCES

[1] JOY, D. B., AND DOWNES, A. C.: "Characteristics of High-Intensity Arcs," *J. Soc. Mot. Pict. Eng.*, **XIV** (March, 1930), p. 291.

[2] JOY, D. B.: "A 13.6-Mm Super-High-Intensity Carbon for Projection," *J. Soc. Mot. Pict. Eng.*, **XXVII** (Sept., 1936), p. 243.

[3] JOY, D. B., LOZIER, W. W., AND NULL, M. R.: "Carbons for Transparency Process Projection in Motion Picture Studios," *J. Soc. Mot. Pict. Eng.*, **XXXIII** (Oct., 1939), p. 353.

[4] LOZIER, W. W., JOY, D. B., AND SIMON, R. W.: "A New Negative Carbon for Low-Amperage High-Intensity Trims," *J. Soc. Mot. Pict. Eng.*, **XXXV** (Oct., 1940), p. 349.

[5] LOZIER, W. W., CRANCH, G. E., AND JOY, D. B.: "Recent Developments in 8-Mm Copper-Coated High-Intensity Positive Carbons," *J. Soc. Mot. Pict. Eng.*, **XXXVI** (Feb., 1941), p. 198.

CURRENT LITERATURE OF INTEREST TO THE MOTION PICTURE ENGINEER

The editors present for convenient reference a list of articles dealing with subjects cognate to motion picture engineering published in a number of selected journals. Photostatic copies may be obtained from the Library of Congress, Washington, D. C., or from the New York Public Library, New York, N. Y. Micro copies of articles in magazines that are available may be obtained from the Bibliofilm Service, Department of Agriculture, Washington, D. C.

American Cinematographer

22 (September, 1941), No. 9

Enlarging 16-Mm Kodachrome to 35-Mm Technicolor (pp. 414–415, 440)	W. Stull
A Three-Dimensional Exposure-Meter for Professional Use (pp. 416–417, 440, 442)	W. Leahy
What Should Tests Show? (pp. 418, 442)	L. White
Are We Making the Most of Modern Resources? Typewriter Title Trickery (pp. 426–427, 444)	R. W. Teorey

Communications

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Standards for Electrical Transcriptions (pp. 10–11, 33)	H. A. Chinn
"Add-A-Unit" Amplifiers Widen Application Scope (pp. 14, 16, 34–35)	H. Paro

Educational Screen

20 (September, 1941), No. 7

Motion Pictures—Not for Theaters (pp. 284–285, 292), Pt. 29	A. E. Krows

International Projectionist

16 (July, 1941), No. 7

Reproducer Troubles Due to "Grounds" (pp. 7–9)	L. Chadbourne
Recent Advances in Non-Reflective Lens-Coating Processes (pp. 11–12, 15, 26)	W. C. Miller
Projector Factory Overhaul Procedure (pp. 18–19)	

Motion Picture Herald (Better Theaters Section)

144 (September 20, 1941), No. 12

Accurate Calculation of Screen Size and Lighting Needs (pp. 33–34, 36, 38)	C. E. Shultz

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PROCEEDINGS OF THE FIFTIETH SEMI-ANNUAL BANQUET

OF THE

SOCIETY OF MOTION PICTURE ENGINEERS

HOTEL PENNSYLVANIA, NEW YORK, N. Y.

OCTOBER 22, 1941

Nearly 200 members and guests of the Society assembled at the Fiftieth Semi-Annual Banquet held at the Hotel Pennsylvania, New York, N. Y., on October 22nd. This banquet commemorated the twenty-fifth anniversary of the Society's founding.

Guests and officers at the Speakers' table were: President Emery Huse; Mr. Otto S. Shairer, Vice-President of RCA Laboratories, and Mrs. Shairer; Mr. Glenn L. Dimmick, recipient of the 1941 Progress Medal, and Mrs. Dimmick; Dr. John G. Frayne, one of the recipients of the 1940 Journal Award; Mr. Ralph E. Farnham, citationist for Dr. Frayne and Dr. V. Pagliarulo (who was not present); Mr. and Mrs. Herbert Griffin; Mr. and Mrs. Donald E. Hyndman; Mr. and Mrs. E. Allan Williford; Mr. and Mrs. Paul J. Larsen; Mr. and Mrs. George Friedl, Jr.; Mr. and Mrs. Edward M. Honan; Mr. William C. Kunzmann; Mr. and Mrs. Reeve O. Strock; Mr. and Mrs. Frank E. Carlson; Mr. John A. Maurer; and Mr. Arthur C. Downes.

After introducing those seated at the Speakers' table, President Huse announced the results of the election of officers and governors of the Society for 1942,* which were as follows:

Engineering Vice-President: DONALD E. HYNDMAN
Financial Vice-President: ARTHUR S. DICKINSON
Secretary: PAUL J. LARSEN
Treasurer: GEORGE FRIEDL, JR.
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* For complete list of officers and governors for 1942, see p. 640 of this issue of the JOURNAL.

Governor: EDWARD M. HONAN
Chairman, Atlantic Coast Section: ALFRED N. GOLDSMITH
Chairman, Pacific Coast Section: JOHN G. FRAYNE

Following this announcement, President Huse gave a brief description of the nature of the Progress and Journal Awards made each year by the Society at the banquet of the Fall Convention, and called upon Mr. Paul J. Larsen, Secretary of the Society, to report for the Progress Award Committee in the absence of its Chairman, Mr. Kenneth F. Morgan. The Progress medal is awarded by the Society each year to an individual in recognition of any invention, research, or development, which, in the opinion of the Committee and the Board of Governors, has resulted in a significant advance in the development of motion picture technology. Mr. Larsen reported that the Committee had selected as the 1941 recipient of the Progress medal, Mr. Glenn L. Dimmick of RCA Manufacturing Company, Indianapolis, Indiana, and that the report of the Committee had been approved by the Board of Governors at the meeting held on October 19th. Thereupon, President Huse called upon Mr. Otto S. Shairer, Vice-President of RCA Laboratories, to give an account of the work of the recipient that formed the basis for the Progress Medal Award.

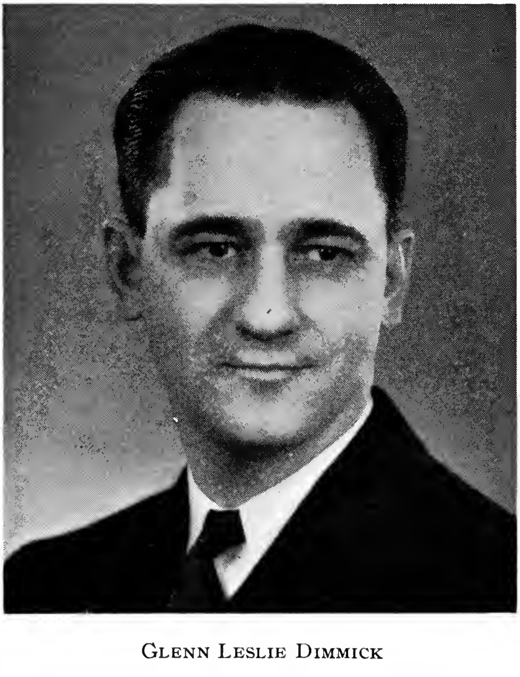
GLENN L. DIMMICK

RECIPIENT OF THE 1941 SMPE PROGRESS MEDAL

Otto S. Shairer

It is a real privilege to be accorded this opportunity to speak of the accomplishments of the man whom this Society has chosen to receive its Progress Award. The associates and friends of Glenn Leslie Dimmick believe that this honor is well deserved, and they salute him.

Born and reared in Missouri and educated in its public schools and University, his ability was early recognized by his election to the honorary engineering and scientific societies, Tau Beta Pi and Sigma Xi. Almost immediately after graduation he developed a recording galvanometer capable of modulating ten times more light than the previous oscillographic type of galvanometer, and free from the objectionable requirement of oil damping. The increased light made many other improvements possible, among which probably the most important was the introduction of ultraviolet light for recording and printing. While making no claim to priority in conception of the possible advantages of ultraviolet light, Mr. Dimmick performed the equally important service of "proving it in," which meant overcoming the numerous minor difficulties and problems needed to give the system a fair trial, analyzing the factors contributing to its success, and proving by actual results that the anticipated benefits were amply afforded. Ultraviolet recording and printing are now practically universal where variable-area recordings are employed.



GLENN LESLIE DIMMICK

Time permits only a brief mention of a few of Mr. Dimmick's many other developments, which include improvements in galvanometers; advanced and refined designs of optical systems; new and improved types of sound-tracks; a variable-intensity system for making density recordings; a system for making direct positives particularly low in ground noise; sound-powered telephones of high efficiency, in large use in the Navy; the sound-recording system for a 16-mm camera, probably the smallest and lightest complete sound and picture recording equipment ever built; optics for projection sound printers; and optics to meet the unusual requirements for printing and reproducing *Fantasia;* and the "class B" system in which the positive and negatives half-waves are recorded on separate parts of the track. The "class B" system, which requires no auxiliary ground-noise equipment but is inherently the quietest of known methods of photographic recording, appeared to many to present almost insurmountable difficulties, but Mr. Dimmick found means of bringing all the factors under control, not only for laboratory conditions but for practical field conditions, and the system is in wide commercial use.

For his contributions to science and engineering he has received recognition as a Modern Pioneer by the National Association of Manufacturers. Eleven of his technical papers have been published in the JOURNAL of this Society. They are reports of accomplishments and marvels of conciseness. His many patents are but by-products of his original and imaginative thinking, rather than objectives in themselves. They represent an unusually high percentage of inventions now in use. He is outstanding in his audacity in undertaking the difficult and the seemingly impossible and in his ability to produce practical results.

Mr. Dimmick would be the last person to wish to receive credit for his many developments without acknowledging the assistance and coöperation of his associates. However, they agree that it has been largely through his energy, confidence, and enthusiasm that their joint efforts have so often been brought to successful fruition. His home life and his lovely family are an inspiration and an assurance that the fine traditions already established will be carried on.

All of Mr. Dimmick's associates are grateful for the high honor this Society is bestowing upon him tonight. In honoring one of us, you honor us all. We congratulate Mr. Dimmick upon his award, and this Society upon the fitness of its choice.

Following this account of Mr. Dimmick's work by Mr. Shairer, and the presentation of the medal by President Huse, Mr. Dimmick briefly thanked the officers and the Board of Governors and the members of the Society for the honor thus bestowed upon him.

President Huse next called upon Mr. Ralph E. Farnham, Chairman of the Journal Award Committee to name the recipient or recipients of the Journal Award for 1940 and to present a historical account on the basis of which the award has been granted. Each year at the Fall Convention of the Society a Journal Award certificate is presented to the author or to each of the authors of the most outstanding paper originally published in the Journal of the Society during the preceding calendar year. Mr. Farnham spoke as follows:

JOHN G. FRAYNE AND VINCENT PAGLIARULO

RECIPIENTS OF THE 1940 JOURNAL AWARD

Ralph E. Farnham

President Huse has outlined the purpose of the Society's Journal Award. In order to determine the paper deserving of this honor, the Journal Award Committee had before it the job of studying and analyzing some seventy-six papers published during 1940. These papers were rated, first, on the excellence of presentation of the material; second, the originality and breadth of interest; and last, their technical merit and the importance of the material.

Members of the committee then voted first, second, and third choices. It was felt that this method would result in a fair and accurate appraisal of the paper meriting the Journal Award. The nomination of the Committee was then approved by the Board of Governors of the Society at its recent meeting.

It is my pleasure to announce that award has been granted to the authors of the paper entitled, "The Effects of Ultraviolet Light on Variable-Density Recording and Printing," by Drs. John G. Frayne and Vincent Pagliarulo of Electrical Research Products, Inc., Hollywood, published in the June, 1940, issue of the JOURNAL of the Society.

This paper, in the opinion of the Committee, deserves the Journal Award because of the excellence of organization of its material, the originality displayed in the design of charts, and their arrangement. It is a relatively short paper, and yet it adequately covers an important development. This paper can well serve as a model for other papers of this type. Of its two capable authors we have the following brief information:

Dr. John G. Frayne, Superintendent of Methods Engineering, for Electrical Research Products, Inc., was born in Ireland, and after following the general arts and science courses at Kilkenny College as well as Trinity College, came to the United States in 1914. He has to his credit experience as a miner, a farm-hand, and college instructor, and received a Fellowship in Physics at the University of Minnesota. He was a Lieutenant in the U. S. Signal Corps, stationed at the Camp Vail Radio Laboratories during our participation in the World War I.

JOHN G. FRAYNE

He received his degree as Doctor of Philosophy from the University of Minnesota in 1921 and organized the Physics department at Antioch College under Doctor Arthur E. Morgan. Dr. Frayne is a Fellow of the National Research Council, a Fellow of the American Physical Society, a Fellow Member of the Society of Motion Picture

Engineers, a Research Council associate of the Academy of Motion Picture Arts and Sciences, and is Chairman of the Pacific Coast Section of the Society.

Among his outstanding contributions, have been the introduction of sensitometric controls in the processing of variable-density soundfilm, the introduction of noise-reduction systems in sound-recording, and the development of an electrical densitometer that is becoming the standard of the film industry. He has been a prolific contributor to the JOURNAL of our Society.

VINCENT PAGLIARULO

Vincent Pagliarulo was born in Italy. He came to this country in 1900 and received his general school education in Chicago and is a graduate of Armour Institute of Technology.

His earlier experience was with the Kellogg Switchboard and Supply Co., in charge of automatic telephone development as well as telephone equipment manufacture.

Like Dr. Frayne, Dr. Pagliarulo likewise had a notable career in the U. S. Signal Corps during the World War I. He was commissioned a

Captain and spent a considerable period in the A. E. F. in France, in charge of radio communication equipment, inspection, and supplies, and was later Chief Signal Officer with the American Forces stationed in Holland.

Following his war experiences he entered the University of Chicago in advanced courses in physics and mathematics, and received a Doctorate of Philosophy in 1924.

His entry into Electrical Research Products, Inc., was by way of the Western Electric Co. Since 1928 he has been identified with developments in sound recording, noise-reduction methods, and fine-grain film technics. He is a contributor to the technical literature of the SMPE and is a member of the Society.

At the conclusion of Mr. Farnham's address, President Huse presented the Journal Award certificates to Dr. Frayne, who accepted Dr. Pagliarulo's certificate in the absence of the latter. Dr. Frayne responded with appropriate words of thanks.

At the meeting of the Board of Governors of the Society, held on October 19th, action was taken to honor Mr. William C. Kunzmann in recognition of his long service in behalf of the Society. President Huse called upon Mr. E. Allan Williford, Past-President of the Society, to present to Mr. Kunzmann a testimonial certificate prepared by the Board as a token of their deep appreciation. Mr. Williford spoke as follows:

WILLIAM C. KUNZMANN

E. Allan Williford

As you have been told, this makes the twenty-fifth Anniversary of the founding of our Society. Since that day, July 24, 1916, when six men got together, recognizing the need for such a body as ours to bring order out of the technical chaos existing in equipment and processes at that time, the Society has grown in numbers and in influence. As with all institutions, no matter how worthy, ours did not grow of itself. Guiding the Society through these years have been men giving of their spirit, their time, and their energies. Some have been men in high office, some men in the ranks of our Society. Some of these men have passed on from this earth, and some have lost interest, or otherwise ceased activity in our Society. But the majority of the hardest workers are still in harness, still working for the advancement of our Society.

There is one among us who has never missed a Convention. Upon his shoulders have fallen the tasks of making preparations for each Semi-Annual Meeting, and appointing and supervising the work of the various convention committees. When the opening of a session was upon us, if some piece of equipment was missing, it was to him that we have all looked to get us out of the hole. The banquet arrangements, including entertainment, are part of his responsibilities, and we all know he has discharged them well.

WILLIAM C. KUNZMANN

During twenty-one of these twenty-five years, it has been my privilege to be closely associated with him in business. It has been more than just a business relationship, for during these years he has become one of my close and most revered of friends. He has always been as kind in looking after my interests, at the expense of his own convenience, as he has in looking after the interests of our Society—likewise, at the cost of his own convenience. And so it is with deep appreciation of the privilege here given to me that I now ask Bill Kunzmann, our beloved Convention Vice-President, to stand while I read to him and to you, this certificate which has been awarded to him by unanimous vote of our Board of Governors as a special token of our esteem:

> "In recognition of his long and faithful service as a member of the Society since 1916, as a member of the Board since 1929, and as Convention Vice-President since 1933, the Board of Governors of the Society by unanimous action have on this date presented this certificate to William C. Kunzmann as a testimonial of their appreciation and esteem."

At the conclusion of Mr. Williford's address, Mr. Kunzmann responded briefly, and the banquet concluded with dancing and entertainment.

A COMPACT DIRECT-READING REVERBERATION METER*

E. S. SEELEY**

Summary.—*Conditions surrounding widespread measurement of reverberation time in theaters by a theater service organization require that the measuring equipment stress economy in size, in cost, and in time for a set of measurements, and the readings provided must be in such form that an acoustical specialist is not required for their interpretation. These requirements must be satisfied even to the sacrifice of information on secondary properties of the decay characteristic.*

Several types of direct-reading reverberation-time meter circuits were devised and one of these types, in trial quantity, is now giving service in the field. These instruments integrate the decaying signal over approximately a 5-db interval beginning after approximately 18 db of decay, and the result is translated into reverberation time by meter scales. Thus the first 22 db (approx.) of the decay characteristic is encompassed by the reading and it is shown that the contained energy includes essentially all the reverberant energy important to quality.

Reverberation measurements are made with these instruments at the time that acoustical response measurements are being made, and under these conditions 150 time readings may be made throughout the auditorium and over the audio spectrum in a total added time of forty minutes. Practically no further treatment of the data is required.

The requirements placed on reverberation-measuring equipment are determined by the objective of the measurements and the conditions surrounding the use of the equipment. For example, if it is necessary to chart 60 to 90 db of decay or to reveal the fine detail in the decay characteristic, the resulting complexity and high cost of the measuring equipment may be readily acceptable. In other work, the penalties paid for the unneeded exceptional delicacy of measurement may exclude the equipment from use.

In the continuous effort to advance the art of theater service, it appeared that the performance of reverberation measurements on a broad scale offered considerable promise as a step toward the objective of uniformly best sound quality in all theaters. It would be anticipated that any member of a large field personnel would be ex-

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received April 11, 1941.

** Altec Service Corp., New York, N. Y.

pected to add the ability to make such measurements to his present diversified skills. Special considerations attach to such a project, and these have a dominant effect on the form and functions of the measuring equipment selected. These considerations are:

(*1*) The equipment must be particularly compact and rugged.

(*2*) Work done in theaters during off-show hours involves expense to the exhibitor for theater personnel and to the service organization for the engineer's time. Such cost makes it imperative that the time spent in the theater making measurements be reduced to an acceptable level, that the equipment be operable by a single engineer, and that the process of "working up the data" into a form permitting proper interpretation be reasonably short.

FIG. 1. Reverberation-measuring equipment.

(*3*) The technic for operation of the equipment and interpretation of the results must be sufficiently simplified to secure satisfactory measurements without inordinate personnel training.

(*4*) The equipment must be of modest cost since it is intended for use in a non-revenue-producing service.

(*5*) The equipment must be coördinated with other equipment carried by the engineer.

In connection with requirement *5*, a considerable part of the equipment required for reverberation-time measurements is used also in the measurement of acoustical response. Our organization, coöperating in the work of the Academy Research Council Sub-Committee on Acoustic Characteristics, described in the March, 1941, JOURNAL is making many measurements of acoustical response in theaters. It is important that the reverberation-measuring equipment avoid duplication of microphone, amplifier, cables, *etc.*, used for the response measurement, since a number of sets of such equipment are already distributed to the field. This equipment is shown in Fig. 1. An essentially non-directional crystal microphone was selected for this work. A small pre-amplifier together with its filament cell is built into a flashlight case mounted on the tripod. The pre-amplifier permits the use of a 100-ft unshielded cable to convey the signal at relatively high level and low impedance to the measuring amplifier and meter. This arrangement possesses several advantages including that of virtually eliminating the effect of temperature on the characteristic of

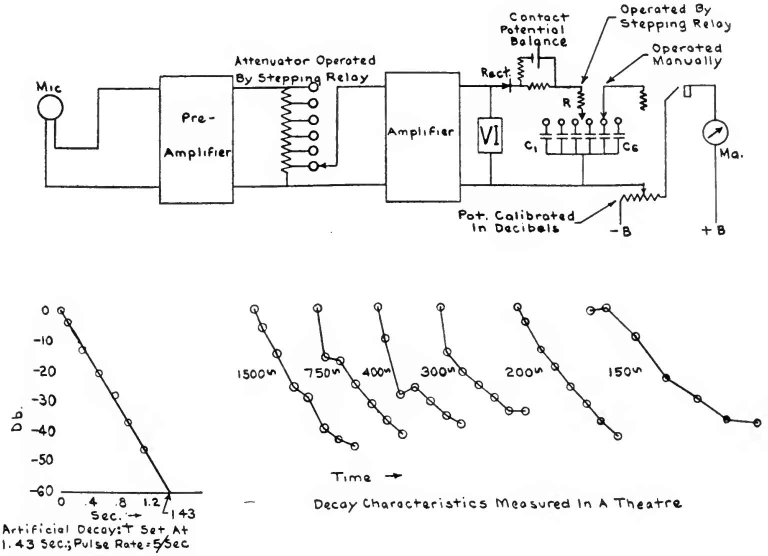

FIG. 2. First form of circuit for providing data from which the decay characteristic can be plotted and appraised in terms of reverberation time.

the microphone by terminating the latter with a very high impedance. The measuring amplifier used is a high-quality emergency amplifier carried by all engineers and designed to replace in an emergency any entire theater amplifier system. The level indicator is likewise one carried by all engineers in this organization for transmission measurements.

Several designs of reverberation-measuring equipment more or less fulfilling the foregoing requirements were considered. The first form was one which provided numerical data from which the decay characteristic could be plotted and appraised in terms of reverberation time. The method was a variation of the variable-interval method, but considered to have the advantage of being less susceptible to local irregularities in the decay characteristic. It was also expected to be fast enough to meet the requirements and to be sufficiently inexpensive to build. Fig. 2 refers to this instrument.

The equipment contained a timing device in the form of a vibrating reed to divide the decay period into suitable intervals. The reed produced electric pulses to operate a stepping relay. The relay carried three contactors, each of which passed over its own series of contacts and performed a separate function. The first was to interrupt the electrical signal entering the speaker system. The second was to control, through attenuation steps, the level delivered by the microphone to the amplifier, beginning with maximum attenuation at start of decay. The third switches the signal, amplified and rectified, to a series of condensers through resistors of appropriate value. Thus, for, let us say, the first one-fifth of a second the relatively strong signal was considerably attenuated and made to charge the first condenser to a value determined by the average acoustic pressure during that portion of the decay period; during the second one-fifth of a second, the weaker signal, less attenuated, was stored in the second condenser, *etc.* The infinite-resistance voltmeter permitted evaluation of the condenser voltages without discharging them.

The resulting readings, corrected for the corresponding attenuation values, were then plotted to reveal the decay characteristic. The value of reverberation time was then approximated in the usual manner by estimating the trend of the irregular decay characteristic and extrapolating it to the 60-db ordinate.

To prove the accuracy of this instrument, an equipment was constructed which produced electronically a logarithmic decay of an oscillator input signal. The decay rate could be set to any desired value. An example of such an accuracy check is shown in Fig. 2 along with a few typical decay curves taken in a theater.

A number of possible improvements in this equipment were evident on reëxamining the design after considerable experience was obtained with it in theaters. However, this experience proved also that a point-to-point device would not fulfill the requirements surrounding our reverberation measurements in theaters. Theater working time was excessive, since each measurement required that a number of readings be observed and recorded. When the theatre work was finished the laborious task of correcting and interpreting the data followed. Finally, the irregularity of most of the decay characteristics, whether measured by this equipment or any other, made the technic of interpreting them one for an acoustic specialist.

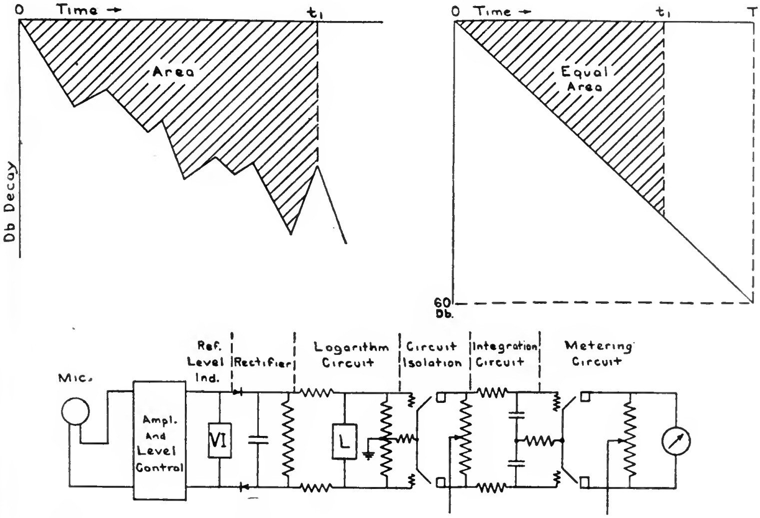

FIG. 3. Circuit for evaluating the 60-db time abscissa of a pure exponential which, plotted as db *vs.* time, has the same integral as the actual decay characteristic.

To close the gap between equipment performance and its requirements, it was decided that only a direct-reading instrument would solve the problem. Two-slope decays, prevalence of small irregularities, and other secondary properties of the decay characteristic would not be revealed by such a method, but the equipment could be simplified and its use speeded up so that the essential requirements could be met. Furthermore, the labor and expertness necessary to convert decay curves to reverberation-time values would be eliminated.

Three versions of a direct-reading reverberation meter were devised and considered, one of them constructed and tested in "breadboard" form and another built in substantial trial quantity and now giving service in the field.

At this point it seems desirable to digress with a discussion of the definition of reverberation time. The Acoustical Society of America has adopted the following definition for this quantity: the time required for the average sound-energy density to decrease to one-millionth of its initial value. The usual method of measuring reverberation time is to obtain in some manner a curve representing sound intensity *versus* time over a period beginning with the interruption of the steady-state signal at its source. This decay characteristic is then assigned a value of reverberation time in more or less accord with the definition given above. However, it is not common practice to adhere rigidly to the definition. Difficulty in applying the

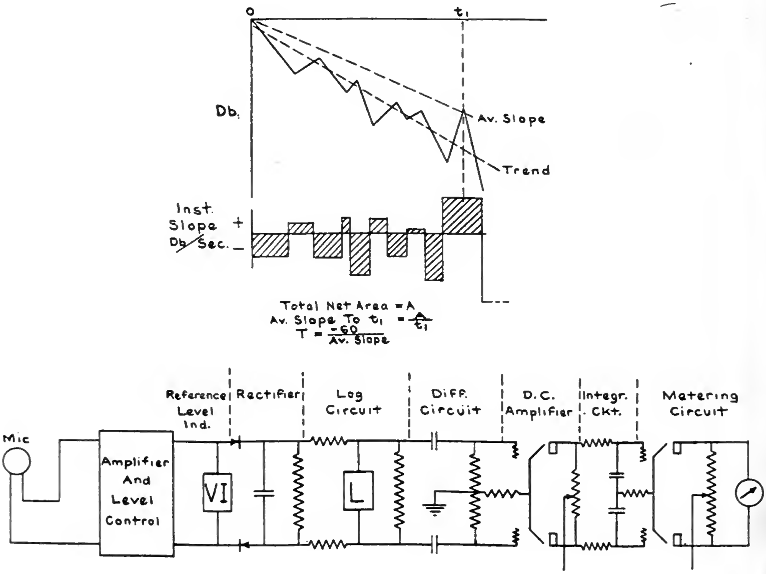

FIG. 4. Circuit interpreting reverberation time as the 60-db abscissa of a true exponential having a slope corresponding to the average slope of the actual decay characteristic slotted logarithmically.

definition results from the fact that decay in any but ideal acoustical enclosures is not usually exponential and, as it will be pointed out later, it is the earlier phases of decay that have the greatest significance. It is an appraised average slope or, more accurately, trend, of the db *versus* time plot that is mathematically converted by most acoustical engineers to reverberation time. General trend of a characteristic is a property not readily defined exactly.

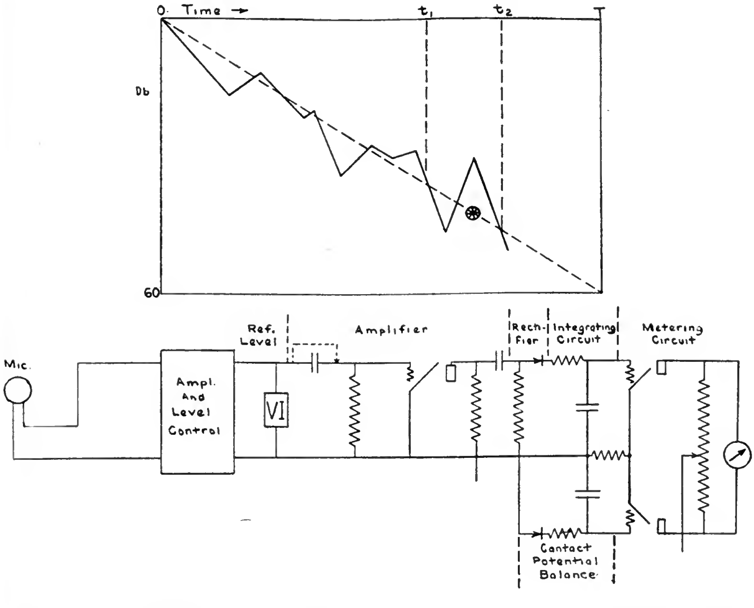

FIG. 5. Circuit for evaluating the 60-db abscissa of an exponential passing the origin and a point having coördinates x, y, where $x = \sqrt{t_1 t_2}$ and y is the intergrated acoustic pressure over the interval $t_1 t_2/(t_2 - t_1)$.

When developing an instrument to make a direct measurement of a physical quantity like reverberation time it is necessary to adopt a precise definition of the quantity to be measured. The three types of direct-reading measuring device referred to performed the measurement on the basis of three different interpretations of the term "reverberation time."

The first circuit was devised to evaluate the 60-db time abscissa of a pure exponential which, plotted as db *versus* time, has the same integral as the actual decay characteristic.

The circuit, as shown in Fig. 3, consists of a microphone and amplifier, a level indicator to permit establishment of a steady-state reference level, a rectifier, a circuit the output voltage of which is proportional to the logarithm of the input voltage, a d-c amplifier to increase the amplitude of the signal and permit circuit isolation, an integrating circuit consisting of a series combination of resistors and condensers, and a metering circuit to permit reading the condenser voltage, thus evaluating the integral. The dial of the meter is calibrated to read reverberation time corresponding to the 60-db abscissa of the true exponential having the same integral as the actual decay curve. It was required to develop a compact network the ouptut voltage of which was proportional to the logarithm of the input voltage, and it was found that a silicon carbide unit in combination with resistors would do this almost exactly over an adequate range.

The second circuit is one which was intended to interpret reverberation time as the 60-db abscissa of a true exponential having a slope corresponding to the average slope of the actual decay characteristic plotted logarithmically.

The circuit, as illustrated in Fig. 4, took the logarithm of the amplified microphone output, differentiated it to obtain the instantaneous rate of decay, and then integrated the result to provide the average rate or average slope of the decay curve. A direct-reading meter scale interpreted that slope in terms of reverberation. However, it is not average slope (a precise quantity) that represents the usual interpretation of a decay curve, but trend slope (an inexact concept) which is often a different number. The time constant of the differentiating section of this circuit could be varied to bring about a result representing something between average slope and trend.

The so-called logarithm, differentiating, and integrating circuit sections illustrated performed extremely well. When the last-described circuit was assembled and tested with an artificial decay its response agreed with predicted performance with an error slightly over 1 per cent.

The third form of direct-reading circuit evaluated the 60-db abscissa of the exponential which passed through the origin and a point having coördinates x,y, where x equals the geometric mean time $\sqrt{t_1t_2}$, and y equals the integrated acoustic pressure over the interval t_1t_2 divided by $t_2 - t_1$. This relationship is illustrated geometrically in Fig. 5 which shows also the circuit in rudimentary form. When the circuit just described was assembled and tested with an artificial decay, it was found to agree with predicted performance to 1 per cent.

The circuit of direct-reading instrument *3* shows the microphone, amplifier, and level indicator in the same relation as in the previous circuits. After the amplified signal is adjusted to reference value, the time-measured sequence starts with the signal interruption. When time t_1 has elapsed, the circuit is closed to the amplifier tube, following which the signal is rectified and applied to an integrating circuit. At time t_2 this process is terminated. The metering circuit, as before, responds to the voltage developed by the condenser charge, and the meter scale is designed to express this voltage as reverberation time.

If the decay characteristic were the simple exponential which it is frequently considered, all the described measurement methods and a variety of others would give identical results. Since almost any decay curve obtained in theaters only approximates an exponential but is evaluated in terms of the exponential deemed best to generalize its erratic pattern, no method of evaluating reverberation time is precise. Hence, in the practical case, all the existing methods may disagree in their evaluations of reverberation time for a given decay. A direct-reading instrument interprets a given decay characteristic in accordance with some specific formula, and thus does not enjoy the element of experienced judgment which is often an important factor in the interpretation of a high-speed level recorder trace. This judgment must therefore be applied in a broader way in selecting the formula to which the direct-reading device is calibrated. One case in point is associated with the fact that many decay curves exhibit two or more general slopes in different parts of the decay period and their evaluation is influenced by the amount of decay taken into account. The selection of the time-periods covered by the direct-reading device is therefore an important one. Whereas reverberation determinations are sometimes based upon measurements embracing decay extending to 40 db or 60 db, or even more, it was considered feasible to reduce these ranges materially in theater measurements with considerable benefit in operating convenience and equipment simplification and without vitiating the significance of the readings.

In a paper by W. A. Mueller[1] loudness measurements in a number of theaters were reported which showed that the difference between average dialog level and average audience noise level is 23 db. Thus it appears unlikely that reverberation could have an important bearing on intelligibility of speech after a decay of 20 db has developed, since at this time the speech energy has dropped to the level of audience noise.

However, reverberation has an important bearing on quality of reproduction quite apart from its interference with intelligibility. In this category we have the effects of reverberation on total energy density, on the ability of the listener to distinguish direct from reverberant sound, and the bearing of this factor on presence, and the property termed "liveness" which in proper degree is essential to good quality.

When a sound is originated the first wave-train that reaches an observer is, of course, the direct wave, followed by the reflected wave-train having the shortest path; and this in turn by that having the next shortest path, *etc.* When the power of the sound-source stops, the first wave-train to disappear at the observer is the direct wave, the second is the shortest-path reflected wave, *etc.*, in the same sequence as existed during growth. As a consequence, the time required for the energy-density to grow to half its steady-state value is the same as the time required for it to decay 3 db. During the period of intonation of the longer speech sounds, about 0.3 sec., and in a room having a reverberation time of 1.5 sec., the reverberant energy grows to 93 per cent of its final value, or, in the time-periods decay will proceed to only 12 db. Thus the wave terminations that pass an observer during the first 20 db of decay would seem to include all the energy that has a significant bearing on the aural effects of reverberation.

From the foregoing discussion it seems logical to conclude that a decay of 20 db is adequate to form the basis of a measurement. This is fortunate as it permits simplification of the measuring equipment and facilitates the problem of providing a reading uncontaminated by the influence of noise or unaltered by the effects of noise-suppressing filters. It is believed, however, that measurements of short decay periods are less exactly reproduced than long-period measurements due to the effects of phase of the warble cycle at which the signal is interrupted. The facility with which data are obtained and the absence of need for further treatment of the readings in the case of the direct-reading reverberation meter permits a substantial number of repetitions at a minor extension in the total time required for a series of measurements.

It remained to select one of the three direct-reading circuits discussed. Study of a number of actual decay characteristics led to the conclusion that, while none of the three circuits possessed a dominant theoretical advantage over the others, the one finally selected interpreted the more erratic curves in a manner somewhat more consistent with analyses in which the element of judgment had full play. The adopted circuit is perhaps as simple as a direct-reading circuit can be, and the resulting greater stability of its calibration is expected to make it somewhat to be preferred over the other circuits.

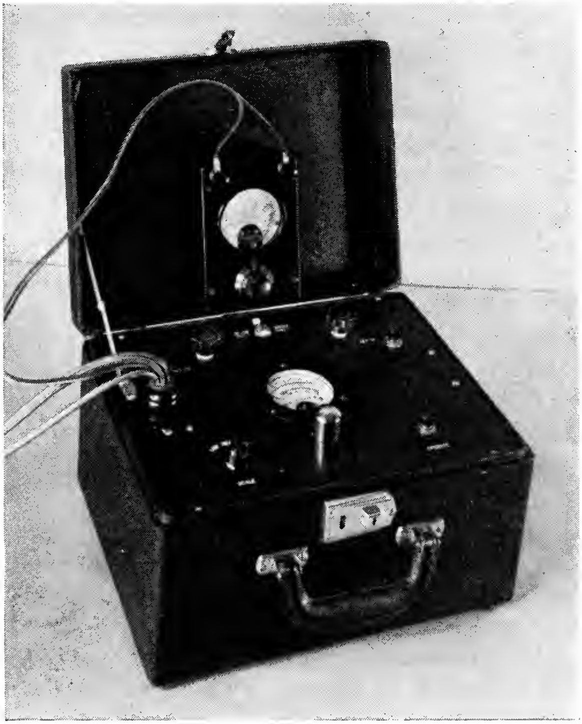

FIG. 6. View of the instrument.

The instrument in its existing form contains as a timing device a small geared-down induction motor having negligible variation in slip. The motor drives a series of cams and the cams operate leaf switches. The complete sequence of events is started by pressing a button which causes the motor to start and continue in operation for one complete cam revolution. The first event is the excitation of a relay located backstage or in the booth which interrupts the signal to the horns. The next event is the closing of the measuring circuit to start the integration of the decay signal. The third event is the disconnection of the integrating circuit from the preceding equipment to terminate the integration process after a particular time interval. The meter on the panel of the instrument assumes a deflection as soon as the integrating condenser obtains a charge.

The instrument is shown in Fig. 6. There are three scales, covering the overall range 0.6 to 3.5 seconds, although ranges extending into shorter times or longer times could readily be built in.

For reverberation time falling at the middle of any scale, the instrument timing is such that the 20-db point occurs at the middle of the integrating period and the signal decays 5 db during the intergrating period. These figures vary moderately over the scale range.

Due to the drooping frequency characteristics of most theater systems, consideration must often be given to room noise when high-frequency measurements are made. The major portion of the noise energy is confined to the lower frequencies, and means are therefore provided for switching in a condenser at 1000 cycles or higher to attenuate all components of the microphone signal below this frequency.

In application, reverberation measurements are made at the time that acoustic response measurements are being made. Immediately following a series of acoustic response readings for a given microphone location, a series of reverberation measurements at 26 frequencies is made without pausing to rewind the warble film. This procedure is repeated in a number of microphone locations in the auditorium. As a result of this method of procedure and the rapidity with which the instrument can be operated, 150 reverberation-time readings may be obtained in an auditorium by a single engineer in an added time of about forty minutes including set-up. The work to be done with the data after the theater work consists in averaging the readings at a given frequency for the various microphone locations or for certain groups of locations such as under balcony, front of balcony, *etc.*, and perhaps plotting the results on semilog paper. This economy of time, the economy of equipment cost, and the compactness of the instrument seem to fulfill the requirements set forth in the beginning of this paper.

REFERENCE

[1] MUELLER, W. A.: "Audience Noise as a Limitation to the Permissible Volume Range of Dialog in Sound Motion Pictures," *J. Soc. Mot. Pict. Eng.*, **XXXV** (July, 1940), p. 48.

ON THE PLAYBACK LOSS IN THE REPRODUCTION OF PHONOGRAPH RECORDS*

O. KORNEI**

Summary.—*A theory is set forth to explain the well known level losses, in particular of the upper frequency range, occurring in the reproduction of lateral-cut records.*

The performance of a pick-up stylus with a spherical point, riding in a laterally modulated record groove, is discussed from the point of view of the elastic properties of the record material. After introducing certain permissible simplifications, the elastic deformations of the two supporting groove walls are calculated, under the influence of the steady vertical pick-up force, the stylus inertia, and the stylus stiffness. Due to the fact that both forces and geometry are different on the two walls the respective elastic deformations are also found to be different for both walls. This fact results in a displacement of the pick-up stylus from the position which it would assume in an ideally rigid record groove and is responsible for the difference between the reproduced amplitude and the recorded one. Playback loss and translation loss are thus explained and quantitatively predicted.

The discussion of the loss equation leads to a number of conclusions. It is found that in contradistinction to a theoretical pick-up with infinitely small vertical force and stylus impedance, it appears advisable to provide a practical pick-up with a definite stylus mass, in order to counteract effectively the playback loss due to the steady vertical force. The translation loss can thus be reduced to zero in systems with constant groove velocity if the pick-up constants—in particular, the stylus mass—are properly chosen. In systems with variable groove velocity (standard disk recording) the translation loss can not be made to vanish but an increase in the absolute playback level of the upper frequency range can be achieved, thus improving the signal-to-noise ratio.

INTRODUCTION

In any system for mechanically recording and reproducing sound, various undesired effects take place which tend to impair the tonal quality by introducing both frequency discrimination and non-linear distortion. Some of these effects are present even with inherently perfect means of electromechanical conversion, since they are caused

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** The Brush Development Co., Cleveland, Ohio.

by the geometry of the recording and reproducing means on the one hand, and by the physical properties of the record material on the other hand.

The first group of these phenomena is usually referred to as tracing and tracking conditions. They comprise the kinematics of the reproducing stylus scanning a record groove which is assumed to be cut in a material of infinite stiffness. The related questions have been dealt with extensively in the literature and a selection of the more comprehensive publications is enumerated in the bibliography.[1–8]

The second group of the above-mentioned effects has received, so far, but little attention. The few publications concern themselves only with experimental investigations [9, 12] (compare also *Discussion*[1]) and with attempts to compensate in the recording process for some of the deficiencies incurred during the reproducing process.[10, 11] Only one publication,[13] which came to the writer's attention after completion of this paper, deals with an approximate qualitative explanation of the encountered effects.

It is the purpose of this paper, therefore, to discuss one of the most apparent effects caused by the physical properties of the record material, namely, the frequency discrimination, or, more specifically, the level loss of the upper frequency range in the reproduction of lateral-cut sound records. (Basically, similar effects exist for hill-and-dale records but shall not be treated here in detail.)

The following investigations are based upon sinusoidal tones only and disregard non-linear distortions. This latter assumption is justified as long as the distortions do not exceed comparatively small percentages, a condition that must be met in a practical system in any event if an intolerable reproduction is to be avoided. The permissibility of this simplification within the errors of measurement has furthermore been proved by extensive experiments.

THE PLAYBACK PROCESS

Definitions.—The fact has been known for several years that the reproduction of the upper frequency range from lateral-cut sound recordings is subject to a considerable level loss if the record groove velocity, *i. e.*, the recorded wavelength, is reduced. However, no satisfactory explanation has thus far been advanced to account for this effect. This case of decreasing groove velocity is realized in the playback from normal record disks as the pick-up stylus travels gradually from the outside to the inside of the record. The corresponding loss in the playback level has been termed translation loss.

A similar case of loss exists for a sound carrier with constant groove velocity: If a frequency band of constant amplitude is recorded on such a carrier, a certain deficiency in the reproduction of the upper frequency range will usually be observed. This loss, too, shall be included in the concept of the translation loss.

The definition of the translation loss as a level difference implies the existence of an absolute playback loss for any given point of the sound record. This loss, in turn, may be defined as the decrease of the excursion of the reproducing stylus from the actual deviation of the record groove from its neutral line.

The knowledge of the playback loss is, in practice only of secondary interest; it is, however, of importance for the later considerations. To avoid confusion in the terminology the two given definitions should be kept in mind: The *playback loss* is the difference between the recorded and the reproduced level in the very same point of a record; the *translation loss* is the difference between the reproduced levels at two different, but equally modulated points of a record, in other words, the difference between the playback losses in the two points.

In the experimental determination of the translation loss, account must be taken of any possible loss due to the recording process. Experiments have shown that the record impedance to be overcome by the cutter increases rapidly—for a given frequency and amplitude—with decreasing groove velocity. Hence, a certain loss in the recorded level (generally about 1 to 3 db) is usually experienced toward the record inside. The most convenient way to determine the actually recorded amplitude is the well known light-pattern method.[14]

Geometry and Dynamics.—It has been pointed out before that only sinusoidal wave-forms will be considered in the following investigations and that non-linear distortions will and can be neglected. The problem of finding the level difference between recorded and reproduced signals is consequently reduced to the determination of the amplitude differences; this means that a consideration of the conditions at the crest of the wave only is sufficient.

It is helpful to start with the purely geometric aspect of the conditions in a record groove. Fig. 1 shows the tip of a pick-up stylus, represented as a sphere, riding at the crest of a sinusoidally modulated record groove with infinitely stiff walls, *i. e.*, deflected by the amount a from its neutral position. The sphere is supposed to be supported by the two groove walls only,* the left one forming part of a concave cylinder, the right one part of a convex cylinder.

The engagement between the sphere (representing the stylus tip) and either groove wall will be the more intimate the more closely the curvature of the wall approaches the curvature of the stylus. The support at the concave groove wall will consequently always be more effective than the support at the convex side.

The two minimum radii of curvature of the groove walls, ρ_1 and ρ_2, respectively, are the radii of the intersections with the walls of the two planes perpendicular to them and passing through the center of the sphere. Both radii are evidently equal but have opposite signs.

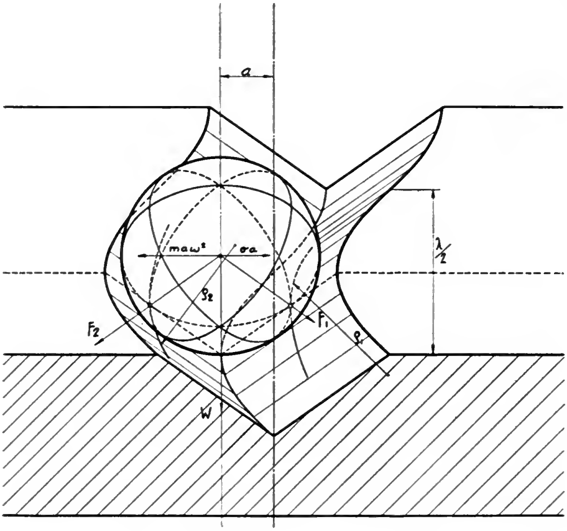

FIG. 1. Spherical stylus tip in rigid record groove.

The magnitude of $\rho_{1,2}$ can be found from the general expression for the radius of curvature

$$\rho = \frac{\left[1 + \left(\frac{dy}{dx}\right)^2\right]^{2/3}}{\frac{d^2y}{dx^2}}$$

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* This is the only positive support for the stylus. Any partial or total support by the rounded bottom of the groove, although sometimes encountered, is mechanically not well defined and may lead to "chattering" of the stylus and consequent distortion. It is, furthermore, mathematically hardly accessible.

In the case under consideration the value is computed for a sine wave,*

$$y = a \sin \omega \frac{x}{V}$$

i. e., the path of the recording stylus in a horizontal plane. The values of the first and second derivative at the crest of this sine curve are

$$\frac{dy}{dx} = 0 \quad \text{and} \quad \frac{d^2y}{dx^2} = -\frac{a\omega^2}{V^2}$$

Since the radii of curvature lie in planes inclined under the angle β to the horizontal plane, the values derived from the above formula have to be divided by cos β to give the radii in the considered planes. Thus

$$\rho_{1,\,2} = \pm \frac{V^2}{a\omega^2} \cdot \frac{1}{\cos \beta} = \pm \frac{a}{\cos \beta} \cdot \frac{V^2}{v^2} \qquad (1)$$

In some cases it is preferable to introduce the frequency and to express the groove velocity by the turntable and record data. Equation *1* may then be written

$$\rho_{1,\,2} = \pm \frac{n^2}{3600 \cos \beta} \cdot \frac{r^2}{af^2} \qquad (1a)$$

It is obvious that the absolute value $|\rho|$ must never become smaller than the radius R of the stylus tip if proper tracing is to be secured.

The forces acting upon the stylus tip in the indicated position are the steady vertical force W and the lateral forces due to the stylus stiffness σa and inertia $ma\omega^2$ (effective values for lateral motions only). In addition to the force W, there is another vertical force caused by the pinch effect. This force, which reverses its direction with twice the frequency of the recorded frequency, is due to the translatory acceleration of the stylus-system mass as effective for vertical motion. It can be shown, however, that the influence of the pinch force may be neglected** for most practical purposes, unless the steady vertical force is made very small, as, for instance, below 10 grams.

Elastic Deformations.—All the effective forces may finally be split up into two components F_1 and F_2 directed perpendicularly to the groove walls at the points of tangency with the stylus tip. In spite of the modest actual magnitude of these wall forces, it can be shown

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* For notations see Appendix 1.

** See Appendix 2.

that the specific pressure between stylus and groove walls attains considerable values, ordinarily of the order of 10,000 to 20,000 pounds per square-inch. Under the influence of these pressures, the groove walls *will give elastically,* and will, consequently, cause the stylus to assume a position different from the ideal one, which is shown in Fig. 1. The assumption of elastic wall deformation implies, incidentally, a limitation of the maximum permissible wall pressure: It must at all times remain within the validity of Hooke's law in order to prevent permanent deformation of the material.

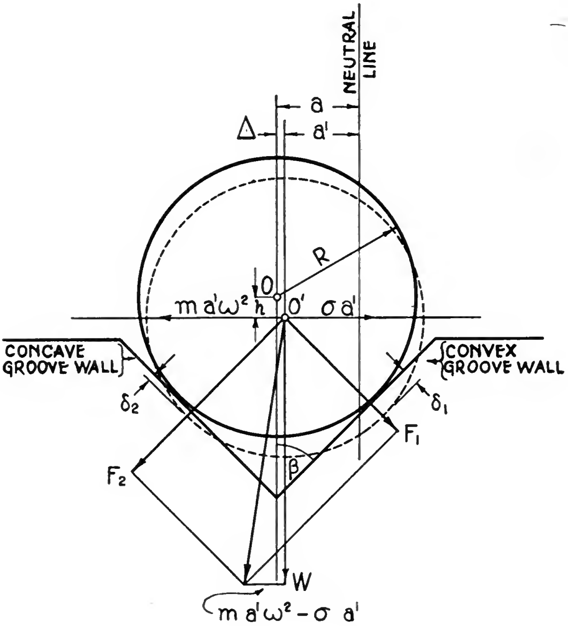

FIG. 2. Elastic deformation of groove walls.

Offhand, it can be predicted from Fig. 1 that for a given pressure, the wall deformation at the convex side of the groove will be larger than that at the concave side, because of the previously mentioned more effective mode of stylus support in the latter case.

Fig. 2 serves to explain these conditions more clearly. It shows the vertical section through the stylus tip and record groove as indicated in Fig. 1. The solid circle (center at *O*) again represents the stylus tip in its ideal position, with no wall deformation; the dotted circle (center in O') shows the stylus tip in its new and actual position after elastic deformation of the groove walls by the amounts δ_1 and δ_2. The resulting lateral deviation Δ of the stylus center from its ideal position* is obviously equal to the difference between the horizontal components of the deformations of the two groove walls:

$$\Delta = (\delta_1 - \delta_2) \cos \beta \tag{2}$$

It can be seen from Fig. 2 that the effective playback amplitude a' is equal to the difference between the recorded amplitude a and the resulting stylus deviation Δ

$$a' = a - \Delta$$

The playback loss L, expressed in decibels, is therefore

$$L = 20 \log \frac{a}{a - \Delta}\, db = 20 \log \frac{1}{1 - \dfrac{\Delta}{a}}\, db \tag{3}$$

The magnitudes of the wall forces F_1 and F_2 may be derived from the vector diagram indicated in Fig. 2. Omitting the details of the simple calculation, one obtains

$$F_{1,2} = \frac{W}{2 \sin \beta} \pm \frac{(\sigma - m\omega^2)a'}{2 \cos \beta} \tag{4}$$

Knowing these forces and the geometric shape of the groove walls, the quantities δ_1 and δ_2 can be determined.

The general problem of the elastic deformation of two curved bodies in mutual contact under the influence of a given force was treated and solved by Heinrich Hertz.[15] His findings have been generally adopted and convenient expressions for the computation of numerical values may be found in any pertinent reference book.[16, 17]

From the last reference,[17] for instance, the elastic deformation δ between a sphere of the radius R and a cylinder of the radius ρ, under the influence of the force F, is found

$$\delta = \varphi\left(\frac{F^2}{k^2} \cdot \frac{2\rho + R}{4R\rho}\right)^{1/3} \tag{5}$$

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* The vertical displacement h is of no direct importance in this connection. However, it should not reach a magnitude to cause "bottoming" of the stylus; proper choice of the groove profile is therefore essential. Compare also Appendix 2.

k is determined by the elastic properties of the two bodies and is given by

$$k = \frac{8}{3} \cdot \frac{1}{\dfrac{1 - \nu_1^2}{E_1} + \dfrac{1 - \nu_2^2}{E_2}}$$

Since the pick-up stylus (usually sapphire) may be considered infinitely stiff ($E_2 = \infty$) as compared to the record material the expression becomes (omitting the subscripts)

$$k = \frac{8}{3} \cdot \frac{E}{1 - \nu^2}$$

The quantity φ can be found from tables,[15, 16, 17] by means of an auxiliary function Θ, which is for the system sphere/cylinder

$$\Theta = \text{arc cos} \frac{R}{2\rho + R}$$

The possible values of ρ range from $\rho_1 = R \rightarrow \infty$ for the convex side and from $\rho_2 = -R \rightarrow -\infty$ for the concave side wall of the record groove, if the extreme cases of maximum modulation and zero modulation are considered, respectively. It can be seen from the quoted references that the value of φ changes so little with Θ, that it may be considered a constant over practically the whole range of ρ. An objectionable error occurs only if ρ approaches $-R$ very closely; however, for $\rho = -1.5R$, for instance, the error is already down to about 6 per cent and decreases rapidly with increasing ρ. Keeping this limitation in mind, φ can be introduced as a constant, whose magnitude is found to be 2.

Introducing this value and the value for k into equation *5*, one obtains

$$\delta = K \left[\frac{2}{RE^2} \left(1 + \frac{R}{2\rho} \right) F^2 \right]^{1/3} \qquad (6)$$

where

$$K = \left[\frac{9}{32} (1 - \nu^2)^2 \right]^{1/3}$$

Equation *6* represents the required general expression for the deformation of the cylindrical and elastic groove wall of radius ρ against which the spherical and rigid stylus tip of radius R is pressed with the force F.

If the values for $\rho_{1,2}$ are now introduced from equation *1*, for F from equation *4* and if $\sin \beta = \cos \beta = 1/\sqrt{2}$ (according to the usual value $2\beta = 90°$) one obtains for the deformation δ_1 of the convex side and δ_2 of the concave side of the groove wall:

$$\delta_{1,2} = K\left(\frac{W^2}{E^2R}\right)^{1/3}\left(1 \pm \frac{R(a-\Delta)\omega^2}{2\sqrt{2}V^2}\right)^{1/3}\left(1 \pm \frac{(\sigma - m\omega^2)(a-\Delta)}{W}\right)^{2/3} \qquad (7)$$

It should be noted specifically that in this equation the actual stylus excursion $a' = a - \Delta$ (not the recorded amplitude a) has to be used. Recalling equation *2* and setting $\sigma = m\omega_0^2$ one obtains finally

$$\Delta = \frac{K}{\sqrt{2}}\left(\frac{W^2}{E^2R}\right)^{1/3}\left[\left(1 + \frac{R\omega^2(a-\Delta)}{2\sqrt{2}V^2}\right)^{1/3}\left(1 - \frac{m(\omega^2-\omega_0^2)(a-\Delta)}{W}\right)^{2/3}\right.$$
$$\left.\left(1 - \frac{R\omega^2(a-\Delta)}{2\sqrt{2}V^2}\right)^{1/3}\left(1 + \frac{m(\omega^2-\omega_0^2)\,(a-\Delta)}{W}\right)^{2/3}\right] \qquad (8)$$

This equation contains implicitly the desired quantity Δ, that is, the difference between the recorded groove excursion a and the reproduced stylus excursion a' (compare Fig. 2). Since the rigorous algebraic solution of this equation is, in general, not possible, resort may be had to a graphical method, as will be shown later.

For most practical cases, however, an approximate solution is more convenient and sufficiently accurate. A simple consideration of the expression *8* shows that the second terms between the parentheses are, in practice, usually small compared with unity. A series expansion of the right side of equation *8* may, therefore, be limited to the linear and quadratic terms, which latter cancel by virtue of the structure of the expression. The equation is thus transformed into

$$\frac{\Delta}{a-\Delta} = \frac{2\sqrt{2}K}{3}\left(\frac{W^2}{E^2R}\right)^{1/3}\left(\frac{R\omega^2}{4\sqrt{2}V^2} - \frac{m(\omega^2-\omega_0^2)}{W}\right)$$

Referring to equation *3* the final, approximate, expression for the playback loss is obtained

$$L = 20\log\left[1 + \frac{2\sqrt{2}K}{3}\left(\frac{W^2}{E^2R}\right)^{1/3}\left(\frac{R\omega^2}{4\sqrt{2}V^2} - \frac{m(\omega^2-\omega_0^2)}{W}\right)\right] db \qquad (9)$$

Discussion of Equation 9.—The detailed discussion of equation *9* is rather interesting. It should be borne in mind, however, that any conclusions must not be extended beyond the range of validity of this approximate expression—the range being determined by the considerations in the preceding paragraph.

(*a*) In the first place, the important fact can be noted that *the playback loss is independent of the recorded amplitude.* The maximum permissible amplitude is, at the same time, determined by the previously mentioned tracing condition

$$|\rho| \geqq R$$

which yields (for $\beta = 45°$)

$$a_{\max} \leqq \frac{V^2\sqrt{2}}{R\omega^2} \tag{10}$$

(*b*) Depending upon the numerical value of the difference term in the parentheses, *the playback loss may be positive, zero, or negative.* The latter case of a "negative loss" is equivalent to a gain of the reproduced over the recorded level. The frequency $\bar{f}$ at which no loss occurs shall be called "zero-loss-frequency;" it divides the range of lower frequencies suffering an amplitude loss from the higher range gaining in playback level. The zero-loss-frequency $\bar{f}$ can be calculated by equating the term between the parentheses of the equation *9* to zero:

$$\frac{R\omega^2}{4\sqrt{2}V^2} - \frac{m(\omega^2 - \omega_0^2)}{W} = 0$$

from which follows:

$$\bar{f}^2 = f_0^2 \frac{1}{1 - \dfrac{RW}{4\sqrt{2}mV^2}} \tag{11}$$

It is interesting to note from this equation that the zero-loss-frequency is independent of the record material; for a given groove velocity it is, therefore, a characteristic of the pick-up only. A real value for $\bar{f}$, however, is obtained only as long as the denominator on the right side in the above equation is greater than zero; if it becomes zero or negative, the zero-loss-frequency becomes infinite or imaginary. This means that a positive playback loss prevails over the whole frequency range.

The physical interpretation of the above considerations is quite obvious: Referring again to Figs. 1 and 2, it can be seen that the force F_2 directed against the concave groove wall and causing the deformation δ_2 tends to decrease the stylus deviation Δ and, consequently, the playback loss. Since F_2 is primarily determined by the inertia reaction $ma'\omega^2$, particularly for the upper frequency range, it follows that for a given recorded frequency *the reproduced amplitude will increase with the stylus mass.* For a given stylus mass, however, the question of gain or loss of the playback level will depend upon whether the deformation due to the inertia force on the one hand, or due to the steady weight and stylus stiffness on the other hand, predominates. This, in turn, is entirely determined by the recorded wavelength, *i. e.*, by the record velocity V. Other conditions being equal, the effect of the inertia force will be the more dominant at the higher record velocities. In other words, the reproduced level (particularly of the upper frequency range) will increase with the record velocity.

(*c*) Another important conclusion can be drawn from equation *9*. If the term associated with the frequency is made to vanish, the loss becomes independent of the frequency and is, for given pick-up constants, a function of the groove velocity, V, only. *In systems with constant groove velocity, it is, therefore, possible to keep the playback loss constant,* provided the pick-up data were properly chosen; this means that the translation loss can, under such circumstances, be reduced to zero.

The condition under which this happens is evidently given by

$$\frac{R}{4\sqrt{2}V^2} - \frac{\overline{m}}{W} = 0$$

from which it follows that the mass $\overline{m}$ for zero translation loss is

$$\overline{m} = \frac{RW}{4\sqrt{2}V^2} \qquad (12)$$

Instead of the mass, R or W could also be made to satisfy the condition; for practical reasons, however, they can not be varied within wide limits.

From equations *9* and *12*, the magnitude of the constant playback loss $\overline{L}$ is thus defined by

$$\overline{L} = 20 \log \left[1 + \frac{2\sqrt{2}K}{3} (E^2RW)^{-1/3}\, \sigma\right] db \qquad (13)$$

if σ is substituted for $m\omega_0^2$.

This expression is, incidentally, identical with the one which can be found for the playback loss at very low frequencies (*i. e.*, for $\omega \rightarrow 0$), where the loss is caused only by the stylus stiffness σ. For average pick-up constants, it is found that the playback loss remains practically constant up to approximately 1500 cps. The numerical value of this loss is ordinarily very small, in the order of less than 1 decibel.

(*d*) It has been customarily postulated that the stylus mass of a "high-fidelity" pick-up should be reduced as far as possible. However, it could already be seen in section *b* that this is not correct for a pick-up with finite vertical force, if the playback loss is taken into account. The conditions can be even better understood if the stylus mass m in equation *9* is made negligible ($m \rightarrow 0$). We then obtain for the playback loss L_0 of a massless pick-up under the influence of the vertical force W

$$L_0 = 20 \log \left[1 + \frac{K}{6}\left(\frac{WR}{E}\right)^{2/3} \frac{\omega^2}{V^2}\right] db \qquad (14)$$

It is seen that this loss vanishes only for very low frequencies; in the upper frequency range, however, it may attain considerable magnitudes. It is evident that this loss is due only to the unequal deformations of the two differently shaped groove walls under the influence of the steady vertical force W.

The postulate for a pick-up having negligible stylus mass is, therefore, justified only in the theoretical case of a simultaneously vanishing vertical force. Since this latter requirement can not be met in any practical design, *it is necessary to provide a finite stylus mass* in order to attain favorable conditions with regard to the playback loss. The magnitude of this mass is determined by the operating conditions. For systems with constant groove velocity it is given by equation *12;* for variable groove velocity, by a certain compromise which will be discussed later.

(*e*) Because of the interaction between the stylus mass and the elastic groove walls, the question arises whether *resonance* may not occur between these two quantities. This problem, however, is rather involved, since it must be borne in mind that the elastic reactions of the groove walls are, in the first place, non-linear; and, in the second place, unsymmetrical, because of the different shapes of the two walls. A rigorous treatment of these conditions goes far beyond the scope of this paper; but for the discussion of similar cases the reader is referred to the pertinent literature.[18, 19]

However, an approximate idea of what may be expected can again be obtained from equation *9*. It is evident that for resonance or, rather, "resonance-like" conditions, the reproduced amplitude must become very large; in other words, the stylus deviation Δ, and with it, the playback loss, must attain very high negative values ($\Delta \rightarrow -\infty$; $L = \rightarrow \infty$). In this case

$$\frac{2\sqrt{2}K}{3}\left(\frac{W^2}{E^2R}\right)^{1/3}\left(\frac{R\omega_R^2}{4\sqrt{2}V^2} - \frac{m(\omega_R^2 - \omega_0^2)}{W}\right) = -1$$

It can be assumed that resonance occurs at a very high frequency ω_R, so that $\omega_R^2 >> \omega_0^2$. Then

$$\omega_R^2 = \frac{\frac{3}{2\sqrt{2}K}\left(E^2RW\right)^{1/3}}{m - \frac{RW}{4\sqrt{2}V^2}} \tag{15}$$

The numerator of the right side of this equation represents the fictitious stiffness of an equivalent simple vibratory system, the denominator, the corresponding fictitious mass. It is seen that the stiffness is determined not only by the elastic properties of the record material but also by stylus radius and vertical force, since these quantities determine the "preloading" of the record material. The equivalent mass turns out to be dependent upon the groove velocity and approaches the actual stylus mass only for infinite velocity, that is, for symmetrical conditions on both sides of the stylus. For finite velocities, the fictitious mass decreases with the groove velocity and finally vanishes for a certain value. Below this value, the resonance frequency becomes imaginary; in other words, it does not occur at all. Comparing equations *15* and *11* it is seen that the limiting conditions for the occurrence of the resonance and the zero-loss-frequency are identical because of the identity of the denominators. Actually, no resonance can be expected in the range below the zero-loss frequency where the reproduced amplitudes are always smaller than the recorded ones.

The resonance between stylus and record material can be experimentally verified and the findings are in reasonably good agreement with the calculations. The observed increase in amplitude is, of course, limited, since damping was neglected in the calculations; however, peaks as high as 10 to 12 db could be measured. As an example, it may be mentioned that a record resonance of approximately 20,000 cps was observed for the pick-up under consideration, at the outside of a 12-inch cellulose nitrate disk at 78 rpm. The value for the same pick-up, but with 3 times its original stylus mass, is approximately 10,000 cps.

Graphical Solution of Equation 8.—It has been pointed out before that the approximate expression *9* is valid only as long as the second terms between the parentheses of equation *8* may be considered small in comparison to unity. The permissible limit will be exceeded, particularly if stylus mass and frequency attain very high values. Under such extreme conditions a more rigorous solution of equation *8* has to be sought, preferably by a graphical method. This may be accomplished in the following way:

Each side of equation *8* is considered a separate function of Δ, the left side being denoted $\Phi_1(\Delta)$, the right side $\Phi_2(\Delta)$. Both functions are plotted as ordinates in a system with Δ as abscissa. The solution of the equation, *i. e.*, the value of Δ, is then represented by the abscissa of the point of intersection between the two functions. The graphical representation of $\Phi_1(\Delta)$ is, evidently, a straight line inclined 45 degrees and passing through the origin of the coördinate system. In plotting the function $\Phi_2(\Delta)$, all quantities of equation *8* referring to the pick-up system and the record groove have to be considered as parameters, Δ being the independent variable. The choice of the amplitude is not very critical, since it was shown before that the loss is, in first approximation, independent of the amplitude. It is, therefore, usually sufficient to plot the curves for only one single value of a. This value, however, should preferably be so chosen as to be permissible under the most adverse conditions of the record under consideration; that means for the highest frequency and the lowest groove velocity to be expected. The magnitude of this amplitude can be determined by means of equation *10*.

Numerical Example.—An example for the graphic procedure is shown in Fig. 3. The numerical values used here and later on refer to a commercial light-weight pick-up with permanent sapphire stylus (see Appendix 1). As to the magnitude of the modulus E of the record material and its experimental determination, reference is made to the Appendix 3. In order to select an extreme case for the graphical example, the conditions as represented refer to a pick-up with three times the original stylus mass. The symbol ζ will be used, hereafter, to denote the multiplying factor applied to the original mass of the pick-up stylus.

The graph of Fig. 3 shows two groups of curves representing the function $\Phi_2(\Delta)$ and a straight line at 45 degrees for the function $\Phi_1(\Delta)$. The two groups of curves refer to the smallest and largest practical groove radius of 5 cm above the Δ axis and 15 cm, below the Δ axis, respectively. Within each group, three different high frequencies are used as parameters. The recorded amplitude, a, used for the computation of the graph was 10^{-4} cm. It is obvious that all

$\Phi_2(\Delta)$-curves must originate from the same point on the Δ-axis with abscissa a, because Δ must equal a when $\Phi_2(\Delta)$ equals zero. All $\Phi_2(\Delta)$-curves lying above the Δ-axis lead to a positive loss, those under the Δ-axis to a negative loss (= gain) of the recorded amplitude.

The playback losses can now be found by proceeding according to the previous explanations: By measuring the abscissae (Δ-values) of the intersection points of the $\Phi_1(\Delta)$-line with the $\Phi_2(\Delta)$-curves and finally computing by means of equation *3*.

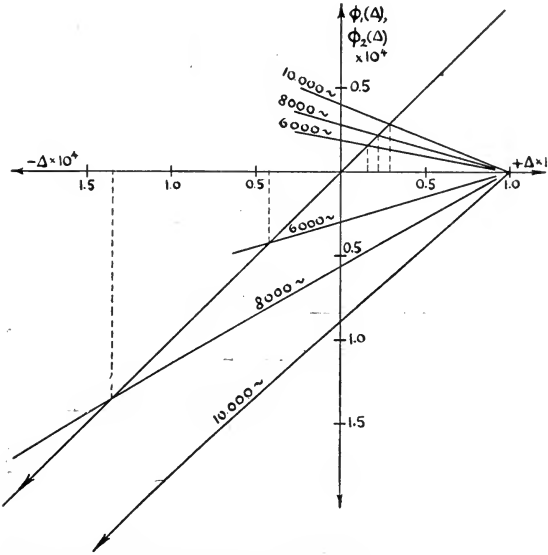

FIG. 3. Example for graphical solution of equation *8*.

It is seen plainly that even under the rather extreme operating conditions chosen for this example all $\Phi_2(\Delta)$-functions turn out to be practically straight lines in the graphs of Fig. 3. This fact confirms once more the previous statement that the simplified equation *9* can be used for the great majority of all practical cases.

Fig. 4(a) shows a set of curves for the *playback loss* as a function of frequency, computed by means of equation *9* and verified by the graphical method. The curves represent the conditions for both the record inside and outside including a variation of the stylus mass (ζ = 0, 1, 2, 3), all other parameters being held constant. Inspection of Fig. 4(a) yields in a pictorial way all the conclusions which have

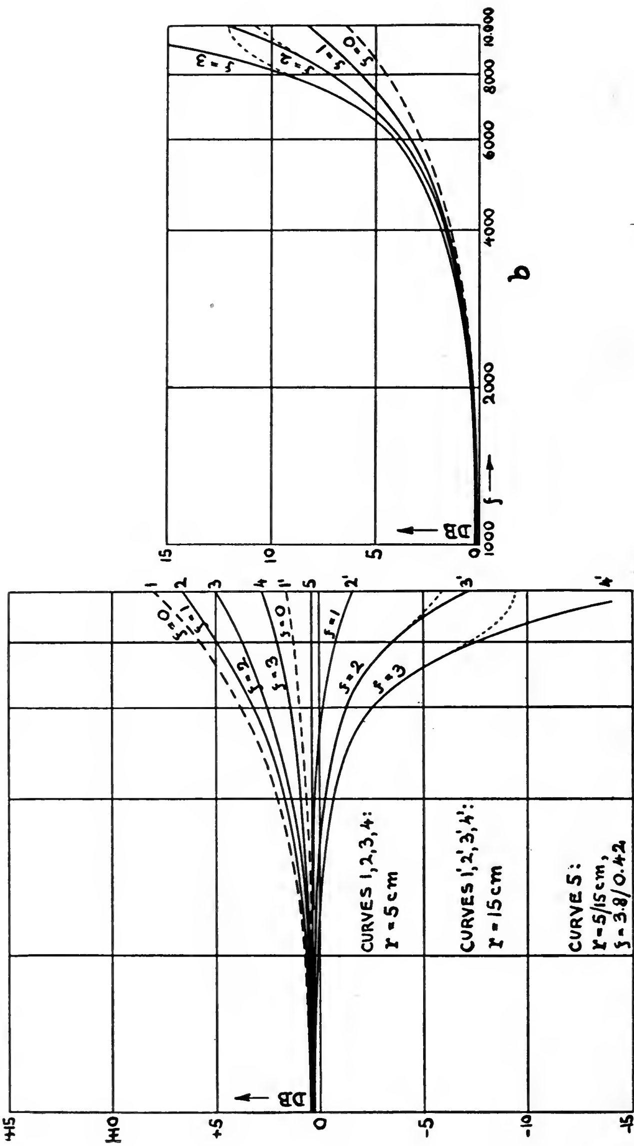

FIG. 4. Calculated playback and translation loss of commercial pick-up on cellulose nitrate record, 78 rpm. (For numerical values see Appendix 1.)

already been derived from the interpretation of equation *9* and which can be summarized as follows:

The playback loss of a pick-up with given mechanical constants depends primarily upon frequency and record velocity. For low frequencies, the loss is always positive, very small and almost constant up to a certain frequency (for the chosen example, approximately 1500 cps). From there on, the loss either increases continuously with rising frequency, or decreases, passing through zero at the zero-loss-frequency and changing into a gain at still higher frequencies. Which one of these two trends actually materializes depends upon the pick-up constants—primarily upon the stylus mass—and the record velocity. High stylus mass and high record velocity favor, in general, a gain, because of the easier deformability of the concave groove walls under such conditions. Examples for the particular case of constant playback loss (curve *5*) and for the loss of a massless pick-up (dashed curves) are also shown in the figure. In accordance with the previous explanations, it is evident that the loss of the massless pick-up with a finite vertical force must be always positive.

The curve of the pick-up with $\zeta = 3$, for the record outside, shows a very steep gain increase toward 10,000 cps, this frequency being the resonance frequency between stylus mass and record material (compare Fig. 3 and equation *15*). The actually observed values were lower, due to the damping; they are approximately indicated in dotted lines (similarly for the case $\zeta = 2$).

Fig. 4(*b*) shows the *translation loss* of the three pick-ups as derived from Fig. 4(*a*) by simply plotting the difference between the corresponding playback loss values for the record inside and outside.

It can be seen that the translation loss rises rapidly with the frequency but also with the stylus mass. This is not contradictory to the decrease of the playback loss with increased mass, because the amplitude gain at the record outside takes a steeper course than the amplitude loss at the record inside. In spite of this fact, however, it must not be overlooked that the absolute playback level for the upper frequency range is always higher for a higher stylus mass (up to the frequency of stylus-record resonance). This is of considerable practical significance, since it improves the signal-to-noise ratio.

Experimental Verification.—The findings and predictions of the theory have been checked by a large number of experiments. They included almost any possible variation of the involved quantities, such as groove velocity, record material, frequency, stylus mass, and vertical force. The agreement between calculated and observed values was very good throughout. A certain amount of variation in the magnitude of the measured quantities has always to be expected, though, primarily because of the experimental difficulties in the exact determination of the pick-up constants and because of the influence of temperature and the aging and wear of the record material. However, the deviations very rarely exceeded objectionable magnitudes.

Practical Considerations.—Some considerations which have a direct bearing upon the practical design of a pick-up will be briefly recapitulated.

Because of the elastic deformation of the record material, any pick-up construction is primarily determined by, and must consequently start from, the steady vertical force. This force should be kept below the limit which causes permanent deformation of the record material (see Appendix 3), but above the vertical acceleration forces to be expected on account of the pinch effect (see Appendix 2). Under average conditions, the vertical pick-up force should range between 10 and 20 grams for lacquer records and if bottoming of the stylus is excluded. The effective mass of the stylus system for vertical motions should be reduced as far as possible in order to cut down the influence of the pinch effect. On the other hand, the effective stylus mass for lateral motions should have a definite value to counteract the inherently unavoidable deformation of the record material caused by the vertical force. That means that the stylus mass should be concentrated as closely as possible to the stylus tip.

The optimal stylus mass for the reproduction with zero translation loss from records with constant groove velocity is given by the theory and depends on vertical force, stylus radius, and record groove velocity, but is independent of the record material (see equation *12*).

In systems with variable groove velocity, as represented by the standard disk-recording process, the optimal stylus mass is not unequivocally defined. It should, however, be chosen in such a way as to give the best compromise between permissible translation loss and signal-to-noise ratio under the particular operating conditions. A fair choice is probably the case for which the playback loss under the most adverse conditions (highest frequency at record inside) does not exceed 5 to 6 db.

The stylus stiffness of a pick-up should be chosen as low as possible in order to reduce not only the level loss for low frequencies (compare equation *13*), but also the required vertical force and the record wear. A low stylus stiffness (low resonance frequency) also increases the effectiveness of the stylus mass in counteracting the playback loss (compare equation *9*).

Some concluding remarks on the frequency performance of a pick-up may be appropriate in this connection. The fact can not be sufficiently stressed that the so-called "frequency response" as it is usually supplied with a pick-up, is entirely without significance unless the conditions pertaining to its establishment are exactly specified. From the considerations of this paper, it is clear that the very same pick-up can yield widely different characteristics if record material, groove velocity, and steady vertical force are varied. It must be borne in mind that no practical pick-up ever reproduces what is on the record—the response will always be an overall effect determined by the geometrical and physical constants of both the record and the pick-up itself.

The only way to establish the "absolute" frequency response of a pick-up consists in directly driving its stylus from a driver (for instance a cutter) with an exactly known frequency characteristic. Such procedure, however, is mainly of theoretical interest and, therefore, not even desirable for the judgment of the actual pick-up performance.

ACKNOWLEDGMENT

The author wishes to thank Mr. A. L. Williams, President of The Brush Development Company, for his active interest in this project. He appreciates also the coöperation of Mr. A. Dank in the numerous experiments, and of Mr. A. Barjansky who computed the numerical values of the equation for the groove wall deformation.

APPENDIX 1

(*Notations, except for those defined in the text*)

Symbol	Meaning	Dimension	Numerical Values for Chosen Example
r	Radius of record groove	cm	5 to 15
n	Speed of turntable, *rpm*	$(60\ \text{sec})^{-1}$	78
V	Record groove velocity	cm-sec^{-1}	40.8 to 122.5
E	Young's modulus of record material	dynes-cm^{-2}	8.5×10^9
ν	Poisson constant of record material		0.3
2β	Angle included by groove walls		90°
a	Recorded amplitude	cm	

APPENDIX 1 (*Continued*)

Symbol	Meaning	Dimension	Numerical Values for Chosen Example
a'	Reproduced amplitude	cm	
v	Stylus velocity	cm-sec^{-1}	
$\rho_{1,2}$	Radius of curvature of convex and concave groove wall, respectively	cm	
$\delta_{1,2}$	Elastic deformation of convex and concave groove wall, respectively	cm	
Δ	Lateral displacement of stylus center due to groove elasticity	cm	
R	Radius of spherical tip of pick-up stylus	cm	6.3×10^{-3} (2.5 mils)
m	Mass of stylus system as effective in center of stylus tip for lateral motions	grams	3.5×10^{-3}
δ	Stiffness of stylus system as effective in center of stylus tip for lateral motions	dynes-cm^{-1}	2.2×10^{6}
W	Steady vertical pick-up force	dynes	2×10^{4} (approx. 20 grams)
f_0	Lateral resonance frequency of stylus system	sec^{-1}	4000
f	Frequency	sec^{-1}	
ω_0, ω	$2\pi f_0, 2\pi f$	sec^{-1}	

APPENDIX 2

(*Pinch-Effect*)

The pinch-effect may be defined as the magnitude of the up-and-down motion of the tracing stylus tip caused by the periodic variation of the included angle between the two modulated groove walls. The effect is caused by the different geometric shape of recording and reproducing styli.[1] Evidently, the extreme positions of the stylus tip occur at the crest of the modulated groove (lowest position) and at the point where the groove intersects the original neutral line (highest position). The total vertical travel of the stylus tip may thus be considered the double amplitude $2a_p$ of an approximately sinusoidal motion of twice the recorded frequency. It can easily be shown[7] that the "pinch amplitude" a_p is, neglecting the record elasticity,

$$a_p = \frac{R}{4\sqrt{2}} \cdot \frac{a^2\omega^2}{V^2} \tag{16}$$

Remembering equation *10* for the maximum permissible lateral amplitude, it is found

$$a_{p\,\max} = \frac{a_{\max}}{4} \tag{17}$$

This means that the theoretical "pinch amplitude" under the most adverse conditions can not exceed one-quarter of the lateral amplitude. The vertical and the lateral accelerations thus become equal (for the worst case) since the pinch frequency is twice the lateral frequency.

The highest lateral inertia force is, therefore,

$$F_e = ma_{\max}\,\omega^2 = m\,\frac{V^2\sqrt{2}}{R} \tag{18}$$

The numerical value of this expression amounts to 1.3 grams (at the record inside) for the chosen example. The vertical acceleration force, due to the pinch-effect, will ordinarily be several times this value, since the stylus mass effective for vertical motion is—for reasons of a practical design—usually greater than that for lateral motion. But even so, it remains small in comparison to the vertical force of 20 grams and can, therefore, be neglected for an approximate calculation. This premise is all the more justified, since the maximum permissible amplitudes are very rarely reached under practical operating conditions.

If the elastic deformations are taken into consideration, the conditions become more complicated but are not materially affected as far as the vertical force is concerned. The relative calculations may be omitted here because they are of no immediate importance in regard to the problems treated in this paper. It may be mentioned, however, that the analytical procedure is very similar to that used for the lateral groove deformations. The analysis is based upon the fact that the vertical stylus deviation h (Fig. 2), due to record elasticity, is $h = (\delta_1 + \delta_2)\cos\beta$, while the lateral one was found $\Delta = (\delta_1 - \delta_2)\cos\beta$ (see equation (2)).

APPENDIX 3

(*Elasticity of Record Material*)

Since no figures have been published for Young's modulus E of record materials, some values were specifically determined for this paper.

In a special test device a standard sapphire stylus of 2.5 mils tip radius was pressed with an adjustable force against the surface to be investigated, and the deformations determined under a measuring microscope. From the obtained readings, E was calculated by means of the Hertz formula, equation *6*. The particular case at which plastic deformation (cold flow) of the material started could also be found from the observations.

The values thus obtained are tabulated below. Under dynamic conditions, the figures should be somewhat higher; experiments indicated, however, that the deviations are comparatively small and may be neglected, considering other errors involved in the experimental part of this paper.

Material	E 10^9 Dynes-Cm^{-2}	Limit for Plastic Deformation (Vertical Force for 90° Groove) Grams
Cellulose nitrate	8.5	20 to 25
Vinylite without filler	21	55
Vinylite pressings	25–32	>80
Shellac pressings	54	

REFERENCES

[1] PIERCE, J. A., AND HUNT, F. V.: "Distortion in Sound Reproduction from Phonograph Records," *J. Soc. Mot. Pict. Eng.*, **XXXI** (Aug., 1938), p. 157.

[2] LEWIS, W. D., AND HUNT, F. V.: "A Theory of Tracing Distortion in Sound Reproduction from Phonograph Records," *J. Acoust. Soc. Amer.*, **XII** (Jan., 1941), p. 348.

[3] LÖFGREN, E.: "On the Non-Linear Distortion in the Reproduction of Phonograph Records Caused by Angular Deviation of the Pick-Up Arm," *Akust. Zeits.*, **III** (1938), p. 350.

[4] BIERL, R.: "A Contribution to the Theory of Disc Records—The Playback Process," *Akust. Zeits.*, **IV** (1939), p. 238.

[5] DITORO, M. J.: "Distortion in the Reproduction of Hill-and-Dale Recording," *J. Soc. Mot. Pict. Eng.*, **XXIX** (Nov., 1937), p. 493.

[6] BAERWALD, H. G.: "Analytic Treatment of Tracking Error and Notes on Optimal Pick-Up Design," *J. Soc. Mot. Pict. Eng.*, **XXXVII** (Dec., 1941), p. 591.

[7] FLEMING, L.: "Notes on Phonograph Pick-Ups for Lateral-Cut Records," *J. Acoust. Soc. Amer.*, **XII** (Jan., 1941), p. 366.

[8] OLNEY, B.: "Phonograph Pick-Up Tracking Error," *J. Acoust. Soc. Amer.*, **X** (Nov., 1937), p. 19.

[9] HASBROUCK, H. J.: "Lateral Disc Recording for Immediate Playback with Extended Frequency and Volume Range," *Proc. I. R. E.*, **XXVII** (March, 1939), p. 184.

[10] SALIBA, G. J.: "Automatic Equalization in Disc Recording," *Communications*, **XVIII** (Aug., 1938), p. 15.

[11] SALIBA, G. J.: "The Improved Automatic Equalizer for Disc Recording," *A. T. E. Journal*, **VII** (July, 1940), p. 18.

[12] LEBEL, C. J.: "High-Frequency and Noise Level Characteristics of an Instantaneous Recording Disc," *A. T. E. Journal*, **VIII** (Jan., 1941), p. 6.

[13] GUTTWEIN, G.: "On the Linear and Non-Linear Distortions in Disc Recording," *Akust. Zeits.*, **V** (Dec., 1940), p. 330.

[14] BUCHMANN, G., AND MEYER, E.: "A New Optical Measuring Method for Phonograph Records," *Elek. Nach. Technik*, **VII** (1930), p. 147.

[15] HERTZ, H.: "Gesammelte Werke," (Leipzig, 1895), pp. 155–196.

[16] TIMOSHENKO, S.: "Theory of Elasticity," *McGraw-Hill Book Co.*, New York (1934), p. 344.

[17] ROARK, R. J.: "Formulas for Stress and Strain," *McGraw-Hill Book Co.*, New York (1938), p. 245. The expression for the factor *k*, erroneous in this book, is given correctly in this paper (see eq. *5*).

[18] TIMOSHENKO, S.: "Vibration Problems in Engineering," *D. Van Nostrand Pub. Co.*, New York (1937), p. 137.

[19] DENHARTOG, J. P.: "Mechanical Vibrations," *McGraw-Hill Book Co.*, New York (1940), p. 403.

ANALYTIC TREATMENT OF TRACKING ERROR AND NOTES ON OPTIMAL PICK-UP DESIGN*

H. G. BAERWALD**

Summary.—*A complete analysis is given of the non-linear distortions due to the tracking error of the pick-up mechanism in the reproduction of lateral-cut disk recordings. The separate treatment of tracking distortion is permissible as long as the overall distortion of the reproduction is tolerable, the system being "almost linear," or the various distortion products superposable.*

For the simplest case of a sinusoidal signal, it is possible to derive explicitly the whole Fourier spectrum of the reproduced signal, the mathematical proposition being the same as in the mechanical two-body problem. For general signals, an explicit operational expansion of the distorted signal is obtained.

As the kinematical effect of tracking error consists of an amplitude controlled advance and delay of the pick-up, the harmonic distortion may be characterized as made up of the side-bands of frequency modulation of the signal by itself. Compared with the ordinary type of non-linear distortion due to curved static characteristics, which may be correspondingly characterized as amplitude automodulation, the spectral character of tracking distortion stresses the higher frequency components. For second-order distortion which is prevalent, the emphasis is proportional to frequency.

The analysis shows, that both absolute and nuisance effects of tracking distortion are considerably greater than commonly assumed, published values usually being underestimates, due to omission of rigorous procedure. Tracking distortion is given approximately by the tracking error weighted with the inverse of the groove radius; the weighted error is referred to the mean groove radius of the record. The recording characteristic affects distortion products independently of their mechanisms.

Pick-up design as based on the analysis should reduce the weighted tracking error as much as possible. For optimal design, Tchebyshev approximation, commonly used in electric wave-filter design, is used. For straight arms, where only one design parameter, i. e., the underhang, is available, optimal approximation of zero distortion is of first order; for offset arms, where both offset angle and overhang are adjustable, it is of second order and thus much closer. The influence of deviations from optimal design due to errors of mounting is investigated as well as the combined effect of offset angle and stylus friction on the lifting force and its reduction by suitably modified design. The compromise design of multi-purpose arms is also treated. Simple design formulas are developed throughout, covering the various record sizes, speeds, and arm lengths. It is found that offset arms are much superior to straight arms. Track-

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ing distortion can be reduced to negligible magnitude with properly designed offset arms even under adverse conditions, such as short arm length and appreciable mounting tolerance.

The tracking mechanism commonly employed for the reproduction of disk recordings consists of an arm swinging about a vertical axis. For lateral recordings, the center of motion of the pick-up stylus is a horizontal axis pivoted in the head of the swing arm. By virtue of the kinematics of this system, the direction of the stylus tip motion does not, in general, coincide with the disk radius. The angular difference, which is equal to that between the direction of the pivotal axis and groove tangent, is known as "tracking error." Its magnitude and sign depend on the geometrical data of the system and on the radial position.

It is well known that the tracking error gives rise to distortions. Among the sources of non-linear distortion encountered in disk recording and reproduction, the tracking error is usually considered as entirely negligible. This, however, is not quite correct. The truth is that tracking distortion *can* be effectively eliminated in a simple way, *i. e.*, by proper geometrical design of the tone arm. Considerable deviations from optimum design, as are sometimes met in commercial pick-ups, lead, however, to quite serious distortions.

As tracking error is obnoxious only by virtue of the distortion caused, quantitative understanding of the effect is the necessary basis for tone arm design. Optimal design should minimize tracking distortion over the entire playing range of the record, which, as analysis shows, is by no means synonymous with minimizing the tracking error itself. Although this may sound commonplace, there is the fact that almost none of the numerous publications on the subject gives an analytic investigation of the effect. This omission frequently leads to erroneous results regarding optimum tone arm design, as in a recent paper by G. E. MacDonald;[1] or it leads to considerable underestimations of the magnitude of tracking distortion and of its nuisance effect which depends on its spectral character. This is the case in a frequently quoted paper by B. Olney[2] who gives a lucid qualitative description of the effect and considerable experimental material. E. G. Löfgren,[3] who first pointed out the error in reference *2* is, as far as the writer is aware, the only author who attacked the subject analytically and also discussed design questions on this basis.

The present paper gives a rigorous analysis of tracking distortion and develops the geometrical tone arm design on this basis.

Part I—Analytical Investigation of the Tracking Error Distortions

s = coördinate along the unmodulated groove
$y(s)$ = laterally recorded signal
$Y(s)$ = stylus elongation or reproduced signal
η = angular tracking error (radians or degrees)
$\left.\begin{array}{ll}\epsilon & = \text{distortion parameter} \\ \eta' & = \text{weighted tracking error}\end{array}\right\}$ defined in the text
t = time
$v(t) = \dfrac{dy}{dt}$ = velocity of recorded signal
$V(t) = \dfrac{dY}{dt}$ = velocity of picked-up signal
Ω = angular disk speed in $\sec^{-1} = \dfrac{\pi}{30} \times$ speed in rpm
r = radius of an arbitrary groove
r_1; r_2; $r_m = \sqrt{r_1 r_2}$ = inner; outer; mean groove radius of a disk record
$\left.\begin{array}{ll}\omega & = \text{recorded angular frequency in sec}^{-1} \\ y_0 & = \text{recorded amplitude} \\ v_0 & = \omega y_0 = \text{recorded velocity amplitude} \\ \lambda & = \text{recorded wavelength} \\ \varphi & = \text{recorded phase} \\ \psi & = \text{picked-up phase}\end{array}\right\}$ of a sinusoidal signal

(*a*) *General Considerations.*—Fig. 1 gives a picture of the stylus motion. The curve $y(s)$ represents the center line of the laterally displaced groove or the recorded signal. Due to the angular error η, the instantaneous position of the stylus tip P becomes S' instead of S, *i. e.*, its abscissa is displaced by Δs. The relation between the recorded elongation $y(s)$, the picked-up elongation $Y(s)$, and the instantaneous shift Δs is evidently

$$Y(s) = \sec \eta \cdot y(s + \Delta s); \quad \Delta s = \tan \eta \cdot y(s + \Delta s) \qquad (1)$$

Kinematically, the effect thus constitutes an alternating advance and delay of the reproduced signal with respect to the recorded one, or a "frequency modulation" of the signal by itself. The associated harmonic distortion can be interpreted as the "side-bands" of this auto-modulation. This interpretation may prove helpful for the understanding of the results of the analysis. It leads to the anticipatory result that, due to the increased depth of frequency auto-modulation, harmonic distortion of a given signal should increase with decreasing groove velocity. For a given distortion limit, larger tracking error should thus be permissible at the outer grooves of a record than at its inside. This is confirmed by analysis.

Fig. 1 represents idealized conditions, as the finite dimensions of groove and stylus tip are neglected. As kinematic implication, the effects connected with the groove geometry, which give rise to tracing distortion,[4] are thus ignored. As mechanical implication, the elastic deformations caused by the bearing weight and the lateral stiffness and inertia forces, are neglected. They lead to both linear and non-linear distortions, but only the former have been investigated so far.[5] They are referred to as "playback loss."[5] While in the strict sense, tracking distortion and harmonic distortion from other sources inherent in the playback process, are interdependent, they can be treated as superposable under practical conditions, *i. e.*, as long as the square of relative overall harmonic distortion is small compared with 1. This corresponds to "almost-linearity" as put forward by Feldtkeller and others.[6] Thus the idealized picture represented by Fig. 1 and equation *1* is usually adequate for the treatment of tracking distortion, if $y(s)$ signifies the signal as modified by the linear effects.* As the playback loss is usually positive, the neglected effects would tend to reduce tracking distortion.

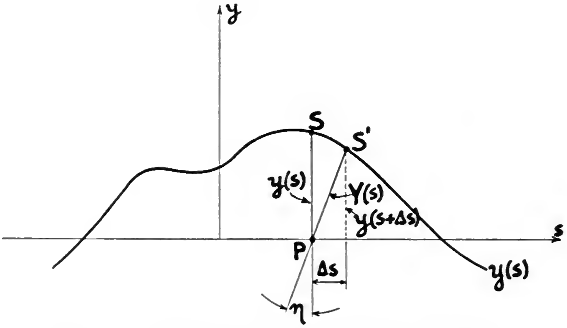

FIG. 1. Idealized representation of tracking.

(*b*) *Rigorous Solution for a Sinusoidal Signal; Bessel's Solution of the Kepler Problem.*—The relation *1* is an implicit equation involving

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* It is further assumed that no tracking error is introduced by the cutter. The distortions due to angular error of the cutting tool which may be present in home recorders, are of a more complicated character and will be treated in a separate paper.

the unknown shift Δs. In order to obtain from it the tracking distortion explicitly, the picked-up signal $Y(s)$ has to be expressed in terms of the recorded one, $y(s)$. The desired result will be obtained in the form of an operational expansion, similarly as in other cases of calculation of modulation products.[7] Before, however, taking up the general case of complex signals, we shall deal first with the simplest case, *i. e.*, with a sinusoidal signal

$$y(s) = y_0 \sin \frac{2\pi}{\lambda} s \equiv y_0 \sin \varphi, \qquad (2)$$

for which the solution of equation *1* can be obtained in closed form.

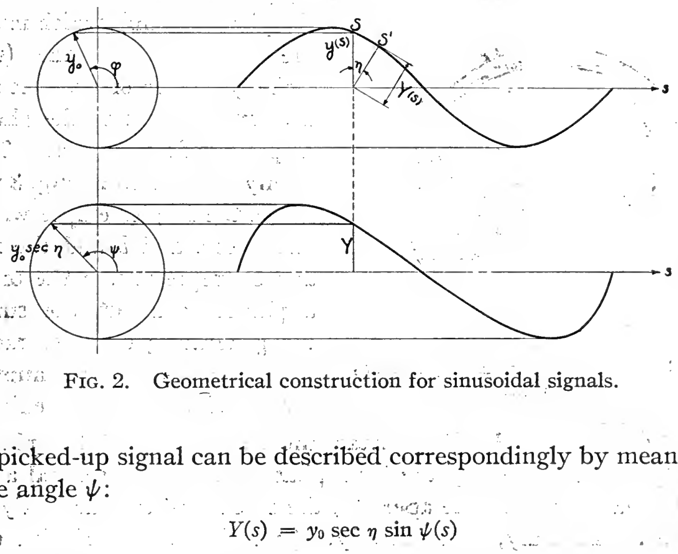

FIG. 2. Geometrical construction for sinusoidal signals.

The picked-up signal can be described correspondingly by means of a phase angle ψ:

$$Y(s) = y_0 \sec \eta \sin \psi(s) \qquad (3)$$

The simple graphical construction of *3* from *2* according to equation *1* is carried out in Fig. 2 for an exaggerated case ($\eta = 30°$), in order to make the distortion plain. The corresponding implicit relation is evidently:

$$\psi - \epsilon \sin \psi = \varphi; \quad \epsilon \equiv 2\pi \frac{y_0}{\lambda} \tan \eta = \text{distortion parameter.} \qquad (4)$$

Introducing time as the independent variable, by means of the relation

$$s = r\Omega t; \quad \frac{\lambda}{2\pi} = \frac{r\Omega}{\omega}, \qquad (5)$$

it follows

$$y(t) = y_0 \sin \omega t \equiv y_0 \sin \varphi \tag{2a}$$

and

$$\text{distortion parameter } \epsilon = \frac{y_0 \omega}{r\Omega} \tan \eta \equiv \frac{v_0 \tan \eta}{r\Omega}, \tag{4a}$$

where v_0 denotes the recorded velocity amplitude while $r\Omega$ is the longitudinal groove velocity.

As a matter of historical interest, it is worth pointing out that the solution of eq. *4* or Fourier expansion of ψ in terms of φ, *i. e.*, the tracking distortion of a sinusoidal signal proves to be the same mathematical proposition as the classical two-body problem of celestial mechanics (Kepler problem), which involves the description of the (undisturbed) motion of a planet about the sun in terms of the phase of its period of revolution. This is briefly illustrated in Fig. 3 which shows the Kepler ellipse with the half-axes a and b and the foci S and S', representing the orbit of a planet P about the sun S;* the generating circle of radius a is also shown. The numerical eccentricity of the ellipse is $\epsilon = \sqrt{1 - (b/a)^2}$. The instantaneous position of the planet is usually characterized by the focal phase ϑ or by the central angle ψ (both measured from the apex A), the so-called "true anomaly" and "eccentric anomaly," respectively. Quantitative description of the planetary motion requires an expression of these angles in terms of time t or of the phase angle ("mean anomaly") $\varphi = 2\pi t/T$ (T = period of revolution). From the well known geometrical relations between focal radii and anomalies:

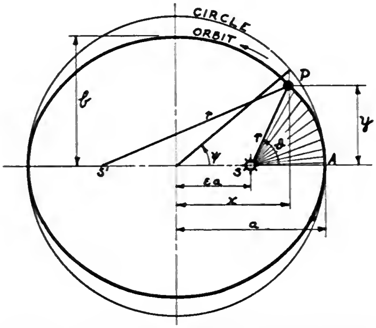

FIG. 3. Representation of planetary motion.

$$r = a(1 - \epsilon \cos \psi);\ \tan \frac{\vartheta}{2} = \sqrt{\frac{1+\epsilon}{1-\epsilon}} \tan \frac{\psi}{2};\ \sin \psi = \frac{\sqrt{1-\epsilon^2}\sin \vartheta}{1 + \epsilon \sin \vartheta},\ \textit{etc.},$$

and from the dynamical theorem of the invariance of the momentum

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* Actually, S represents the center of gravity of sun and planet; as, however, the mass of the sun is usually very large compared to that of a planet, the difference will be negligible.

vector (Kepler's second law), which requires the orbital area (shaded in Fig. 3) to be equal to the mean anomaly:

$$\pi \int_0^{\vartheta} r^2(\vartheta)d\vartheta = 2\pi \frac{t}{T} \equiv \varphi,$$

there follows, by elimination of ϑ, at once the relation

$$\psi - \epsilon \sin \psi = \varphi. \tag{4'}$$

This is identical with *4* and *4a;* eccentricity, mean, and eccentric anomaly correspond to distortion parameter, phase of the recorded, and phase of the picked-up signal, respectively. Equation *4'* was first given by Lagrange[8] in a famous memoir in 1770; he obtained power expansions of the first three Fourier coefficients of sin ψ. The complete solution of the problem (including the Fourier analysis of ϑ and r) was obtained by Bessel[9] in 1824 in a classical investigation where he introduced his well known integral representation, and which is considered as the beginning of the modern theory of Cylinder Functions. (For historical notes see Chapter I, Part 1.4 of Watson's *Treatise.*[10])

The solution of *4* follows at once upon application of the Bessel-Sommerfeld integral (see[10] Chapter VI, or,[11] or [12]); it may be found, together with related results, in Chapter XVII (Kepteyn Series), No. 17.2, pp. 551–558 of Watson's *Treatise;*

$$Y = \frac{v_0}{\omega} \sec \eta \cdot \sum_{n=1}^{\infty} \frac{J_n(n\epsilon)}{{}^1/_2 n\epsilon} \sin n\omega t; \quad \frac{dY}{dt} \equiv V(t) = v_0 \sec \eta \cdot \sum_{n=1}^{\infty} \frac{J_n(n\epsilon)}{{}^1/_2 \epsilon} \cos n\omega t \tag{6}$$

(J_n denotes the Bessel function of nth order.)

Apart from the factor sec η, the relative amplitude a_1 of the fundamental frequency is thus $J_1(\epsilon)/{}^1/_2\epsilon$, those a_n and b_n of the nth harmonic, $J_n(n\epsilon)/{}^1/_2 n\epsilon$ and $J_n(n\epsilon)/{}^1/_2\epsilon$, for the picked-up elongation and velocity, respectively. The relative harmonic distortion is defined by the rms values

$$\sqrt{\frac{\sum\limits_{n=2}^{\infty} a_n^2}{\sum\limits_{n=1}^{\infty} a_n^2}} = \sqrt{1 - \frac{a_1^2}{\sum\limits_{n=1}^{\infty} a_n^2}} \text{ and } \sqrt{1 - \frac{b_1^2}{\sum\limits_{n=1}^{\infty} b_n^2}}, \text{ respectively.}$$

By virtue of the well known relation

$$\sum_1^\infty a_n^2 = \frac{1}{\pi}\int_{(2\pi)} Y^2(\psi)d\varphi, \sum_1^\infty b_n^2 = \frac{1}{\pi}\int_{(2\pi)} V^2(\psi)d\varphi,$$

we obtain

$$\sum_1^\infty a_n^2 = \left(\frac{v_0}{\omega}\sec\eta\right)^2 \cdot \frac{1}{\pi}\int_{(2\pi)} \sin^2\psi d\varphi = -\left(\frac{v_0}{\omega}\sec\eta\right)^2 \cdot \frac{1}{\pi}\int_{(2\pi)} \sin(2\psi)\varphi d\psi = -\left(\frac{v_0}{\omega}\sec\eta\right)^2$$

by virtue of *4*. Similarly,

$$\sum_1^\infty b_n^2 = (v_0 \sec\eta)^2 \cdot \frac{1}{\pi}\int_{(2\pi)}\left(\cos\psi\frac{d\psi}{d\varphi}\right)^2 d\varphi =$$

$$(v_0\sec\eta)^2\frac{1}{\pi}\int_{(2\pi)}\frac{\cos^2\psi}{1-\epsilon\cos\psi}d\psi = \frac{(v_0\sec\eta)^2}{\sqrt{1-\epsilon^2}\cdot{}^1/_2(1+\sqrt{1-\epsilon^2})}$$

Therefore relative harmonic distortion

$$\left.\begin{aligned} &\text{of } Y: \sqrt{1-\left(\frac{J_1(\epsilon)}{{}^1/_2\epsilon}\right)^2} = \frac{\epsilon}{2}\left(1-\frac{5}{24}\left(\frac{\epsilon}{2}\right)^2+\frac{31}{1152}\left(\frac{\epsilon}{2}\right)^4\cdots\right) \\ &\text{of } V: \sqrt{1-\sqrt{1-\epsilon^2}\cdot\frac{1+\sqrt{1-\epsilon^2}}{2}\cdot\left(\frac{J_1(\epsilon)}{{}^1/_2\epsilon}\right)^2} = \epsilon\left(1-\frac{29}{96}\left(\frac{\epsilon}{2}\right)^2+\right. \\ &\qquad\qquad \left.\frac{4567}{18436}\left(\frac{\epsilon}{2}\right)^4\cdots\right) \end{aligned}\right\} \quad (7)$$

(*c*) *Discussion—The Prevalent Type of Distortion.*—Equation *7* shows that if the relative rms distortion is restricted to moderate values, the 1st term alone: $\epsilon/2$ or ϵ, on the basis of elongation or velocity, respectively, gives a satisfactory approximation. The next higher term is negligible for overall distortions even as high as 50 per cent. The first term represents the relative amplitude of the second order harmonic a_2 or b_2, respectively; this is seen from *6* upon substituting for the Bessel coefficients the initial terms of their power expansions. The relative amplitudes of the higher-order harmonics are of corresponding order in ϵ; they are

$$\frac{({}^1/_2 n\epsilon)^{n-1}}{n!} \text{ and } \frac{({}^1/_2 n\epsilon)^{n-1}}{(n-1)!}, \text{ respectively.}$$

Under normal conditions, the distortion is therefore essentially of second order. For complex signals, the 2nd-order cross-modulation products will thus be the prevalent distortion components.

(*d*) *Distortion Spectrum of Complex Signals.*—For general signals, a solution of *1* in closed form does not exist. Expansional solution is thus called for and can be expected to converge satisfactorily, in view of the rapid convergence of the expansions in case of sinusoidal signals. The implicit form of equation *1* would require an approach by iteration; it is possible, however, to obtain the final result at once by means of a well known expansion theorem due to Lagrange[13, 14*] which is a special case of Teixeira's Theorem.[14] The simple intermediate calculation is omitted. The result is analogous to that for the sinusoidal signal, eqs. *6* and *7*, the relevant quantity, *i. e.*, the distortion parameter $\epsilon = (\omega y_0/r\Omega)$ being replaced by the distortion operator $\tan\eta/r\Omega\dfrac{d}{dt}$ applied to $y(t)$:

$$\left.\begin{aligned}\cos\eta\cdot Y(t) &= y(t+\Delta t) = \sum_{n=1}^{\infty}\frac{1}{n!}\left(\frac{\tan\eta}{r\Omega}\frac{d}{dt}\right)^{n-1}\{(y(t))^n\}\\ \cos\eta\cdot V(t) &= \frac{r\Omega}{\tan\eta}\cdot\sum_{n=1}^{\infty}\frac{1}{n!}\left(\frac{\tan\eta}{r\Omega}\frac{d}{dt}\right)^{n}\{(y(t))^n\}\end{aligned}\right\} \qquad (8)$$

or symbolically:

$$\cos\eta\cdot V(t) = \frac{r\Omega}{\tan\eta}\left[e^{\left\{\frac{\tan\eta}{r\Omega}\frac{d}{dt}\right\}(y(t))} - 1\right]. \qquad (8a)$$

(For sinusoidal signals, *8* is re-obtained from *6* by means of the power expansion of the Bessel Functions—as it must be.)

Similar considerations as in the case of a sinusoidal signal show that, for moderate overall distortion, the first term, which represents second-order distortion is in general predominant:

$$\left.\begin{aligned}\cos\eta\cdot Y(t) - y(t) &= \frac{\tan\eta}{r\Omega}\frac{d}{dt}\left(\frac{y^2}{2}\right) + \cdots\\ \cos\eta\cdot V(t) - v(t) &= \frac{\tan\eta}{r\Omega}\frac{d^2}{dt^2}\left(\frac{y^2}{2}\right) + \cdots\end{aligned}\right\} \qquad (8b)$$

For the ordinary type of non-linear distortion as met in tubes, *etc.*, the distortion terms corresponding to *8b* would be const. $y^2/2$ and const. $(d/dt)(y^2/2)$, respectively. It will be appreciated that it is

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[*] The convergence conditions are automatically fulfilled by virtue of the limitation of the frequency spectrum inherent in the recording process: $y(s)$ is, therefore, continuous and of bounded oscillation.

appropriate to interpret the two cases as amplitude and frequency auto-modulation. In order to illustrate the difference between the two associated distortion spectra, let us consider the simple two-component signal*

$$y(t) = y_1 \sin \omega_1 t + y_2 \sin \omega_2 t \tag{9}$$

For the case of ordinary second-order distortion, we obtain, in addition to y itself, the following distortion components:

Frequency	0	$2\omega_1$	$2\omega_2$	$\lvert\omega_1 - \omega_2\rvert$	$\omega_1 + \omega_2$
Amplitude	$\frac{c}{2}(y_1^2 + y_2^2)$	$\frac{c}{2}y_1^2$	$\frac{c}{2}y_2^2$	cy_1y_2	cy_1y_2

where c denotes the second expansion coefficient of the normalized non-linear characteristic. For the second-order tracking error distortion of the same signal, we obtain from *8b*

Frequency	0	$2\omega_1$	$2\omega_2$	$\lvert\omega_1 - \omega_2\rvert$	$\omega_1 + \omega_2$
Amplitude	0	$\frac{\tan \eta}{r\Omega}\omega_1\frac{y_1^2}{2}$	$\frac{\tan \eta}{r\Omega}\omega_2\frac{y_1^2}{2}$	$\frac{\tan \eta}{r\Omega}\lvert\omega_1 - \omega_2\rvert\frac{y_1y_2}{2}$	$\frac{\tan \eta}{r\Omega}(\omega_1 + \omega_2)\frac{y_1y_2}{2}$

It is seen that the amplitudes of the distortion components are weighted with their respective frequencies, relative to the former case; this corresponds to the application of d/dt. Comparison on the velocity basis, which is more appropriate to the major part of the conventional recording characteristic, gives the corresponding result

Frequency	$2\omega_1$	$2\omega_2$	$\lvert\omega_1 - \omega_2\rvert$	$\omega_1 + \omega_2$
Amplitude, ord. dist.	$c\frac{v_1^2}{\omega_1}$	$c\frac{v_2^2}{\omega_2}$	$c\frac{\lvert\omega_1 - \omega_2\rvert}{\omega_1\omega_2}v_1v_2$	$c\frac{\omega_1 + \omega_2}{\omega_1\omega_2}v_1v_2$
Amplitude, track. error	$\frac{\tan \eta}{r\Omega}v_1^2$	$\frac{\tan \eta}{r\Omega}v_2^2$	$\frac{\tan \eta}{r\Omega}\frac{(\omega_1 - \omega_2)^2}{2\omega_1\omega_2}v_1v_2$	$\frac{\tan \eta}{r\Omega}\frac{(\omega_1 + \omega_2)^2}{2\omega_1\omega_2}v_1v_2.$

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* Löfgren[3] carries out, and points out the salient results of, the multi-component signal analysis, but he does not give the general expansion *8*, *8a*. Application of the Laplace integral (spectrum analysis) to the general expansion *8* would yield the spectra of the distortion components of nth order of signals with continuous and/or line spectra. The character of such distortion spectra was studied and discussed by Lewis and Hunt[4] for the tracing distortions. It could easily be carried out in the same way for tracking distortion, but this does not lead to any fundamentally new conclusions pertinent to tone-arm design, beyond those based on the simple case *9*. It should be mentioned, however, that the spectrum of lateral tracing distortion, which is of odd order only, is weighted with a power of frequency still higher—by one—than that of tracking distortion.

(*e*) *Nuisance Effect of Distortion; Influence of Recording Characteristic; Permissible Size of Tracking Error; Weighted Tracking Error.*—The definition of the distortion parameter ϵ (eq. *4a*) can easily be extended to the two-component signal *9*. In particular, for $y_1 = y_2$:

$$y = y_0(\sin \omega_1 t + \sin \omega_2 t), \qquad (9a)$$

we obtain

$$\epsilon_0 = \frac{\tan \eta \cdot y_0 \omega_0}{r\Omega}; \quad \omega_0 \equiv \sqrt{\omega_1 \omega_2} \qquad (4b)$$

Let us compare the second-order ordinary-type and tracking distortions of *9a* on a common basis, *i. e.*, for equal rms values, whereby the d-c component is not counted as it is without significance for electro-acoustic purposes. The ratio of the distortion parameters c and ϵ_0 then becomes

$$\frac{c}{\epsilon_0} = \sqrt{0.3(a + a^{-1})}; \quad a \equiv \frac{\omega_2}{\omega_1}$$

This gives, apart from a common factor, the following values for the amplitudes of the distortion components:

Frequency	$2\omega_1$	$2\omega_2$	$\lvert\omega_1 - \omega_2\rvert$	$(\omega_1 + \omega_2)$
Ord. type	$\sqrt{0.3(a + a^{-1})}$	$\sqrt{0.3(a + a^{-1})}$	$2\sqrt{0.3(a + a^{-1})}$	$2\sqrt{0.3(a + a^{-1})}$
Tr. err.	$\frac{1}{\sqrt{a}}$	$\sqrt{a}$	$\sqrt{a} - \frac{1}{\sqrt{a}}$	$\sqrt{a} + \frac{1}{\sqrt{a}}$

If (ω_1, ω_2) represents a consonant musical interval, the second-order modulation products are also consonant with it, with the possible exception of the summation tone. For instance, for a Fourth with $a = 4/3$ (in the natural scale; $2^{5/12} = 1.3347$ according to equal temperament), the difference tone is 2 octaves below ω_2, *i. e.*, consonant, while the frequency of the summation tone is $7/6$ times that of the octave of ω_1; this does not represent an interval of the musical scale and is therefore dissonant. For unity rms value, the relative amplitudes are in this case:

Frequency	$2\omega_1$	$2\omega_2$	$\lvert\omega_1 - \omega_2\rvert$	$(\omega_1 + \omega_2)$
Ord. type distortion	0.316	0.316	0.632	0.632
Track. err. distortion	0.346	0.462	0.115	0.808

This is represented in Fig. 4.

The preceding considerations show that the spectral character of tracking distortion is roughly taken into account on the velocity basis. This means that the distortion parameter ϵ as originally defined for sinusoidal signals gives a fair estimate of the relative tracking distortion produced by complex signals, if ω signifies a dominant frequency range and y a suitable average amplitude. (If the distortion were of the ordinary type, $\epsilon/2$ would have to be used instead.)

The spectral character of all kinds of harmonic distortion produced in the playback process is uniformly modified by the playback frequency characteristic which is the inverse of the recording characteristic. In case of the conventional constant-velocity characteristic, for instance, distortion components are emphasized, in playback, proportionally to their respective frequencies.* It can be generally shown that, for any particular distortion term, the effects of the playback characteristic and of the distortion mechanism itself simply superpose; the relative amplitude of any resulting distortion component is thus the product of two mutually independent factors. For instance, the relative amplitude of the second-order distortion component of frequency ω_p, which is produced by the two signal com-

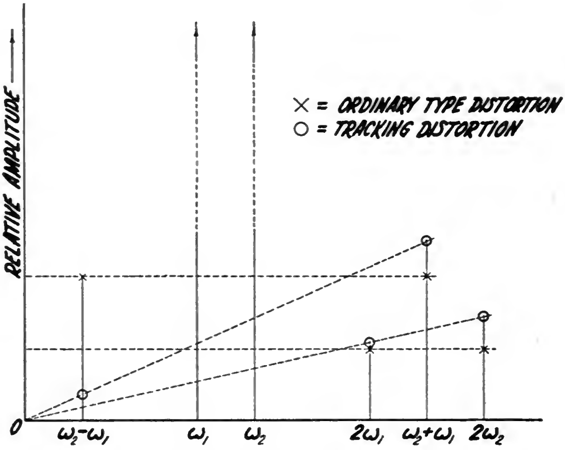

FIG. 4. Comparison of tracking and ordinary distortion spectra of a two-component signal.

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* The emphasis of the constant-velocity characteristic on the higher distortion components is stressed in Guttwein's paper.[5]

ponents of frequencies ω_a and ω_b, is proportional to $F(\omega_a;\ \omega_b;\ \omega_p)\cdot\dfrac{f(\omega_a)f(\omega_b)}{f(\omega_p)}$ where $f(\omega)$ denotes the recording characteristic and $F(\omega_a;\ \omega_b;\ \omega_p)$ accounts for the distortion mechanism; in case of tracking distortion, F is given by the second table following *9*.

The physiological effect of harmonic distortion of a given rms value is usually increased by high-frequency emphasis.[15] It follows that tracking distortion—in particular as produced by signal components of large amplitude in the upper middle audio range—will have a relatively high nuisance effect, not adequately accounted for on the elongation basis.[2]

The preceding analysis and discussion of tracking distortion furnishes the basis for rational pick-up design. In order to have a fixed aim, it is useful to set a limit of permissible tracking distortion, in terms of the distortion parameter ϵ. This limit should be kept low, for three reasons: (*1*) The nuisance value of tracking distortion is likely to be increased on account of high-frequency emphasis; (*2*) an amount of harmonic distortion too small to be troublesome by itself, may become so when superposed upon distortion which is already appreciable. This is the case here, due to the presence of harmonic distortions obtained in cutting, pressing, and playback, more often than not in objectionable amounts; (*3*) while, in the present state of the art, the overall effect of these distortions, whose mechanisms are still partly unexplained, can not be reduced below nuisance level under commercial conditions, it is possible to eliminate tracking distortion substantially by proper tone arm design.

For these reasons, an upper limit of harmonic distortion—as represented by $|\epsilon|$, the absolute value of the distortion parameter—of only 2 per cent is postulated for a signal level of 8 cm/sec velocity amplitude, over the whole playing range of any record size and speed for which an arm is designed. This corresponds to 1 mil elongation at 500 cps and represents approximately maximum conditions in transcription and about half the permissible amplitude in commercial recordings.

The two conventional speeds and associated playing ranges are $33^1/_3$ rpm, $r_{1\,\min} \sim 3^1/_2$ inches, $r_{2\,\max} \sim 8$ inches for transcription and 78 rpm, $r_{1\,\min} \sim 2$ inches, $r_{2\,\max} \sim 6$ inches for commercial disks. The associated minimum and maximum groove velocities are 31 and $41^1/_2$ cm/sec, and 71 and 124 cm/sec, respectively. With the limit set for $|\epsilon|$, the maximum value of $|\tan\eta|$ occurring under any conditions is then 0.3, according to *4a*. It will be seen later that it is usually considerably smaller. It is thus permissible to neglect $\eta^2/2$ against 1, *i. e.*, to put

$$\tan\eta \doteq \eta \doteq \sin\eta,\ \cos\eta \doteq 1 : |\epsilon| = \frac{v|\eta|}{r\Omega}. \tag{10}$$

As tracking distortion is inversely proportional to the groove radius, it is preferable to use for design purposes the

$$\text{weighted tracking error } \eta' \equiv \frac{r_m}{r}\cdot\eta \tag{11}$$

which is referred to the mean groove radius r_m, rather than η itself. Distortion is then proportional to η', independently on the radius r. The factor of proportionality becomes 17 for transcription recordings with $v_{\max} \sim 8$ cm/sec, 22 for commercial disks with $v_{\max} \sim 16$ cm/sec.

$$\text{Distortion } |\epsilon|_{\max} (\text{in per cent}) \sim (17 \text{ to } 22)\cdot|\eta'| \text{ (in radians)}. \tag{12}$$

For $|\epsilon|_{\max} = 2$ per cent at $v = 8$ cm/sec, it is thus $|\eta'|_{\max} \sim 0.12$ and 0.18 for transcription and commercial conditions, respectively. For the tracking error itself the following upper limits are obtained: $4^1/_2$ to 10° for transcription, 6 to $17^1/_2$° for commercial disks, for $r = r_{1\,\min}$ to $r = r_{2\,\max}$.

PART II—PICK-UP DESIGN FOR MINIMUM TRACKING ERROR DISTORTIONS

Additional notations

$$\left.\begin{array}{l} L = \text{length of tone arm (swing axis to stylus tip)} \\ L + d = \text{distance between turntable axis and swing arm axis} \\ (d \text{ is called ``underhang'' if } > 0, \text{ ``overhang'' if } < 0) \end{array}\right\}\ \text{(see Fig. 5)}$$

$\delta \equiv \dfrac{d}{L}$ = numerical under- or overhang

$x \equiv \dfrac{r}{L}$ = numerical groove radius; $x_{1;\,2;\,m} \equiv \dfrac{r_{1;\,2;\,m}}{L}$

$a \equiv \dfrac{r_2}{r_1}$; $p \equiv \dfrac{1}{2}\left(\sqrt{a} + \dfrac{1}{\sqrt{a}}\right) = \dfrac{x_1 + x_2}{2x_m}$

$\eta'_{1;2}$ = weighted tracking error for $r_{1;\,2}$; $\eta'_0 \equiv \eta'(x_0)$ = extremum of the weighted tracking error

γ = angle between groove tangent and line from stylus tip to swing axis

α = angle between direction of pivotal axis of stylus and line from stylus tip to swing axis—"offset angle"

δ_{opt}; d_{opt}; α_0; α_{opt}; α_{crit}; α': explained in text

$T_n(x)$ = Tchebychev polynomial of nth order

P = bearing weight of stylus
F = longitudinal friction force between stylus and groove
F_h = horizontal centripetal component
F_v = vertical component
(explained in text; P, F, F_h, F_v in grams)
ρ = coefficient of friction between stylus and record groove

(*a*) *Geometrical Relations; Tchebychev Method of Approximation.*—The geometrical conditions are represented in Fig. 5 for both straight arms (left side) and arms with offset head (right side). In both cases, C represents the axis of the turntable, A that of the swing-arm, P the stylus point, and D the intersection of arm radius with the line CA.

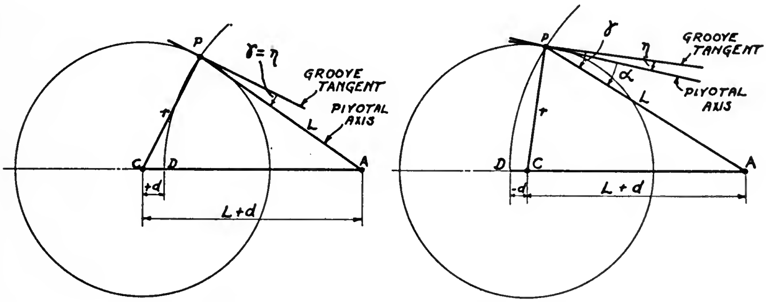

FIG. 5. Geometry of straight and offset tone arms.

It is

$$\left.\begin{aligned}\sin\eta = \sin\gamma = \frac{r^2-2d-d^2}{2r} \equiv \frac{x^2-2\delta-\delta^2}{2x}\ (\delta>0),\ \text{for the straight arm}\\ \eta=\gamma-\alpha,\ \sin\gamma = \frac{x^2-2\delta-\delta^2}{2x}\ (\delta<0),\ \text{for the offset arm}\end{aligned}\right\}\qquad (13)$$

With the approximation *10*, this gives for the weighted tracking error η', according to *11:*

$$\left.\begin{aligned}\eta' = \frac{x_m}{2}\left(1-\frac{2\delta+\delta^2}{x^2}\right),\ \text{for straight arms}\\ \eta' = \frac{x_m}{2\cos\alpha}\left(1-\frac{2\delta+\delta^2}{x^2}-\frac{2\sin\alpha}{x}\right),\ \text{for offset arms}\end{aligned}\right\}\qquad (14)$$

An arm that is designed optimally for a single speed and record size, will be called single-purpose arm; otherwise we speak of multi-purpose arms. Single-purpose arms will be treated first.

The design should minimize tracking distortion over the whole playing range by suitable choice of the design parameters. In case of straight arms, only one parameter is available, *i. e.*, the underhang, whose optimal value turns out to be positive under any conditions (Fig. 5, *left*). Offset arm design has two parameters available, *i. e.*, offset angle and underhang; it turns out that for optimal design, the latter is always negative, and thus constitutes an overhang (Fig. 5, *right*). The result, namely the tracking distortion for optimal design, will appear in terms of the arm length. This will yield the minimal length compatible with a prescribed distortion limit.

The design reduces to elementary procedure as soon as a definition of minimum distortion over the playing range is agreed upon; in other words, we have to decide, which function $\eta'(x)$ containing the parameters α and δ (or δ alone in case of the straight arm) should represent the "best" approximation of the ideal $\eta' \equiv 0$ in the playing interval $x_1 \leqslant x \leqslant x_2$. In general, the success of the approximation, in a prescribed interval, of a given function by another that contains adjustable parameters, can be judged by different criteria. For instance, minimal rms value of the difference may be postulated (this would imply the well known method of least squares). More generally, any monotonic increasing function of the difference, integrated over the fundamental interval, could be chosen as criterion. In particular, this "weight function" by which the seriousness of local deviation is gauged, could be chosen as zero below a certain limit which should be made as small as possible, and very large above this limit; in this case, that approximation is considered best, for which the maximum of the absolute difference between the two functions or their "tolerance" becomes minimum. This mode of approximation was proposed and investigated by Tchebychev[17] and has recently found increasing application in engineering, *e. g.*, in the design of electric wave-filters.[18,19] Tchebychev's approximation is appropriate whenever deviation becomes rapidly objectionable beyond a certain limit. This applies, more or less, to the nuisance value of harmonic distortions. It seems therefore that the tone-arm design should be carried out in the Tchebychev manner, provided that the associated calculations are not unduly complicated. They will actually prove to be of satisfactory simplicity. As a matter of fact, the relation *14* is so simple that almost any mode of approximation could be used on that account. While the design is not greatly altered when applying different types of approximation, it seems that the Tchebychev manner is somewhat preferable to the minimal mean square suggested by Löfgren.[3]

Tchebychev has proved that under rather general conditions the smallest tolerance between the given and the approximation function is obtained if the available parameters are so adjusted that the difference alternates as many times as possible in the given interval between the positive and negative tolerance. This is precisely the result one would expect. The point is illustrated in Fig. 6, which shows the graphs of the first four Tchebychev polynomials $T_n(x)$; $n = 1 \ldots 4$, defined as those polynomials of nth degree with the coefficient 1 of x^n, which approximate the function $x = 0$ with the smallest tolerance in the interval $-1 \leqslant x \leqslant +1$. They are[17,20]

$$T_n(x) = 2^{-(n-1)} \cos (n \cdot \arccos x);$$

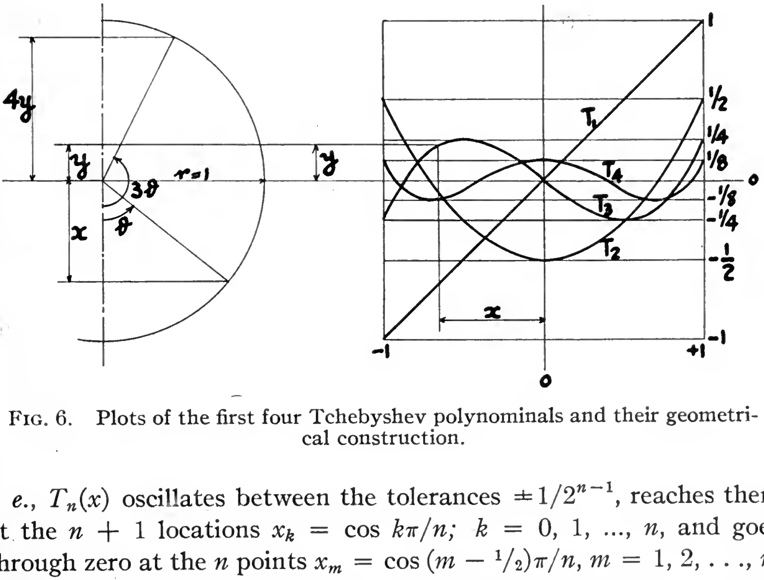

FIG. 6. Plots of the first four Tchebyshev polynominals and their geometrical construction.

i. e., $T_n(x)$ oscillates between the tolerances $\pm 1/2^{n-1}$, reaches them at the $n + 1$ locations $x_k = \cos k\pi/n$; $k = 0, 1, \ldots, n$, and goes through zero at the n points $x_m = \cos (m - {}^1/_2)\pi/n$, $m = 1, 2, \ldots, n$.

In the general case where the approximation functions are not polynomials and this symmetry is no longer present, nth-order approximation is still characterized by the fact that the tolerance is reached $(n + 1)$ times, including the ends of the interval. In general, the order of the approximation is equal to the number of available parameters. Consequently, the best approximation to be expected for straight arms is, in general, of 1st order, with η' running from $-\eta'_{\max}$ at $r = r_1$ through 0 to $+\eta'_{\max}$ at $r = r_2$, the distortion being equal and maximum at the ends of the record; in this way, the smallest maximum distortion is realized. For the offset arm, second-order approximation should be obtainable with the tracking error passing twice through zero and the distortion reaching the maximum value three times, *i. e.*, for r_1 and r_2 and an intermediate radius r_0. Considerably smaller values of distortion can be expected for the offset arm.

(*b*) *Single-Purpose Straight Arm Design.*—Tchebychev approximation of the underhang in eq. *14* for $\alpha = 0$ gives the following results:

Optimal underhang

$$\delta_{\text{opt}} = \sqrt{1 + \frac{x_m^2}{2p^2 - 1}} - 1 \doteq \frac{x_m^2}{2(2p^2 - 1)};\ d_{\text{opt}} \doteq \frac{r_1^2 r_2^2}{L(r_1^2 + r_2^2)} \qquad (15a)$$

Maximal weighted tracking error

$$|\eta'_1| = |\eta'_2| \equiv |\eta'|_{\max} = \frac{x_m}{2} \cdot \frac{a^2 - 1}{a^2 + 1} \equiv \frac{\sqrt{r_1 r_2}}{2L} \cdot \frac{r_2^2 - r_1^2}{r_2^2 + r_1^2} \qquad (15b)$$

Maximal harmonic distortion, according to *12*

$$|\epsilon|_{\max}\ (\%) \sim (8 \text{ to } 11) \cdot \frac{\sqrt{r_1 r_2}}{L} \cdot \frac{r_2^2 - r_1^2}{r_2^2 + r_1^2} \qquad (15c)$$

Weighted tracking error as function of groove radius

$$\frac{\eta'}{|\eta'|_{\max}} = \frac{{}^1\!/_2(a + a^{-1}) - \left(\frac{x_m}{x}\right)^2}{{}^1\!/_2(a - a^{-1})} \equiv \frac{r_2^2 + r_1^2 - 2\frac{r_1^2 r_2^2}{r^2}}{r_2^2 - r_1^2} \qquad (15d)$$

Distortion vanishes at $r = \dfrac{r_1 r_2}{\sqrt{{}^1\!/_2(r_1^2 + r_2^2)}}$ (*15e*)

In Fig. 7, equation *15d* is plotted as $\eta'/|\eta'|_{\max}$ *vs.* $x/x_m = r/\sqrt{r_1 r_2}$ for the three values $a = 2, 3$, and 4. When inserting the numerical values of the playing ranges of transcription and commercial disks, as given at the end of Part I, one obtains

$$|\epsilon|_{\max}\ (\%) \sim \frac{30 \text{ to } 31}{L_{(\text{inches})}}\,. \qquad (15f)$$

This shows that for correct mounting, distortion can just be kept within the limits set previously for commercial recordings with the conventional arm length of 8 inches, while for high-fidelity achievement in transcription, L should be not less than about 15 inches for a straight arm. For these conditions, the actual tracking error becomes about 4.5° at the extreme inner, about 10.3° at the outer groove for transcription, and about 5.9° and 17.8°, respectively, for commercial recordings.

Incorrect mounting may increase tracking distortions considerably. The quantitative influence will be discussed later on for both straight and offset arms. It will be found that, for straight arm mounting, conditions are much more critical at the inner end than at the outer end of the playing range, and that therefore a mounting error which reduces the underhang slightly below the optimal value *15a* is much less harmful than an increase by the same amount. For instance, for an 8-inch arm and 12-inch disks, equation *15a* gives $d_{\text{opt}} = 0.438$ inch $\doteq {}^7/_{16}$ inch. It is found that an increase by only ${}^1/_{16}$ inch would increase the maximal distortion by 33 per cent. A decrease of d by the same amount, however, would increase $|\epsilon|_{\max}$ by only 3.7 per cent. It is thus safe to keep somewhat below rather than above the optimal overhang.

(*c*) *Single-Purpose Offset Arm Design.*—The second-order Tchebychev approximation gives the following optimal values:

Optimal offset

$$\sin \alpha_{\text{opt}} = \frac{2px_m}{p^2+1} \equiv \frac{r_2+r_1}{L\left[\dfrac{\left(\dfrac{r_2+r_1}{2}\right)^2}{r_2r_1}+1\right]} \qquad (16a)$$

Optimal overhang

$$-\delta_{\text{opt}} = 1 - \sqrt{1-\frac{2x_m{}^2}{p^2+1}} \doteq \frac{x_m{}^2}{p^2+1}; \quad -d_{\text{opt}} \doteq \frac{r_2r_1}{L\left[\dfrac{\left(\dfrac{r_2+r_1}{2}\right)^2}{r_2r_1}+1\right]} \qquad (16b)$$

Maximal weighted tracking error; maximal harmonic distortion

$$\left.\begin{aligned} |\eta'|_{\max} = \frac{p^2-1}{p^2+1}\cdot\frac{x_m}{2\cos\alpha_{\text{opt}}} \equiv \frac{(r_2-r_1)^2}{8L\sqrt{r_2r_1}}\cdot \\ \frac{1}{\sqrt{\left[\dfrac{\left(\dfrac{r_2+r_1}{2}\right)^2}{r_2r_1}+1\right]^2-\left(\dfrac{r_2+r_1}{L}\right)^2}}; \quad |\epsilon|_{\max} \sim (18-22)\cdot|\eta|_{\max} \end{aligned}\right\} \qquad (16c)$$

Weighted tracking error as function of radial position

$$\frac{\eta'}{|\eta'|_{\max}} = 2\,\frac{\left(p-\dfrac{x_m}{x}\right)^2}{p^2-1} - 1 \equiv 2\left[\frac{r_2+r_1-\dfrac{2r_2r_1}{r}}{r_2-r_1}\right]^2 - 1. \qquad (16d)$$

$$\left.\begin{aligned} |\eta'| = |\eta'|_{\max} \text{ at } r = r_1,\ r = r_2, \text{ and } r_0 = \frac{2r_2r_1}{r_2+r_1} \\ \eta' = 0 \text{ at } r = \frac{2r_2r_1}{\left(1\mp\dfrac{1}{\sqrt{2}}\right)r_2+\left(1\pm\dfrac{1}{\sqrt{2}}\right)r_1}. \end{aligned}\right\} \qquad (16e)$$

Fig. 8 shows $\eta'/|\eta'|_{\max}$ *vs.* r/r_m, again for the three values $a = 2, 3,$ and 4. Comparison of the Figs. 7 and 8 with 6 shows that the two classes of curves correspond, in their character, to the first two Tchebychev polynomials T_1 and T_2. With the values of r_1 and r_2 used previously, it follows then

$$|\epsilon|_{\max}\ (\%) \doteq \begin{cases} \dfrac{3.7}{\sqrt{(L_{(\text{inches})})^2 - (5.3)^2}} & (\textit{transcription}) \\ \dfrac{5.5}{\sqrt{(L_{(\text{inches})})^2 - (3.4)^2}} & (\textit{commercial}) \end{cases} \qquad (16f)$$

This shows that with an accordingly designed offset arm, it is possible to obtain practically distortion-free tracking even with arms of the shortest practicable length, which is somewhat more than the disk radius.

This result is important as it implies a considerable flexibility of pick-up design, which is necessary in order to meet a number of practical requirements which so far have not been taken into account. One of these factors is the limited accuracy of mounting under practical conditions of production and service. This affects only one of the two parameters, namely, the overhang. It is necessary that the maximum distortion occurring within the playing range does not exceed the prescribed limit as long as the deviation from the optimal overhang *16b* is kept within reasonable tolerances. Another practical factor which has not been considered so far, is connected with the tangential friction force of the stylus in the groove. This gives rise to certain adverse conditions discussed below which depend on the offset angle and are improved by decreasing it from its optimal value *16a*. Finally, multi-purpose tone arms must be designed on a compromise-optimal basis for playing commercial as well as transcription records. This implies deviations from optimal single-purpose design and thus an increase of the maximal distortion. The result *16f* shows that with the theoretical optimal design, tracking distortion is still considerably below the permissible limit even for the shortest practicable arm lengths. Thus it can be expected that sufficient margin is left for taking into account the three factors just mentioned by compromise design not requiring increased arm length, which is undesirable for economic reasons. For straight arms, on the other hand, this is indeed the only means to meet the situation, as seen from *15c* and *15f*. This flexibility of the two-parameter design demonstrates the superiority of the offset head.

It is now necessary to investigate the influence of the stylus friction as well as the general dependence of the maximum distortion on α and δ on the basis of *14*.

(*d*) *The Influence of Stylus Friction.*—Only part of the friction force F between groove and stylus is taken up by the tone arm as this can freely rotate about the axis A (Fig. 5). The remaining component $F_h = F \tan \gamma$ is taken up by the groove wall (Fig. 5). Evidently, γ, and therefore F_h, increases with the offset angle, and for near-optimal offset, F_h is centripetal throughout the play range. This gives rise to an undesirable excess pressure on the inner groove wall which may increase the linear translation loss and create even-order distortion components due to asymmetry of wall deformation.[5] Because of the groove wall inclination, F_h creates a vertical component F_v, which is directed upward. For light-weight pick-ups for high-fidelity reproduction,[21, 22] where the bearing weight is kept to a minimum sufficient to overcome the vertical components of tracking and tracing forces—particularly due to pinch-effect[23, 24]—and spurious accelerations due to unevenness of the record and ambient mechanical vibrations, the influence of the additional force F_v is sometimes considered so detrimental that return to the straight arm is advocated.

A fair estimate of F_v can be obtained for soft records where stylus pressure is most critical. Measurements of the friction for cellulose nitrate show that, from about 10 grams up to a "critical" bearing weight P of 25–30 grams where record wear sets in, F increases linearly with P, according to the empirical relation

$$F \doteq 3 + \frac{P}{4} \text{ (}F\text{ and }P\text{ in grams)} \qquad (17a)$$

(Ref. 21, Fig. 8, p. 215.) F_h is resolved into three components, *i. e.*, one normal to the groove wall, one tangential (frictional), and the vertical, F_v. For a groove angle of 90 degrees, $F_v = F_h(1 - \rho)/(1 + \rho)$, where ρ denotes the coefficient of friction between groove wall and stylus. $\gamma = \alpha + \eta$. It will be shown below that η attains its largest positive value at the outer radius for any design with $\alpha \leqslant \alpha_{\text{opt}}$ (*16a*) and optimal overhang. This gives

$$(F_v)_{\max} \doteq \left(3 + \frac{P}{4}\right) \frac{1 - \rho}{1 + \rho} \cdot \tan (\alpha + \eta_2) \quad \text{(grams)}$$

It will be shown that under practical conditions $(\alpha + \eta_2)$ will never exceed 30 degrees appreciably, while ρ will not be smaller than $^1/_4$, the value of the corresponding coefficient in *17a*. With these assumptions,

$$(F_v)_{\max} \doteq (1.8 + 0.15P) \cdot \tan(\alpha + \eta_2) \lesssim \frac{12 + P}{11.5} \text{ (grams)}. \quad (17b)$$

(For offset angles $\alpha \geqslant \alpha_{\text{opt}}$, it will be found that $|\eta|_{\max}$ is small compared with α; then $\tan \alpha$ may be substituted in *17b*.) For a bearing weight of 15 grams—approximately the lowest commercially available—equation *17b* gives $(F_v)_{\max} = 1^1/_2$ and $2^1/_3$ grams for $\alpha + \eta_2 =$ 20° and 30°, respectively; for the "critical" weight of 30 grams, 2.3 grams and 3.6 grams, respectively. Considering these values, it must be borne in mind that only the difference between $\tan \eta_2$ for the straight arm and $\tan(\alpha + \eta_2)$ for the offset arm represents the increase of F_v due to offsetting. As η_2 is much larger for $\alpha = 0$ than for $\alpha = \alpha_{\text{opt}}$, this increase of F_v is considerably smaller than F_v itself, usually one-half or less of the values found, as will be shown by numerical examples. It appears therefore that even for the lowest bearing weights commercially used, the increase of F_v due to offsetting is inconsiderable, and that there is certainly no reason for giving up the offset with its inherent advantages on that account. However, a choice of α somewhat $< \alpha_{\text{opt}}$ (*16a*) will give some benefit without exceeding the permissible distortion.

(*e*) *Compromise Design and Influence of Mounting Error.*—It has been shown that for practical reasons, it is partly desirable, partly unavoidable to deviate from the theoretical optimal design values *16*. In order to see how far one can go in this respect without infringement on the distortion limit set, the dependence of distortion on α and δ according to *14* must be investigated. For this purpose, it is useful to introduce the numerical radius

$$x_0 = \frac{-2\delta - \delta^2}{\sin \alpha} \quad (18)$$

where η' attains its minimum η'_0. In terms of x_0 and $\sin \alpha$, it is

$$\eta' = \frac{x_m}{2 \cos \alpha} \left\{ 1 - \frac{\sin \alpha}{x} \left(2 - \frac{x_0}{x} \right) \right\} \quad (18a)$$

Starting from $\alpha = 0$, let us first increase the offset continually under adjustment of the underhang or overhang δ for Tchebychev approximation. Between $\alpha = 0$ where $\delta > 0$, and $\alpha = \alpha_{\text{opt}}$ where $\delta < 0$, there must be an angle α_0 for which $\delta = 0$, *i. e.*, where the stylus tip passes through the center C (Fig. 5). It follows

$$\sin \alpha_0 = \frac{x_m}{2p} \equiv \frac{x_2 x_1}{x_2 + x_1} \equiv \frac{r_2 r_1}{L(r_2 + r_1)}; \quad \delta(\alpha_0) = 0. \quad (19)$$

This angle is convenient from the point of ease of mounting. For α_0, the radius x_0 (*18*) becomes zero; it is negative, *i. e.*, has no significance, for $\alpha < \alpha_0$. For α_0, x_0 is thus still outside the playing range $x_1 \leqslant x \leqslant x_2$, which implies that the $\eta'(x)$ is monotonic increasing over the playing range, like the curves of Fig. 7. With further increase of α, however, x_0 becomes $= x_1$. Then the curve $\eta'(x)$ has a horizontal tangent at $x = x_1$. The corresponding value of α is called α_{crit}, and it follows

$$\sin \alpha_{\text{crit}} = \frac{x_1}{1 - \frac{1}{2}\left(1 - \frac{x_1}{x_2}\right)^2} \equiv \frac{r_1}{L\left[1 - \frac{1}{2}\left(1 - \frac{r_1}{r_2}\right)\right]^2} \qquad (20)$$

For $\alpha > \alpha_{\text{crit}}$, the curve $\eta'(x)$ has a negative slope at $x = x_1$ up to the

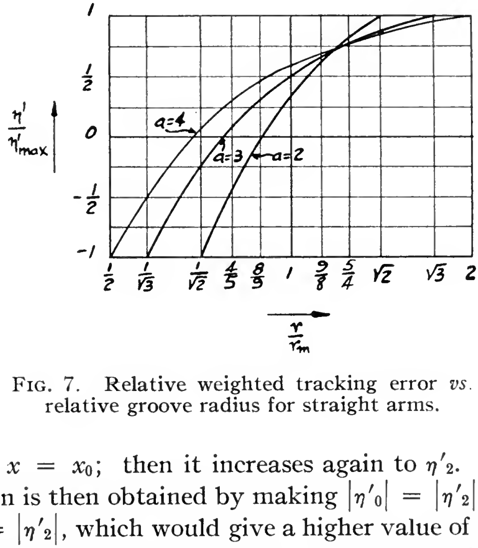

FIG. 7. Relative weighted tracking error *vs.* relative groove radius for straight arms.

minimum at $x = x_0$; then it increases again to η'_2. Tchebychev's approximation is then obtained by making $|\eta'_0| = |\eta'_2| \equiv |\eta'|_{\max}$, and not by $|\eta'_1| = |\eta'_2|$, which would give a higher value of $|\eta'|_{\max}$. (This is readily shown and follows also from continuity with the domain $\alpha < \alpha_{\text{crit}}$.) The value η'_1, which in this range of values of α does not play any part in the Tchebychev design, lies between $\eta'_0 = -\eta'_{\max}$ and $\eta'_2 = +\eta'_{\max}$ and increases, with increasing α, monotonically from $-\eta'_{\max}$ at $\alpha = \alpha_{\text{crit}}$ to $+\eta'_{\max}$ for $\alpha = \alpha_{\text{opt}}$ (eq. *16a*). This case, which has already been dealt with in equation *16* and Fig. 8, represents the second-order approximation. Increasing α beyond α_{opt} leads into the domain where $-\eta'_0 = \eta'_1 = |\eta'|_{\max}$ and $\eta'_2 < \eta'_1$. Finally, there should be an upper critical value of α where η'_2 has decreased to $-\eta'_0$, and x_0 has increased to x_2. For this offset angle,

$$\sin\alpha = \frac{x_2}{1 - \frac{1}{2}\left(\left(\frac{x_2}{x_1}\right)^2 - 1\right)}. \tag{20a}$$

For practical values of x_1 and x_2, this leads to imaginary α, *i. e.*, under actual conditions, $x_0 < x_2$ for α up to 90°.

The design formulas for different offsets follow.

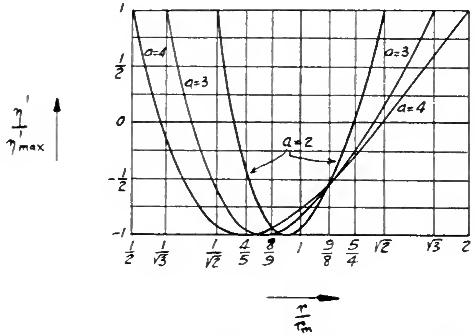

FIG. 8. Relative weighted tracking error *vs.* relative groove radius for offset arms.

For $\alpha \leqslant \alpha_{\text{crit}}$, we obtain:

$$\left.\begin{aligned}
&-\eta'_1 = \eta'_2 = |\eta'|_{\max} = \frac{(x_2 - x_1)\sqrt{x_2 x_1}}{(x_2^2 + x_1^2)\cos\alpha}\Big\}\frac{x_2 + x_1}{2} - \sin\alpha\Big\{ \\
&\frac{\eta'}{|\eta'|_{\max}} = \frac{\left(\frac{x_2}{x}\right)^2 (x - x_1)(x + x_1 - 2\sin\alpha) - \left(\frac{x_1}{x}\right)^2 (x_2 - x)(x_2 + x - 2\sin\alpha)}{(x_2 - x_1)(x_2 + x_1 - 2\sin\alpha)} \\
&-2\delta - \delta^2 = 2\,\frac{(x_1^{-1} + x_2^{-1})\sin\alpha - 1}{x_1^{-2} + x_2^{-2}};\ \delta = 0 \text{ for } \sin\alpha_0 = \frac{1}{x_1^{-1} + x_2^{-1}}
\end{aligned}\right\} \tag{21}$$

For $\alpha = 0$, this reduces, of course, to equation *15*. For $\alpha_{\text{crit}} \leqslant \alpha \leqslant \alpha_{\text{opt}}$:

$$\left.\begin{aligned}
&-\eta'_0 = \eta'_2 = |\eta'|_{\max} = \frac{1}{2\cos\alpha}\sqrt{\frac{x_1}{x_2}}\Big\}\sqrt{\sin^2\alpha + (x_2 - \sin\alpha)^2} - \sin\alpha\Big\{ \\
&\frac{\eta'}{|\eta'|_{\max}} = \frac{x_2\Big\{1 - \frac{2\sin\alpha}{x} + \left[\sqrt{\sin^2\alpha + (x_2 - \sin\alpha)^2} - (x_2 + \sin\alpha)\right]\cdot\frac{x_2}{x^2}\Big\{}{\sqrt{\sin^2\alpha + (x_2 - \sin\alpha)^2} - \sin\alpha} \\
&x_0 = \frac{x_2}{\sin\alpha}\Big\}\sqrt{\sin^2\alpha + (x_2 - \sin\alpha)^2} - (x_2 - \sin\alpha)\Big\{;\ -2\delta - \delta^2 = x_0\sin\alpha
\end{aligned}\right\} \tag{22}$$

For $\alpha \geqslant \alpha_{\text{opt}}$:

$$\left.\begin{aligned}
\eta'_1 = -\eta'_0 = |\eta'|_{\max} &= \frac{1}{2\cos\alpha}\sqrt{\frac{x_2}{x_1}}\left\{\sqrt{\sin^2\alpha + (\sin\alpha - x_1)^2} - \sin\alpha\right\}\\
\frac{\eta'}{|\eta'|_{\max}} &= \frac{x_1\left\{1 - \dfrac{2\sin\alpha}{x} + \left[\sqrt{\sin^2\alpha + (\sin\alpha - x_1)^2} + (\sin\alpha - x_1)\right]\dfrac{x_1}{x^2}\right\}}{\sqrt{\sin^2\alpha + (\sin\alpha - x_1)^2} - \sin\alpha}\\
x_0 = \frac{x_1}{\sin\alpha}&\left\{\sqrt{\sin^2\alpha + (\sin\alpha - x_1)^2} + (\sin\alpha - x_1)\right\}; -2\delta - \delta^2 = x_0\sin\alpha
\end{aligned}\right\} \quad (23)$$

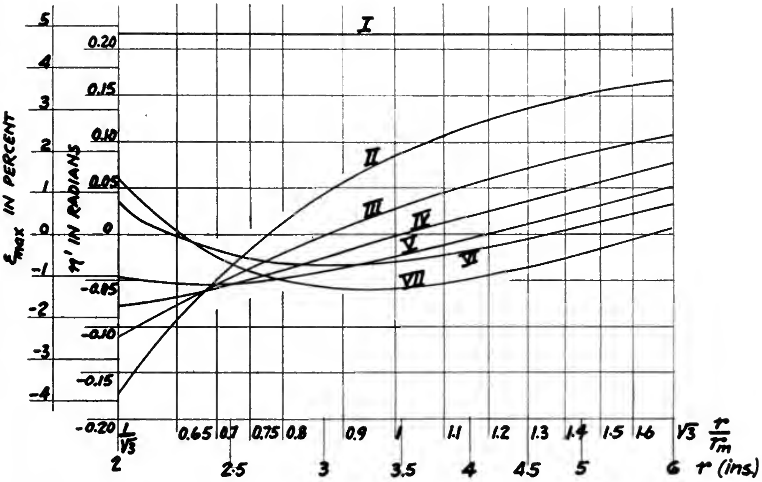

FIG. 9. Numerical example: Plots of weighted tracking error and distortion of optimally hung arm *vs.* groove radius for various offset angles.

Conditions are illustrated in Fig. 9 which shows plots of weighted tracking error and associated harmonic distortion for 2-mil elongation at 500 cps *vs.* the groove radius, for an 8-inch arm and 12-inch disks, with $r_1 = 2$ inches, $r_2 = 6$ inches. The straight line *I* refers to the case of zero offset and underhang, which gives, according to eq. *14*, $\eta' = x_m/2 = 0.217$ rad. $= 12.4°$ or 4.8 per cent distortion, according to *12*. Curve *II* represents $\eta'(x)$ for $\alpha = 0$ and optimal underhang $\delta \doteq {}^9/_{160}$; $d \doteq 0.45$ inch, according to eq. *15*, resulting in $|\eta'|_{\max} = 0.173$ rad. $= 9.9°$; the curve is the same as in Fig. 7 for $a = 3$, with different scales. The angle α_0 where $\delta_{\text{opt}} = 0$, becomes $\sin\alpha_0 = {}^3/_{16}$, $\alpha_0 = 10.8°$, according to eq. *19;* the associated $\eta'(x)$ with $|\eta'|_{\max} = 0.11$ rad. $= 6.4_3°$ is plotted as curve *III;* it leads to

$\gamma_2 = \alpha + \eta_2 = 22^\circ$, which is only $4{}^1/_2{}^\circ$ larger than for $\alpha = 0$. Curve *IV* belongs to an angle α which is still $<$, but close to, α_{crit} and $> \alpha_0$: $\sin \alpha = {}^2/_7$, $\alpha = 16.6^\circ$; $|\eta'|_{\max} = 4.4_4{}^\circ$; $\alpha + \eta_2 = 24.3^\circ$. According to eq. *20*, $\sin \alpha_{\text{crit}} = {}^9/_{28}$, $\alpha_{\text{crit}} = 18.7_5{}^\circ$. Curve *V* refers to $\sin \alpha = {}^5/_{14}$, $\alpha = 20.9^\circ$ which is $> \alpha_{\text{crit}}$. As different from *IV*, the minimum occurs no longer at $x = x_1$, but at $x_0 = 0.290$, according to equation *22;* $-\eta'_1/|\eta'|_{\max} = -0.863$; $|\eta'|_{\max} = 0.0538$ rad. $= 3.08^\circ$; $\alpha + \eta_2 = 26.2^\circ$. The curve *VI*, the same as in Fig. 8 for $a = 3$, represents the second-order Tchebychev approximation, with $\sin \alpha_{\text{opt}} = {}^3/_7$, $\alpha_{\text{opt}} = 25{}^1/_3{}^\circ$, $x_0 = {}^3/_8$; $|\eta'|_{\max} = 0.0343$ rad. $= 1.97^\circ$. The improvement over the straight arm, curve *II*, is striking. $\alpha_{\text{opt}} + \eta_2(\alpha_{\text{opt}}) = 28{}^3/_4{}^\circ$. Finally, curve *VII* pertains to $\sin \alpha = {}^1/_2$, $\alpha = 30^\circ > \alpha_{\text{opt}}$, with $\eta'_2 < -\eta'_0 = |\eta'|_{\max} = 0.059$ rad. $= 3.38^\circ$; $x_0 = 0.405$; $\eta'_2/|\eta'|_{\max} = {}^1/_9$, according to eq. *23*. It is seen that the increase of x_0 and decrease of $\eta'_2/|\eta'|_{\max}$ is comparatively slow above α_{opt}, in accordance with the fact that the critical angle (eq. *20a*) is usually non-existent; in the present example, $x_1 = {}^1/_2$, $\eta'_2/|\eta'|_{\max} = -{}^7/_9$ for $\alpha = \pi/2$, according to eq. *23*.

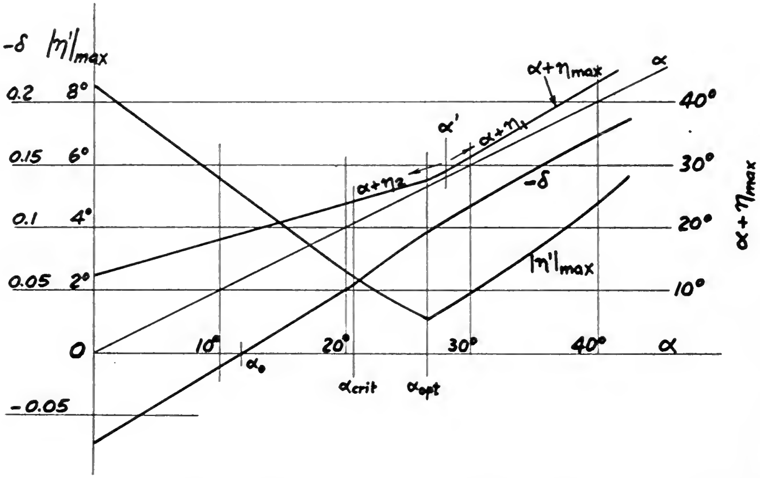

FIG. 10. Numerical example: Plots of various parameters *vs.* offset angle.

Fig. 10 shows the dependence of the optimal numerical underhang or overhang, of the associated maximum weighted tracking error, and of the angle $(\alpha + \eta_{\max})$ which occurs in *17b*, on the offset angle α.

The curves refer to 16-inch disks and $33^1/_3$ rpm, with $L = 12$ inches, $r_1 = 3.6$ inches, $r_2 = 8$ inches ($x_1 = 0.3$, $x_2 = ^2/_3$). The characteristic angles are $\alpha_0 = 12°$, $\alpha_{\text{crit}} = 20.7°$, and $\alpha_{\text{opt}} = 26.5°$. The kinks of the curves at $\alpha = \alpha_{\text{opt}}$ are due to the Tchebychev condition. The minimum of $|\eta'|_{\max}$ represents, according to *12*, a maximum distortion of only $^1/_3$ per cent, while about $2^1/_2$ per cent is obtained for the straight arm, which is somewhat more than the permissible limit. It is seen that α may be chosen considerably below α_{opt}, without infringement on the distortion limit, but that the resulting reduction of the vertical force *17b* is comparatively modest, because $(\alpha + \eta_2)$ increases only slowly with α for $\alpha < \alpha_{\text{opt}}$. If $\alpha > \alpha_{\text{opt}}$, η'_2 becomes rapidly $< \eta'_1$ (curve *VII* of Fig. 9), and for a certain angle α', η_2 becomes $= \eta_1$; for $\alpha > \alpha'$, $\eta_{\max} = \eta_1$. According to eq. *23*, it is

$$\left.\begin{aligned} \sin\alpha' &= x_2\left[\sqrt{2\left(1+\frac{x_1}{x_2}\right)}-1\right] \quad (\eta_1 = \eta_2) \\ &\text{and} \\ \eta_{\max} \doteq \eta_1 &= \frac{1}{2}\tan\alpha\left[\sqrt{1+\left(1-\frac{x_1}{\sin\alpha}\right)^2}-1\right] \text{ for } \alpha \geqslant \alpha' \end{aligned}\right\} \quad (24)$$

Thus the curve $(\alpha + \eta_{\max})$ has 2 kinks: at $\alpha = \alpha_{\text{opt}}$ and $\alpha = \alpha'$. The line α is shown for comparison; it is seen that for $\alpha \geqslant \alpha_{\text{opt}}$, $\eta_{\max} \ll \alpha$, as expected for $\eta_{\max} = \eta_1$. Therefore α may be used instead of $\alpha + \eta_{\max} = \gamma_{\max}$ in the estimate *17b*.

In order to obtain the influence of inaccurate mounting on tracking distortion, it is necessary to supplement the preceding calculations which concerned the case of optimal overhang $-\delta$ for variable offset angle, by those for variable δ. It has already been mentioned in connection with the straight arm design that distortion increases rapidly if the underhang is increased beyond the optimal value, while a decrease is much less harmful; it can be shown that the ratio of the two effects is $(r_2/r_1)^2$. This is easily understood on the ground that the design is based on the *weighted* tracking error. Conditions are therefore most critical at the inner groove radius. This is true not only for straight arms but for all under-critical offset angles. An illustration is given by Fig. 11, which shows $|\eta'|_{\max}$ *versus* $-\delta$ for the same numerical example as used in Fig. 10. The curves are plotted for the four cases $\alpha = 0$, $\alpha = \alpha_0$, $\alpha = \alpha_{\text{crit}}$, and $\alpha = \alpha_{\text{opt}}$. The unsymmetry noted for $\alpha = 0$ persists up to α_{crit}, while the mounting becomes more and more critical with increasing offset angle due to the decrease of $|\eta'|_{\max}(\delta_{\text{opt}})$. For $\alpha > \alpha_{\text{crit}}$, the steepness of ascent for $\delta < \delta_{\text{opt}}$ increases rapidly, due to the appearance of the minimum η_0. At $\alpha = \alpha_{\text{opt}}$, the inclination on the side of positive $(\delta - \delta_{\text{opt}})$ is still substantially unaltered, but the side of negative $(\delta - \delta_{\text{opt}})$ is now the steeper one. At the same time, the influence of the mounting becomes most severe, which is understood, as the optimal approximation is achieved through compensation. In the present numerical example, a deviation $|\delta - \delta_{\text{opt}}|$ of about 4.10^{-3} corresponding to a mounting error of only $^3/_{64}$ inch, already doubles the value of $|\eta'|_{\max}$. The full realization of the second-order approximation would thus call for an accuracy of a few tenths of a millimeter. But as the distortion associated with the minimum of $|\eta'|_{\max}$ is far below the permissible limit, requirements can be considerably relaxed, under practical conditions. Liberal mounting tolerances of about $^1/_2$ to 1 per cent of the arm length or $\pm {}^1/_{16}$ to $^1/_8$ inch will be permissible in most practical cases. They are easily determined by calculating the slopes of the $|\epsilon|_{\max}$–δ curves at both sides of $\delta = \delta_{\text{opt}}\ (\alpha)$. For all designs with $\alpha < \alpha_{\text{opt}}$, which were found preferable on account of the decrease of F_v *(17)*, an overhang δ somewhat larger than δ_{opt} should be prescribed, which is likewise found in terms of the two slopes.

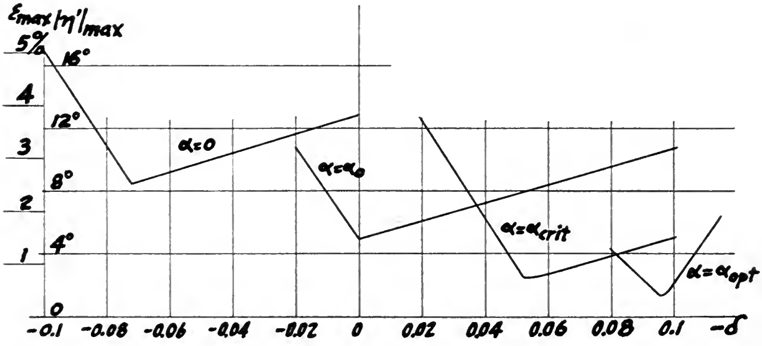

FIG. 11. Numerical example: Distortion *vs.* mounting error for characteristic offset angles.

(*f*) *Design of Multi-Purpose Arms.*—When it is desired to play records of different sizes and/or speeds with the same tone arm, this should be designed on a compromise basis so as to render as small as possible the maximal tracking distortion occurring under any conditions thus included. As the mean radii r_m of different types of disk records are different, the design is based on the original relations *10* and *14* or *18a* combined:

$$\epsilon \doteq \frac{v}{2L\Omega \cos \alpha}\left(1 - \frac{\sin \alpha}{x}\left(2 - \frac{x_0}{x}\right)\right); \quad x_0 = \frac{-2\delta - \delta^2}{\sin \alpha} \qquad (25)$$

It should furnish for α and x_0 such values that minimize $|\epsilon|_{\max}$ simultaneously for the different types of records which are characterized by their values of Ω, r_1, and r_2, v being considered as constant (*i. e.*, 8 cm/sec at 500 cps for permissible $|\epsilon|_{\max} = 2$ per cent). In practice, only the following combinations are used

(*1*) 78 rpm; $r_1 \sim 2$ inches, $r_2 \sim 6$ inches
(*2*) 78 rpm; $r_1 \sim 2$ inches, $r_2 \sim 8$ inches
(*3*) $33^1/_3$ rpm; $r_1 \sim 3^1/_2$ inches, $r_2 \sim 8$ inches

For design purposes, (*1*) can be disregarded as it is fully included in the range of (*2*). Using upscripts in referring to (*2*) and (*3*), the following six values have to be considered as potential maxima of distortion

$$\Delta_1{}^{(2)} = \left|1 - \frac{\sin \alpha}{x_1{}^{(2)}}\left(2 - \frac{x_0}{x_1{}^{(2)}}\right)\right|; \; \Delta_0{}^{(2)} = \left|1 - \frac{\sin \alpha}{x_0}\right|; \; \Delta_2{}^{(2)} = \left|1 - \frac{\sin \alpha}{x_2{}^{(2)}}\left(2 - \frac{x_0}{x_2{}^{(2)}}\right)\right|; \; \Delta_1{}^{(3)} = 2.34\left|1 - \frac{\sin \alpha}{x_1{}^{(3)}}\left(2 - \frac{x_0}{x_1{}^{(3)}}\right)\right|; \; \Delta_0{}^{(3)} = 2.34\left|1 - \frac{\sin \alpha}{x_0}\right|;$$

$$\Delta_2{}^{(3)} = 2.34\left|1 - \frac{\sin \alpha}{x_2{}^{(3)}}\left(2 - \frac{x_0}{x_2{}^{(3)}}\right)\right|.$$

Here, Δ stands as abbreviation for $(2L\Omega_2 \cos \alpha)|\epsilon|/v$ with $\Omega_2 = 78\pi/30 \text{ sec}^{-1}$; 2.34 = ratio of the two speeds. $\Delta_0{}^{(k)}$ has to be omitted if $x_0{}^{(k)} \leqslant x_1{}^{(k)}$ ($k = 2$ or 3) as being outside the playing range. The optimal numerical values of x_0 and $\sin \alpha$ are those which minimize the largest of the four to six Δ's, *i. e.*, which make the three largest of them equal. $\Delta_2{}^{(2)}$ can obviously be omitted from the comparison, but not necessarily $\Delta_0{}^{(2)}$, as x_0 may be $< x_1{}^{(3)}$ but $> x_1{}^{(2)}$.

As an example, the design of a double-purpose 12-inch arm is given. The numerical limit radii are $x_1{}^{(2)} = {}^1/_6$, $x_1{}^{(3)} = {}^7/_{24}$, and $x_2{}^{(2)} = x_2{}^{(3)} = {}^2/_3$. It is found that for $|\Delta_1{}^{(2)}| = |\Delta_1{}^{(3)}| = |\Delta_2{}^{(3)}| \equiv \Delta_{\max}$, $|\Delta_0{}^{(2)}| < \Delta_{\max}$ and $x_1{}^{(3)} > x_0 = 0.288_5$; $\sin \alpha = 0.344$; $\alpha = 20.1°$. $\delta = 0.050_9$, $d = 0.61_1$ inch. Fig. 12 shows the resulting distortion ϵ, according to *25*, for $v = 8$ cm/sec at 500 cps; its maximum is only 1 per cent. This is only half the permissible limit and leaves thus a safety margin for inaccurate mounting. It is seen that x_0 is only slightly $< x_1{}^{(3)} = 0.292$; *i. e.*, for the speed $33^1/_3$, the design is close to that for $\alpha = \alpha_{\text{crit}}$. For the speed 78 rpm, on the other hand, $\alpha > \alpha_{\text{opt}}$, and the overhang

$-\delta < -\delta_{\text{opt}}(\alpha)$. If the same arm were to be used for 78 rpm alone, the optimal design as given by equation *16* would be: $\alpha_{\text{opt}} = 19°$, $-d_{\text{opt}} = 0.532$ inch, $|\epsilon|_{\text{max}} = 0.39$ per cent; if it were designed for use at $33^1/_3$ rpm alone: $\alpha_{\text{opt}} = 26°$, $-d_{\text{opt}} = 1.023$ inches, $|\epsilon|_{\text{max}} = 0.36$ per cent. It is seen that the double-purpose design lies closer to the first case.

OTHER EFFECTS OF TRACKING ERROR

The harmonic distortions due to tracking error depend, as shown, only on the distortion parameter ϵ (*4a*), *i. e.*, on the weighted tracking error η' (*11*). Consequently, the design was based on this quantity.

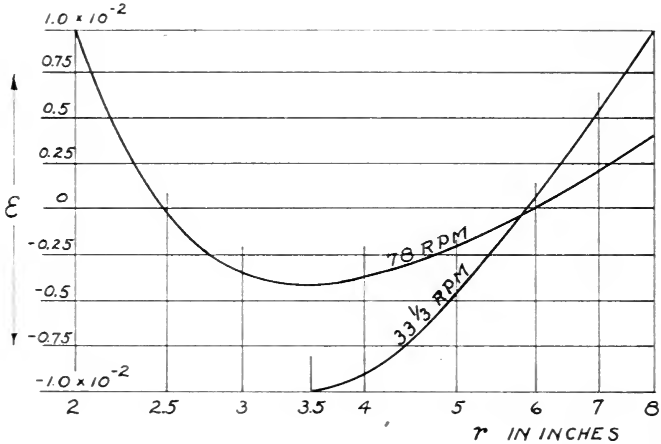

FIG. 12. Numerical example for multi-purpose arm design: Tracking distortion over playing range.

There are, however, effects which depend on the tracking error η itself rather than on η'. Although they are in general unimportant, they should at least be mentioned here.

Going back to the rigorous expressions *6*, *7*, and *8* for the picked-up signal, it is seen that this contains the factor sec η. This implies an increase, not only in signal amplitude, but also in the lateral reaction force (both stiffness and inertia), by sec η. This increase, however, is of negligible magnitude for all practical purposes although the design minimizing $|\eta'|_{\text{max}}$ does not minimize $|\eta|_{\text{max}}$. The largest value which η may take occurs at the outer rim for straight arms. It was shown (Part II, *b*) that even for maximal permissible distortion—

which is nearly obtained with a properly underhung 8-inch arm for 12-inch records— $\eta_2 \doteq 18°$, *i. e.* $(\sec \eta_2 - 1) \doteq 0.05 \ll 1$. This is in line with the assumption $\eta^2/2 \ll 1$ on which the design procedure was based.

It has been claimed that tracking error may cause appreciable record wear. Again, this supposed wear would not depend on η' and therefore would not be minimized by the proposed design. But, as in case of the signal amplitude, it does not seem that, within the permissible range as based on the presented design method, tracking error could have any noticeable effect of this kind. No clear experimental evidence of additional record wear caused by tracking error of usual magnitude has ever been presented. Careful listening tests undertaken by Olney[2] did not reveal any clear effect. Besides, it is hard to understand how record wear could ever be produced by tracking error of permissible magnitude. For permanent stylus points, it is certainly ruled out as they are surfaces of revolution. All commercial light-weight pick-ups have permanent styli. In case of steel needles, on the other hand, high stylus tip pressure and motional impedance cause appreciable record wear, quite independently of the tracking mechanism. Wear due to tracking error is supposedly caused by the rate of change of tracking error along the groove spiral: the needle is initially ground to fit the groove and is therefore no longer a surface of revolution; turning about its axis due to change of η therefore entails regrinding of the projecting edge. It is certainly hard to see how this regrinding which occurs very gradually as compared with the initial grinding in the first few grooves, could possibly cause any wear noticeable against the background of that due to excessive stylus pressure and impedance, as met in cheaper grade pick-ups.

I wish to tender my acknowledgment to the Brush Development Company for making this work possible. I am also obliged to Dr. S. J. Begun, head of the recording department, for hints and enlightening discussions.

REFERENCES

[1] MacDonald, G. E.: "The Reduction of Pick-Up Tracking Error," *Communications*, **XXI** (Jan., 1941), p. 55.

[2] Olney, B.: "Phonograph Pick-Up Tracking Error *vs.* Distortion and Record Wear," *Electronics*, **X** (Nov., 1937), p. 19.

[3] Löfgren, E. G.: "On the Non-Linear Distortion in the Reproduction of

Phonograph Records Caused by Angular Deviation of the Pick-Up Arm," *Akust. Zeits.*, **III** (1938), p. 350.

[4] Lewis, W. D., and Hunt, F. V.: "A Theory of Tracing Distortion in Sound Reproduction from Phonograph Records," *J. Acoust. Soc. Amer.*, **XII** (Jan., 1941), p. 348.

[5] Kornei, O.: "On the Playback Loss in the Reproduction of Phonograph Records," *J. Soc. Mot. Pict. Eng.*, **XXXVII** (Dec., 1941), p. 569. After completion of the manuscript, a paper by G. Guttwein, *Akust. Zeits.*, **V** (Dec., 1940), p. 330, on linear and non-linear distortions in recording and playback, was received.

[6] Feldtkeller, R., and Wolman, W.: "Almost-Linear Networks," *Telegraph. u. Fernsprech. Tech.*, **XX** (1931), p. 167.

[7] Bartlett, A. C.: "Calculation of Modulation Products," *Phil. Mag.*, Part I, **XVI** (Oct., 1933), p. 834; Part II, **XVII** (Mar., 1934), p. 628.

[8] Lagrange, J. L.: *Hist. de l'Acad. R. des Sci. de Berlin*, **XXV** (1771), p. 242.

[9] Bessel, F. W.: *Berliner Abh.* (1826).

[10] Watson, G. N.: "A Treatise on the Theory of Bessel Functions," Cambridge (1922).

[11] McLachlan, N. W.: "Bessel Functions for Engineers," Part I, Oxford (1934).

[12] Jahnke-Emde: "Tables of Functions," Third Ed., Leipsic and Berlin (1938), p. 147.

[13] Lagrange, J. L.: *Mem. de l'Acad. de Berlin XXIV*, Oeuvres, **II**, p. 25.

[14] Whittaker, E. T., and Watson, G. N.: "A Course of Modern Analysis," Fourth Ed., Cambridge (1935), 7:31 and 7:32, p. 131.

[15] Massa, F.: "Permissible Amplitude Distortion of Speech in an Audio Reproducing System," *Proc. IRE*, **XXI** (May, 1933), p. 682.

[16] Lynch, T. E., and Begun, S. J.: "General Considerations of the Crystal Cutter," *Communications*, **XX** (Dec., 1940), p. 9.

[17] Tchebychev, P. L.: *Mem. Acad. Sc. Petersb.*, Series 6, **VII** (1859), p. 199; Oeuvres, **I**, p. 271.

[18] Guillemin, E. A.: "Communication Networks," **II** (1935), p. 386.

[19] Cauer, W.: "An Interpolation Problem with Functions with Positive Real Values," *Math. Zeits.*, **XXXVIII** (1933), p. 1.

[20] Courant, R., and Hilbert, D.: "Methods of Mathematical Physics," Berlin, **I** (1931), p. 75.

[21] Williams, A. L.: "Further Improvements in Lightweight Record Reproducers and Theoretical Considerations Entering into Their Design," *J. Soc. Mot. Pict. Eng.*, **XXX** (Aug., 1939), p. 203.

[22] Lynch, T. E.: "Some Considerations in Phonograph Pick-Up Design," *Brush Strokes*, **III** (April–June, 1939), p. 3.

[23] Pierce, J. A., and Hunt, F. V.: "Distortion in Sound Reproduction from Phonograph Records," *J. Soc. Mot. Pict. Eng.*, **XXXI** (Aug., 1938), p. 157; *J. Acoust. Soc. Amer.*, **X** (July, 1938), p. 14.

[24] Fleming, L.: Notes on Phonograph Pick-Ups for Lateral-Cut Records," *J. Acoust. Soc. Amer.*, **XII** (Jan., 1941), p. 366.

THE SPECIALIZATION OF FILM DELIVERY*

J. H. VICKERS**

Summary.—*The problem of transporting film and of distributing it to the thousands of theaters in the country is a considerable economic problem. Approximately ninety per cent of all film shipped between exchanges and theaters is handled by trucks operating out of thirty-two film-distributing centers scattered throughout the country.*

The paper describes in considerable detail the truckman's routine in picking up and delivering film between the exchanges and the theaters.

In order to discuss film transportation with an audience such as this it is not necessary to review the history of the development of the motion picture business; however, it is well to remember that a complete program for the old nickelodeon had a film weight of about thirty pounds, whereas today the average small town theater often uses in excess of one hundred pounds of film in building its program. In fact, there is very little difference between programs offered the patrons of small towns and those shown in the palatial theaters of the large cities.

The millions spent annually in advertising motion pictures naturally create a desire to see the pictures and stars as soon as possible and, as with any other useful product, a public demand for it is created. Due to radio, magazines, and newspapers reaching all the byways and small hamlets of the country, the demand for pictures soon after release date is no longer confined to the large centers of population. Supplying this rural demand is an economic problem, as good business limits the number of prints available for exhibition; therefore fast and efficient transportation is a necessary bridge between the economics of furnishing pictures and the public demand for seeing them.

Throughout the country truck companies specializing in the delivery of film have been organized to furnish this fast and efficient transportation. At most of the thirty-two film distributing centers throughout the United States you will find one or more trucking firms

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* Presented at the 1941 Spring Meeting at Rochester, N. Y.; received April 14, 1941.

** National Film Carriers, Inc., Philadelphia, Pa.

performing special film delivery service, commonly known as film carriers. Approximately 90 per cent of all the film shipped between exchanges and theaters are handled by trucks.

To understand better how film carriers vary from ordinary truck operators, let us look in detail at the film carrier's operations. As the film carrier's work is an endless chain, a convenient beginning will be with a truck loaded with film ready to start on its nightly pick-up and delivery journey. The driver has a key for every theater on his route, and, by prearrangement, each theater has a designated place to leave the film ready for return and a place for the incoming film. On a route making a loop from and back to the exchange center, the first stop will be made after the first theater on the route closes; here the film for the next day's use will be delivered and the film just shown picked up. After working the theaters on this loop route, the truck will be back to the exchange center early the following morning, having delivered all the film for that day's use and returned all that used the previous day. This film is delivered immediately to the various exchanges for inspection and reshipment. Much of this film will probable be booked that day in nearby suburban theaters. Immediate inspection makes the film ready for shipment to these theaters before opening time of that day. Such films will be picked up by the film carrier and delivered to the suburban theater with the print having been inspected and no time lost between play-dates. During the day shipments are made ready for the next day's play-dates and late in the afternoon the film carrier picks up these films from the exchanges and again loads the truck ready for the next day's delivery. This is the complete chain in its simplest form, but there are many more details and much more complicated operation in a complete film delivery service.

In addition to the early morning suburban delivery previously mentioned, there is usually a late pick-up after the suburban theater closes at night. This is especially true in the distributing centers located in large cities where some film carriers maintain a night inspection service as well as some of the distributors. The film picked up from suburban theaters after closing time is rushed to the inspection rooms, and those booked for the next day's showing are inspected and made ready for shipment on trucks leaving around 2:00 A. M. These late routes are usually loop routes.

In order to reach the more distant and off-route points, small towns, and hamlets not on the main line, junction points are necessary. At these junction points relay trucks meet the main-line truck. These relay trucks leave the last town on the line at the theater's closing time, picking up film from this and other theaters on the relay. At the junction point all the pick-up is delivered to the main-line truck, and the film for the next days' showing is received. Very often a relay has one or more feeders, or sub-relays, which serve off-route points. When more than two or three relays meet at a common point a sub-terminal is usually set up by the film carrier. The management of this sub-terminal supervises the proper transfer of film from one route to another and maintains a refueling station and inspection service where emergency repairs and adjustments can be made. As a rule main-line trucks run directly out to the junction points and return over the same route, which enables the truck to reach more distant junction points than if it were making a loop. This type of run has the advantage of an early leaving time over a loop run, as it does not have to wait until the theaters on the route are closed before passing. On the return trip pick-up and delivery are made to the theaters that were not closed on the outgoing trip.

It can readily be seen that a system of this kind easily lends itself to the circuiting of product from one theater to another from the closing time at night to the opening time next day. Products so circuited can not be inspected between play-dates; however, it is of great advantage to both exhibitor and distributor to have this circuiting possibility available, as it saves many dark houses or unwarranted cost when some unforeseen circumstance puts a print out of service, such as damage by bad mechanisms, hold-overs, fire, or an error in booking. Prints having a specific time value, such as newsreels, and not requiring a great deal of inspection, seldom ever see the film exchange until they are worn out or are out of date, as they are set up on circuit from town to town during their useful life.

There is a large amount of detail involved in the proper execution of a specialized film-delivery system, and in addition there is the question of personnel and equipment with which to do this exacting job. One of the great railroad systems of the country was justly proud in publishing a statement regarding their crack train, saying that it maintained its schedule over a period of a year of $92^1/_2$ per cent on time. In order to maintain good service and to avoid missouts, it is necessary for the average film carrier to maintain a schedule at least 95 per cent perfect; the country's average among film carriers is higher than 95 per cent.

Road accidents are one of the greatest hazards to a schedule. Excessive speeds greatly increase road accidents, therefore the film carrier must use moderate speeds and at the same time maintain a fast schedule. This makes it imperative that the right kind of equipment be selected for the job to be done. To do this all factors affecting the minimum speed of the truck must be considered; namely, the average weather conditions, the load to be hauled, the number and percentage of grades to be encountered, and all other road conditions. In order to maintain a consistent average speed without high top speeds it is necessary that the lower speeds on grades be near the average speed desired. Sufficient available horsepower is the only remedy for this equation. When analyzing an engine *Sufficient* Available Horsepower is a much broader term than *Maximum* Available Horsepower as it takes into consideration the maximum torque of the engine and the speed at which this torque is developed, and refers only to the horsepower developed at an engine speed practical for continuous operation. These facts must be taken into consideration, as unfortunately most internal combustion engines develop their maximum horsepower at a speed considerably higher than the speed that will give an economical motor life that is practical for continuous operation. Some truck units have as many as ten forward speeds in order to give the operator a chance to do the most with the horsepower available at a safe engine speed. The next great enemy to a schedule is road breakdown. The secret of eliminating road breakdowns is to have the equipment as nearly perfect on every trip as possible. This can not be done without allowing the mechanical force all the time necessary to make inspections, adjustments, replacements, and repairs, which often calls for a truck's being in the shop longer than the hours between runs, and necessitates a large amount of spare equipment. Some companies have as much as 75 per cent spare equipment.

One of the greatest horrors to a film carrier is a fire on a film truck. Aside from the great physical loss there is the miss-out loss and disappointment of the customer and the public. To reduce this hazard to a minimum gas tanks are equipped with safety devices against spillage on overturn or collision, and the ignition is automatically cut off when the truck reaches any excessive angle from the horizontal. Of course, every precaution such as fire extinguishers properly located, exhaust pipes away from wood and gas lines, and no smoking rules, are in effect. Another enemy to film is excessive cold; to overcome this the film carriers in the northern part of the country use insulated trucks.

In order to render the industry better service and to standardize the film delivery service by truck, a number of the leading film carriers met in New York early in 1933 and formed an Association known as National Film Carriers, Inc. The only requirement for membership is that a member be a truck carrier specializing in the handling and the delivering of film and doing the job in a reliable and dependable manner. The Association has attracted the leading firms engaged in the transportation of film and includes some thirty members. The distributors and exhibitors have met with the members of the Association from time to time and great progress has been made through this coöperative effort. Uniform rules and regulations for carrying the proper insurance and bonds, and other standards of practice have been devised. Standardization of equipment and regulations as to fire prevention and safety have been promoted. Through its representatives the Association has met with the representatives of the government in order to formulate plans and regulations that will benefit and not hinder this type of service. The Association has set up a fire-prevention bureau which issues rules and regulations to reduce the danger of fire to a minimum at the terminal as well as on the road. The Association maintains membership in the Bureau of Explosives and thereby keeps abreast of all the latest rules and regulations which promote safety of operation. The American Trucking Association has recognized that the film delivery service is a highly specialized business and has set up a division in its organization known as the Film Carriers Division.

As stated before film carriers handle approximately 90 per cent of all film shipments between exchanges and theaters, but no exact statistics have been compiled on the number of miles required to do this tremendous job. To get some idea of the magnitude of film-carrier operations the analysis of one exchange center will throw some light on the subject. Charlotte, North Carolina, is a 2 per cent distributing center serving the States of North and South Carolina. The film carriers in this territory handle slightly more than 95 per cent of the film between exchanges and theaters, and the miles involved to do this job weekly would encircle the world twice. This illustration is probably a low average for the miles traveled out of the thirty film distributing centers in the United States.

To summarize the outstanding requirements of an efficient film delivery service: an infallible system for receiving, listing, checking, circuiting, and delivering the many items required in building each program, from a one-sheet to the feature; the selection and training of the highest type driver personnel, as this is the key to maintaining schedules, safety, and dependability; the selection of the proper road equipment, and as nearly perfect maintenance as possible; and last, management that can keep a business that must necessarily stay in a groove out of a rut.

Behind these cold facts there is a lot of romance in the development and operation of the film delivery business. The service rendered and the successful operation of this "backstage" branch of the motion picture industry can largely be attributed to the fact that all its personnel are as thoroughly imbued with the spirit that "the show must go on" as is any actor.

CURRENT LITERATURE OF INTEREST TO THE MOTION PICTURE ENGINEER

The editors present for convenient reference a list of articles dealing with subjects cognate to motion picture engineering published in a number of selected journals. Photostatic copies may be obtained from the Library of Congress, Washington, D. C., or from the New York Public Library, New York, N. Y. Micro copies of articles in magazines that are available may be obtained from the Bibliofilm Service, Department of Agriculture, Washington, D. C., at prevailing rates.

Acoustical Society of America, Journal

13 (October, 1941), No. 2

The Stereophonic Sound-Film System—General Theory (pp. 89–99)	H. Fletcher
Mechanical and Optical Equipment for the Stereophonic Sound-Film System (pp. 100–106)	E. C. Wente, R. Biddulph, L. A. Elmer, and A. B. Anderson
The Stereophonic Sound-Film System—Pre- and Post-Equalization of Compandor Systems (pp. 107–114)	J. C. Steinberg
Phase Distortion in Electroacoustic Systems (pp. 115–123)	F. M. Wiener
The Acoustic Wattmeter, and Instrument for Measuring Sound Energy Flow (pp. 124–136)	C. W. Clapp and F. A. Firestone
A Re-Examination of the Noise Reduction Coefficient (pp. 163–169)	J. S. Parkinson and W. A. Jack
The Flutter Echoes (pp. 170–178)	D. Y. Maa
A Cinematographic Study of the Conduction of Sound in the Human Ear (pp. 179–181)	H. G. Kobrak

American Cinematographer

22 (October, 1941), No. 10

What a Modern 16-Mm Business-Film Studio is Like (pp. 470, 496)	I. B. Dyatt
Remember to Light the Background (pp. 478, 498)	G. Meehan

Communications

21 (October, 1941), No. 10

Cathode Design (pp. 5–8, 28)	O. W. Pike

Educational Screen

20 (October, 1941), No. 8

Motion Pictures—Not for Theaters (pp. 333–335), Pt. 30	A. E. Krows

Electronics

14 (October, 1941), No. 10

Research Beats the Priorities (pp. 27–30, 78, 80, 82–83)	C. J. LeBel
Storage in Television Reception (pp. 46–49, 115–116)	A. H. Rosenthal

Institution of Electrical Engineers, Journal

88 (September, 1941), No. 3, Pt. III

Acoustics of Cinema Auditoria (pp. 175–190)	C. A. Moson and J. Moir

International Projectionist

16 (August, 1941), No. 8

Mechanics of the Modern Projector (pp. 12–14)	H. B. Sellwood
New RCA Lens-Coating Process Available (p. 14)	
Effect of Static on Sound Systems (p. 15)	

Motion Picture Herald (Better Theaters Section)

145 (October 18, 1941), No. 3

How Visual Angles Affect Image Size (pp. 33–34)	C. E. Shultz

BACK NUMBERS OF THE TRANSACTIONS AND JOURNALS

Prior to January, 1930, the *Transactions* of the Society were published quarterly. A limited number of these *Transactions* are still available and will be sold at the prices listed below. Those who wish to avail themselves of the opportunity of acquiring these back numbers should do so quickly, as the supply will soon be exhausted, especially of the earlier numbers. It will be impossible to secure them later on as they will not be reprinted.

	No.	Price
1924	19	$1.25
	20	1.25
1925	21	1.25
	22	1 25
	23	1.25
	24	1.25
1926	25	$1.25
	26	1.25
	27	1.25
	28	1.25
1927	29	1.25
	32	1.25
1928	33	$2.50
	34	2.50
	35	2.50
	36	2.50
1929	37	3.00
	38	3.00

Beginning with the January, 1930, issue, the JOURNAL of the Society has been issued monthly, in two volumes per year, of six issues each. Back numbers of all issues are available at the price of $1.00 each, a complete yearly issue totalling $12.00. Single copies of the current issue may be obtained for $1.00 each. Orders for back numbers of *Transactions* and JOURNALS should be placed through the General Office of the Society and should be accompanied by check or money-order.

HIGHLIGHTS OF THE 1941 FALL CONVENTION

The attendance at the 50th Semi-Annual Convention at the Hotel Pennsylvania in New York was remarkably good and no great difficulty was experienced in securing papers of good quality and interest in spite of the National Emergency. These facts show the wisdom of the decision of the Board of Governors some time ago to continue to hold the usual two conventions per year. On succeeding pages of this issue of the JOURNAL will be found the program of papers as actually followed at the sessions.

The Convention opened formally at 10 A.M. on Monday, October 20th in the Salle Moderne of the Hotel Pennsylvania, Mr. Herbert Griffin, Executive Vice-President of the Society, presiding. The first part of the morning was occupied with the reports of the Financial Vice-President, the Engineering Vice-President, and a welcome by the President of the Society, Mr. Emery Huse. Then followed the announcement of the successful candidates for office for 1942, the ballots having been counted on the previous day by a committee of tellers appointed by the Board. The new officers and governors of the Society for 1942, who are to assume office on January 1st, are as follows:

Engineering Vice-President:	Donald E. Hyndman
Financial Vice-President:	Arthur S. Dickinson
Secretary:	Paul J. Larsen
Treasurer:	George Friedl, Jr.
Governor:	Frank E. Carlson
Governor:	John A. Maurer
Governor:	Edward M. Honan

The terms of other officers and governors of the Society whose names are not listed above have still one year to run. They are as follows:

President:	Emery Huse
Past President:	E. Allan Williford
Executive Vice-President:	Herbert Griffin
Editorial Vice-President:	Arthur C. Downes
Convention Vice-President:	William C. Kunzmann
Governor:	Max C. Batsel
Governor:	Loren L. Ryder

In addition, Drs. Alfred N. Goldsmith and John G. Frayne have been elected Chairmen of the Atlantic Coast Section and Pacific Coast Section, respectively, by virtue of which they become members of the Board of Governors. The results of the elections of the Mid-West Section are not yet available.

The Monday morning session continued with a series of four papers of a general nature, Mr. Richard Griffith of the Museum of Modern Art Film Library beginning the series with a paper on "Adventures of a Film Library." Mr. Robert

Russell, formerly with the Training Film Production Laboratory at Fort Monmouth, N. J., discussed what he called the "Dynamic Screen," pointing out that within its present limits various phases of the motion picture have been brought close to technical exhaustion and artistic satisfaction. However, competition with color television and other forms of entertainment require another "sudden impact of novelty" similar to the previous ones of sound, montage, and color. One great frontier remains; "the selective delimitation of the screen," making the screen area the entire proscenium wall, and selectively limiting projected pictures within this potential area. An interesting discussion of "Motion Picture Cant," meaning the jargon of (technical) motion pictures, was presented by Mr. Barry Buchanan, lexicographer of New York, and Mr. Terry Ramsaye of Quigley Publications presented a brief dissertation on the extremes to which the motion picture industry goes to produce effects not nearly so extreme in scope. The title of his talk was "Lots of How, a Little What."

The usual informal luncheon was held at noon of Monday, October 20th. Approximately a hundred and fifty persons came out to listen to the four well known invited speakers. The Honorable Newbold Morris, President of the Council and Acting Mayor of the City of New York, extended the official welcome of the City of New York to the delegates of the Convention, and referred to the importance of motion pictures in our defense program during these troublous times. The second speaker, Mr. Sol A. Rosenblatt, formerly Administrator of the Motion Picture and Broadcasting Industries, during the NRA, and now General Counsel of the National Democratic Committee, spoke vigorously against the Wheeler-Clark-Nye investigation of alleged propaganda in American motion pictures.

Mr. Francis S. Harmon, Assistant to the President of Motion Picture Producers and Distributors of America, was the third speaker. Mr. Harmon discussed at some length the importance of the motion picture in contributing to the general public morale, and also elaborated on the broad extent to which the motion picture industry is involved in the question of priorities, including very large quantities of such homely materials as typewriter paper, pens, and ink, not to speak of the more technical materials such as are required in the production of film and equipment.

The afternoon session opened with a talk by Alan H. Morgensen on the question of "Work Simplification—Essential to Defense." Mr. Morgensen's paper was illustrated by a 16-mm picture depicting the way in which motion pictures may be used to analyze the motions of industrial workers and to simplify the procedure and render it more efficient.

Next followed two papers on 16-mm production problems. Mr. Lloyd Thompson of the Calvin Company discussed at considerable length "Some Equipment Problems of the 16-mm Producer," pointing out that the direct 16-mm method is now definitely out of the experimental stage. Mr. William H. Offenhauser, Jr., of Precision Film Labs, presented "A Review of the Question of 16-mm Emulsion Position." When a 16-mm sound-film is properly threaded in a 16-mm projector the emulsion on the film may face the screen (which position is called the "standard" position) or it may face the projector light-source (the "non-standard" emulsion position). The well designed 16-mm sound projector of today should be capable of projecting either "standard" or "non-standard" film.

The Monday afternoon session concluded with a talk by Lt. Col. M. E. Gillette of the U. S. Signal Corps, Fort Monmouth, N. J., on "The How and Why of Army Training Films," illustrated by several films produced in the Fort Monmouth Laboratory.

The Monday evening session opened with a paper by Mr. Glenn L. Dimmick of the RCA Manufacturing Company, Indianapolis, in which was described "A New Dichroic Reflector and Its Application to Photocell Monitoring Systems." Certain crystals have long been known to transmit light of one color and reflect light of another color, and some thin metallic films also exhibit the same phenomenon. Such films evaporated on glass have been successfully employed in high-level photocell monitoring systems for sound recorders. Nearly all the actinic value of the modulated light is transmitted to the photographic film, while a large part of the red and infrared is reflected to a caesium photocell for monitoring.

Dr. Peter C. Goldmark, of the Columbia Broadcasting System, gave a brief history of color television, and described the general theory of the system, including color, flicker, and electrical characteristics. Next followed a paper by Dr. Alfred N. Goldsmith of New York on "The IR System: an Optical Method for Increasing Depth of Field." The system was devised for the purpose of attaining greater depth of field than is attainable by existing methods of utilizing a lens system for image formation. The depth of field of a corrected lens system is determined by its focal length, its effective aperture, and the permissible diameter of the in-focus image of a point-source. This limited depth of field restricts freedom of action on motion picture sets, and dictates a stylized, protracted, and costly studio procedure. The IR system is based on a division of the set into optically appropriate regions, each region having identifiable illumination, with the identification and differential focusing at the camera of all regional images within a single exposure.

The evening session was concluded by a paper on "Mobile Television Equipment," by R. L. Campbell, R. E. Kessler, R. E. Rutherford, and K. V. Landsberg of the Allen B. DuMont Laboratories.

The morning session of Tuesday, October 21st, was devoted to a series of papers on projection and lighting. Mr. W. Hotine described "A Constant-Torque Friction Clutch for Film Take-Up" which, when adusted initially to deliver a given safe torque to the take-up spindle, maintains the torque at a constant value which can not be exceeded. Messrs. E. L. Boecking and L. W. Davee of the Century Projector Corp discussed new developments in the design of projector mechanisms, and the session concluded with reports of three technical committees of the Society—the Theater Engineering Committee, the Studio Lighting Committee, and the Standards Committee.

The Theater Engineering report included an account of an investigation by the Projection Practice Sub-Committee into the use of hand fire extinguishers in projection rooms. The sub-committee recommends that such fire-fighting equipment be not required in projection rooms in view of the policy of the Committee expressed last year to the effect that in the event of film fire in the projection room the projectionist should immediately shut down the equipment and leave the room, in which case he would not be inside the room to use such hand extinguishers as might be included therein. The presence of hand extinguishers in a projection room might provide a temptation for the projectionist to remain in the room and attempt to fight the fire.

Another part of the Report of the Theater Engineering Committee, that of the Sub-Committee on Screen Brightness, outlined the admirable work that is being done by that group in attempting to discover or to design, or to induce instrument manufacturers to build, suitable instruments for measuring the light incident upon and reflected from the screens in motion picture theaters. Specifications for such meters were proposed, and several methods of achieving the desired measurement were described. The Sub-Committee on Theater Design described some tests made recently to determine preferred seating areas in theaters.

During the afternoon session of Tuesday, October 29th, Messrs. M. R. Null, W. W. Lozier, and D. B. Joy discussed "The Color Quality of Light on the Projection Screen," and Messrs. Lozier, Joy, and M. T. Jones described the characteristics of "New 13.6-Mm Carbons for Increased Screen Light." The four authors mentioned are engineers of the National Carbon Company at Fostoria, Ohio. The session closed with a brief discussion by W. Scanlon of Larry Strong, Inc., on the question of "How Safe Are Safety Devices," referring especially to devices employing photoelectric cells.

The opening paper on the morning of Wednesday, October 22nd, dealt with "A New Electrostatic Air Cleaner and Its Application to the Motion Picture Industry," by Henry Gitterman of the Westinghouse Electric and Manufacturing Corp. The presentation was attended by a demonstration of the principle of electrostatic precipitation, and in the paper were described a number of installations of such equipment of particular interest to motion picture engineers.

Mr. M. H. Sweet, of Agfa Ansco, described "A Direct-Reading Photoelectric Densitometer," in which a logarithmic amplifier circuit had been modified to provide an accurately linear output, with excellent stability.

Two papers by R. M. Evans, W. T. Hanson, Jr., and P. K. Glasoe of the Eastman Kodak Company discussed "Iodide Analysis in an MQ Developer" and "Synthetic Aged Developers by Analysis." The technical part of the session was concluded by a paper by Messrs. J. I. Crabtree, G. T. Eaton, and L. E. Muehler of the Eastman Kodak Company on the "Effect of Composition of Processing Solutions on Hypo Removal from Motion Picture Film."

On the evening of Wednesday, October 27th, was held the Fiftieth Semi-Annual Banquet of the Society, commemorating the Silver Anniversary of the founding of the Society, which occurred on July 24th, 1916.

The proceedings of the banquet opened with the introduction of the officers and governors elect for 1942, after which occurred the granting of the Journal and Progress Awards. Mr. R. E. Farnham, Chairman of the Journal Award Committee, presented the report of the Committee. The recommendation for the award was the paper entitled "Effects of Ultraviolet Light on Variable-Density Recording and Printing" by Drs. John G. Frayne and Vincent Pagliarulo of Electrical Research Products, Inc., Hollywood, Calif., which appeared in the June, 1940, issue of the JOURNAL. Mr. Farnham's report included brief historical sketches of the two authors.

Mr. Paul J. Larsen, member of the Progress Award Committee, reported on the Journal Award for the Chairman of the Committee, Mr. Kenneth F. Morgan who was unable to be present. The Society's medal was awarded to Mr. Glenn

L. Dimmick of the RCA Laboratories at Indianapolis, in recognition of his outstanding contributions to the advancement of the motion picture art. An historical account of Mr. Dimmick's achievements was given by Mr. Otto S. Schairer, Vice-President in charge of RCA Laboratories.

The formal proceedings of the banquet included the presentation of a testimonial certificate to Mr. William C. Kunzmann, Convention Vice-President of the Society. The certificate read as follows:

"In recognition of his long and faithful service as a member of the Society since 1916 and a member of the Board of Governors since 1929, and as Convention Vice-President since 1933, the Board of Governors of the Society on this day present this certificate to William C. Kunzmann as a testimonial of their appreciation and esteem."

The Thursday morning session was devoted to a symposium of three papers on fine-grain film. C. R. Dailey of Paramount Pictures, Inc., Hollywood, Calif., discussed "Production and Release Application of Fine-Grain Films for Variable-Density Sound Recording"; Messrs. J. R. Wilkinson and F. L. Eich, Paramount Pictures, Inc., Hollywood, Calif., discussed "Laboratory Modification and Procedure in Connection with Fine-Grain Release Printing"; and V. C. Shaner of Eastman Kodak Company, Hollywood, discussed the question of "Hollywood Processing Procedures for Eastman 1302 Fine-Grain Release Positive."

The final session of the Convention, on Thursday afternoon, October 23rd, included four papers devoted to sound. Messrs. John G. Frayne and F. P. Herrnfeld, of Electrical Research Products, Inc., Hollywood, discussed "A Frequency-Modulated Control-Track for Movietone Prints"; in which a 5-mil frequency-modulated track is located between the sound and picture areas to control reproduction in the theater from one or more sound-tracks. Messrs. R. R. Scoville and W. L. Bell, also of Electrical Research Products, described the factors underlying the design and use of biased recording systems, showing how, in order to minimize noise and "shutter bump," special precautions must be taken in filtering. The paper dealt in some detail with the "Design and Use of Film-Noise Reduction Systems."

The third paper of the afternoon was by W. J. Albersheim and L. F. Brown, of Electrical Research Products, Inc., of New York, on "A Feedback Light-Valve" and the Convention concluded with a paper by S. L. Reiches of the Brush Development Company, Cleveland, Ohio, on "The Quarter-Wave Method of Speaker Testing."

ACKNOWLEDGMENT

The Society wishes to acknowledge its indebtedness and appreciation to all those who contributed in time and effort toward the conduct and success of the Convention. This includes the various chairmen and members of the convention committees, various officers of the Society, and a number of companies of the Industry.

In addition, the Society acknowledges the kindness of the Capitol Theater, Radio City Music Hall, Warner's Strand Theater, Roxy Theater, and the Paramount Theater in issuing courtesy admissions to the convention delegates.

PROGRAM OF THE CONVENTION*

MONDAY, OCTOBER 20th

10:00 a.m. **General Session, Herbert Griffin,** *Chairman.*

Report of the Convention Arrangements Committee: W. C. Kunzmann, *Convention Vice-President.*

Report of the Financial Vice-President; A. S. Dickinson.

Report of the Engineering Vice-President; D. E. Hyndman.

Welcome by the President; Emery Huse.

Election of Officers and Governors for 1942.

"Adventures of a Film Library;" R. Griffith, Museum of Modern Art, New York, N. Y.

"Dynamic Screen—a Speculation;" R. W. Russell, New York, N. Y.

"Motion Picture Cant;" Barry Buchanan, New York, N. Y.

"Lots of How, a Little What?" Terry Ramsaye, Quigley Publishing Co., New York, N. Y.

12:30 p.m. **Informal Get-Together Luncheon; Emery Huse,** *Chairman.*

Addresses by:

The Honorable Newbold Morris, President of the Council and Acting Mayor of the City of New York.

Mr. Sol A. Rosenblatt, New York, N. Y.

Mr. Francis S. Harmon, Assistant to the President, Motion Picture Producers & Distributors of America, Inc., New York, N. Y.

Mr. Claude Lee, Director of Public Relations, Paramount Pictures, Inc., New York, N. Y.

2:00 p.m. **General and 16-Mm Session, C. R. Keith,** *Chairman.*

"Work Simplification—Essential to Defense;" A. H. Mogensen, New York, N. Y

"Some Equipment Problems of the Direct 16-Mm Producer;" L. Thompson, The Calvin Company, Kansas City, Mo.

"A Review of the Question of 16-Mm Emulsion Position;" Wm. H. Offenhauser, Jr., Precision Film Laboratories, New York, N. Y.

"The How and Why of Army Training Films;" M. E. Gillette, Lt. Col., Signal Corps, U. S. Army, Fort Monmouth, N. J.

8:00 p.m. **General Session, Paul J. Larsen,** *Chairman.*

"A New Dichroic Reflector and Its Application to Photocell Monitoring Systems;" G. L. Dimmick, RCA Manufacturing Co., Inc., Indianapolis, Ind.

"Color Television;" P. C. Goldmark, J. N. Dyer, E. R. Piore, and J. M. Hollywood, Columbia Broadcasting System, Inc., New York, N. Y.

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* As actually followed at the sessions.

"The IR System: An Optical Method for Increasing Depth of Field;" Alfred N. Goldsmith, Consulting Engineer, New York, N. Y.

"Mobile Television Equipment;" R. L. Campbell, R. E. Kessler, R. E. Rutherford, and K. V. Landsberg, Allan B. DuMont Laboratories, Passaic, N. J.

TUESDAY, OCTOBER 21st

10:00 a.m. **Projection Session, G. L. Dimmick,** *Chairman.*

"A Constant-Torque Friction Clutch for Film Take-Up;" W. Hotine, Rotovex Corp., Newark, N. J.

"Recent Developments in Projection Mechanism Design;" E. L. Boecking and L. W. Davee, Century Projector Corp., New York, N. Y.

Report of the Studio Lighting Committee; R. Linderman, *Chairman.*

Report of the Standards Committee; D. B. Joy, *Chairman.*

Report of the Theater Engineering Committee; Alfred N. Goldsmith, *Chairman.*

2:00 p.m. **General Session, Arthur C. Downes,** *Chairman.*

"Film Production for Education;" Floyde E. Brooker, Defense Training, U. S. Office of Education, Washington, D. C.

"The Color Quality of Light on the Projection Screen;" M. R. Null, W. W. Lozier, and D. B. Joy, National Carbon Co., Fostoria, Ohio.

"New 13.6-Mm Carbons for Increased Screen Light;" M. T. Jones, W. W. Lozier, and D. B. Joy, National Carbon Co., Fostoria, Ohio.

"How Safe Are Safety Devices?" W. Scanlon, Larry Strong, Inc., Chicago, Ill.

WEDNESDAY, OCTOBER 22nd

10:00 a.m. **Laboratory and Business Session, D. E. Hyndman,** *Chairman.*

"A New Electrostatic Air Cleaner and Its Application to the Motion Picture Industry;" Henry Gitterman, Westinghouse Electric and Manufacturing Corp., New York, N. Y.

"A Precision Direct-Reading Densitometer;" M. H. Sweet, Agfa Ansco, Binghamton, N. Y.

Society Business.

"Iodide Analysis in an MQ Developer;" R. M. Evans, W. T. Hanson, Jr., and P. K. Glasoe, Eastman Kodak Company, Rochester, N. Y.

"Synthetic Aged Developer by Analysis;" by R. M. Evans, W. T. Hanson, Jr., and P. K. Glasoe, Eastman Kodak Company, Rochester, N. Y.

"Effect of Composition of Processing Solutions on Hypo Removal from Motion Picture Film;" J. I. Crabtree, G. T. Eaton, and L. E. Muehler, Eastman Kodak Company, Rochester, N. Y.

8:00 p.m. **Fiftieth Semi-Annual Banquet and Dance.**
Introduction of Officers-Elect for 1942.
Presentation of the SMPE Progress Medal.
Presentation of the SMPE Journal Award.
Entertainment and Dancing.

THURSDAY, OCTOBER 23rd

10:00 a.m. **Fine-Grain Film Symposium, John G. Frayne,** *Chairman.*

"Production and Release Applications of Fine-Grain Films for Variable-Density Sound-Recording;" C. R. Daily, Paramount Pictures, Inc., Hollywood, Calif.

"Laboratory Modification and Procedure in Connection with Fine-Grain Release Printing;" J. R. Wilkinson and F. L. Eich, Paramount Pictures, Inc., Hollywood, Calif.

"A Note on the Processing of Eastman 1302 Fine-Grain Release Positive in Hollywood;" V. C. Shaner, Eastman Kodak Co., Hollywood, Calif.

"Stereophonic Sound and the Realistic-Width System;" R. G. Camp, New Philadelphia, Ohio.

2:00 p.m. **Sound Session, John A. Maurer,** *Chairman.*

"A Frequency-Modulated Control-Track for Movietone Prints;" J. G. Frayne and F. P. Herrnfeld, Electrical Research Products, Inc., Hollywood, Calif.

"The Design and Use of Film-Noise Reduction Systems;" R. R. Scoville and W. L. Bell, Electrical Research Products, Inc., Hollywood, Calif.

"A Feedback Light-Valve;" W. J. Albersheim and L. F. Brown, Electrical Research Products, Inc., New York, N. Y.

"The Quarter-Wave Method of Speaker Testing;" S. L. Reiches, The Brush Development Co., Cleveland, Ohio.

Adjournment of the Convention.

BOOK REVIEW

Acoustics. Alexander Wood, *Interscience Publishers, Inc.* (New York, N. Y.) 1941; 575 pp., 310 illustrations; $6.00.

This book is intended for students who desire a more detailed treatment of acoustics than they can find in a book on general physics. A student who has mastered this book should have an exceedingly good fundamental knowledge of modern acoustics. The book is also valuable to the engineers who wish to form a basis for specialization in any of the numerous applications of acoustics. The contents by chapters are Wave Motion; Analytical Discussion of Wave Motion; Forced Vibration; Resonators, Filters, and Horns; Dissipation of Energy of Sound-Waves; Reflection of Sound-Waves; Refraction of Sound-Waves; Superposition or Interference; Diffraction; Measurement of the Velocity of Sound; Vibrations of Strings; Organ Pipes; Intensity of Sound; Pitch and Frequency; Analysis of Sound; Rods, Membranes, and Plates; The Ear and Hearing; Recording and Reproduction of Sound; Acoustics of Buildings; Name and Subject Index.

As indicated by the contents, this book covers the entire gamut of both classical and modern acoustics. This book is valuable and unique in the wide exposition of the classical side of acoustics in a modern style. Due to the wide scope of subjects covered in this book, the treatment is in certain instances quite brief. However, this is compensated for by the inclusion of references to more comprehensive expositions. The book is adequately and appropriately illustrated.

In summary: "Acoustics," by Wood, is a contribution to acoustic literature which is of value and interest to the advanced student, applied physicist, and acoustical engineer.

H. F. Olson

SOCIETY SUPPLIES

The following are available from the General Office of the Society, at the prices noted. Orders should be accompanied by remittances.

Aims and Accomplishments.—An index of the *Transactions* from October, 1916, to December, 1929, containing summaries of all articles, and author and classified indexes. One dollar each.

Journal Index.—An index of the Journal from January, 1930, to December, 1935, containing author and classified indexes. One dollar each.

Motion Picture Standards.—Reprints of the *American Standards and Recommended Practices* as published in the March, 1941, issue of the Journal; 50 cents each.

Membership Certificates.—Engrossed, for framing, containing member's name, grade of membership, and date of admission. One dollar each.

Journal Binders.—Black fabrikoid binders, lettered in gold, holding a year's issue of the Journal. Two dollars each. Member's name and the volume number lettered in gold upon the backbone at an additional charge of fifty cents each.

Test-Films.—See advertisement in this issue of the Journal.

SOCIETY ANNOUNCEMENTS

OFFICERS OF THE SOCIETY FOR 1942

The results of the recent election of Officers of the Society for 1942, are as follows:

***Engineering Vice-President:* DONALD E. HYNDMAN
***Financial Vice-President:* ARTHUR S. DICKINSON
**Treasurer:* GEORGE FRIEDL, JR.
**Secretary:* PAUL J. LARSEN
***Governors:* FRANK E. CARLSON
JOHN A. MAURER
EDWARD M. HONAN

Officers and Governors of the Society, whose terms do not expire until December 31, 1942, are as follows:

**President:* EMERY HUSE
**Past-President:* E. ALLAN WILLIFORD
**Executive Vice-President:* HERBERT GRIFFIN
**Editorial Vice-President:* ARTHUR C. DOWNES
**Convention Vice-President:* WILLIAM C. KUNZMANN
**Governors:* MAX C. BATSEL
LOREN L. RYDER

The three remaining governors are the chairmen of the three local Sections. Dr. Alfred N. Goldsmith* has been elected Chairman of the Atlantic Coast Section and Dr. John G. Frayne,* re-elected Chairman of the Pacific Coast Section. The results of the Mid-West Section elections will be announced as soon as they are available.

Atlantic Coast Section

The results of the election of officers and managers of the Atlantic Coast Section for 1942 are as follows:

**Chairman:* ALFRED N. GOLDSMITH
**Past-Chairman:* REEVE O. STROCK
**Secretary-Treasurer:* HARRY B. CUTHBERTSON
***Managers:* CECIL N. BATSEL
MERVIN W. PALMER

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* Term expires December 31, 1942.
** Term expires December 31, 1943.

EARL I. SPONABLE
*Managers: PETER C. GOLDMARK
H. E. WHITE
WM. H. OFFENHAUSER, JR.

Pacific Coast Section

The results of the recent election of officers and managers of the Pacific Coast Section for 1942 are as follows:

*Chairman: JOHN G. FRAYNE
*Past-Chairman: LOREN L. RYDER
*Secretary-Treasurer: CHARLES W. HANDLEY
**Managers: HOLLIS W. MOYSE
RAY WILKINSON
JOHN HILLIARD
*Managers: BARTON KREUZER
SIDNEY P. SOLOW

The new Officers and Managers assume their positions on January 1, 1942.

PROGRESS AND JOURNAL AWARDS OF THE SOCIETY

It is a requirement each year after the presentation of the Progress Medal and the Journal Award certificate at the Fall Convention of the Society to publish in the JOURNAL a list of the names of all those who have thus far received these awards. The list follows:

Progress Medal

1935	E. C. WENTE
1936	C. E. K. MEES
1937	E. W. KELLOGG
1938	H. T. KALMUS
1939	L. A. JONES
1940	WALT DISNEY
1941	G. L. DIMMICK

Journal Award

1934	P. A. SNELL
1935	L. A. JONES and J. H. WEBB
1936	E. W. KELLOGG
1937	D. D. JUDD
1938	K. S. GIBSON
1939	H. T. KALMUS
1940	R. R. MCMATH
1941	J. G. FRAYNE and V. PAGLIARULO

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* Term expires December 31, 1942.
** Term expires December 31, 1943.

ADMISSIONS COMMITTEE

At a recent meeting of the Admissions Committee, the following applicants for membership were admitted into the Society in the Associate grade:

ALCORN, E. F.
3126 Peachtree Drive,
Atlanta, Ga.

COOK, R. O.
1956 Myra Avenue,
Los Angeles, Calif.

CREWS, R. F.
607 N. La Jolla,
Los Angeles, Calif.

DEMANN, J. L.
c/o Warner Bros. Projection Dept.,
Clark Building,
Pittsburgh, Pa.

DOWNING, WM.
Mills Novelty Co.,
4100 Fullerton Avenue,
Chicago, Ill.

FRANKLIN, R. C.
Popular Science Publishing Co., Inc.,
353 Fourth Avenue,
New York, N. Y.

GULLO, J.
93 West Ferry Street,
Buffalo, N. Y.

HINSHAW, R. M.
Box 294,
Weiser, Idaho

JONES, WATSON
RCA Manufacturing Co., Inc.,
1016 N. Sycamore Avenue,
Hollywood, Calif.

LACKOFF, S. K.
Cineola Corporation,
152 West 42nd Street,
New York, N. Y.

LARGEN, F. C.
Creighton,
Nebraska

LARIME, L. H.
Jam Handy Picture Service, Inc.,
Detroit, Mich.

MOL, J. C.
Multifilm Batavia, N. V.,
Bidara Tjina 125,
Batavia, D. E. I.

OSTINELLI, L. U.
238a, High Street,
Uxbridge, Middlesex, England

REHM, L. H.
7327 Holly Court,
River Forest, Ill.

ROBIN, H. L.
Panoram Soundies Connecticut Co.,
86 Meadow Street,
New Haven, Conn.

ROSSOMANDO, P. T.
Fitzer Amusement Co.,
218 W. Fayette Street,
Syracuse, N. Y.

SMITH, H. L.
P. O. Box 304,
Bound Brook, N. J.

TURNIPSEED, R., JR.
Reagan Visual Education Co.,
614–615 Rhodes Bldg.,
Atlanta, Ga.

In addition, the following applicants have been admitted to the Active grade:

KERNS, E. F.
Museum of Modern Art Film Library,
11 West 53rd Street,
New York, N. Y.

SCHAFFERS, T. W. M.
Philips Export Corp.,
Hotel Roosevelt,
New York, N. Y.

JOURNAL

OF THE SOCIETY OF

MOTION PICTURE ENGINEERS

AUTHOR AND CLASSIFIED INDEXES

VOLUME XXXVII

JULY–DECEMBER, 1941

AUTHOR INDEX, VOLUME XXXVII

JULY TO DECEMBER, 1941

CLASSIFIED INDEX, VOLUME XXXVII

JULY TO DECEMBER, 1941

S. M. P. E. TEST-FILMS

These films have been prepared under the supervision of the Projection Practice Committee of the Society of Motion Picture Engineers, and are designed to be used in theaters, review rooms, exchanges, laboratories, factories, and the like for testing the performance of projectors.

Only complete reels, as described below, are available (no short sections or single frequencies). The prices given include shipping charges to all points within the United States; shipping charges to other countries are additional.

35-Mm. Visual Film

Approximately 500 feet long, consisting of special targets with the aid of which travel-ghost, marginal and radial lens aberrations, definition, picture jump, and film weave may be detected and corrected.

Price $37.50 each.

16-Mm. Sound-Film

Approximately 400 feet long, consisting of recordings of several speaking voices, piano, and orchestra; buzz-track; fixed frequencies for focusing sound optical system; fixed frequencies at constant level, for determining reproducer characteristics, frequency range, flutter, sound-track adjustment, 60- or 96-cycle modulation, etc.

The recorded frequency range of the voice and music extends to 6000 cps.; the constant-amplitude frequencies are in 11 steps from 50 cps. to 6000 cps.

Price $25.00 each.

16-Mm. Visual Film

An optical reduction of the 35-mm. visual test-film, identical as to contents and approximately 225 feet long.

Price $25.00 each.

SOCIETY OF MOTION PICTURE ENGINEERS
HOTEL PENNSYLVANIA
NEW YORK, N. Y.