U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

ACOUSTIC PERFORMANCE OF 16-MILLIMETER SOUND MOTION-PICTURE PROJECTORS

CIRCULAR C439

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ACOUSTIC PERFORMANCE OF 16-MILLIMETER SOUND MOTION-PICTURE PROJECTORS

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I. INTRODUCTION

This Circular presents a discussion of the acoustic performance of 16-mm sound-on-film motion-picture projectors from the point of view of the representative of a large purchaser, the Federal Government—a representative who has had experience over a period of several years in the preparation of specifications and in the testing of both 16-mm and 35-mm equipment, and who also is interested in improving the quality of such commercially available equipment. The preparation of this discussion is the outgrowth of an investigation of the performance of the sound-reproduction system of 16-mm projectors for the Committee on Scientific Aids to Learning, a committee of the National Research Council. From information gathered from this investigation, it is hoped that specifications can be prepared that will be comprehensive in scope and will lay particular stress upon performance rather than upon description of the equipment. The investigation included a study of test methods by means of which the performance can be measured. The specifications and test methods can be used by large school systems and similar agencies with technical departments equipped with suitable testing apparatus or by agencies with access to suitable testing facilities to ensure the purchase of 16-mm sound projectors that will give good performance, yet not be excessive in cost. Throughout the work described in this Circular, educational uses of projectors rather than their use for musical entertainment have been given first consideration.

Sixteen-millimeter sound-on-film projectors are an outgrowth of 35-mm projectors and are the result of technical developments in many branches of engineering and applied science. With the rapid development of the application of sound to 35-mm motion-picture equipment since 1926, it was natural that the same application would be made to 16-mm equipment. Although manufacturers of 16-mm projectors can and do profit from the experience gained by manufacturers of 35-mm equipment, nevertheless, there are many problems peculiar to the16-mm projector. The quality of performance available in commercial 16-mm projectors leaves much to be desired. The very highest quality of performance in sound reproduction and picture projection may not be necessary or attainable with 16-mm projectors, since other factors, such as compactness, portability, ruggedness, simplicity, reliability of operation, and low cost are of the greatest importance. However, the performance of 16-mm projectors should keep pace with the performance of high-grade 35-mm equipment wherever possible. If this point of view is adopted by manufacturers and purchasers, it is possible to apply much of the experience and data on the performance of 35-mm equipment to the problem of specifications for 16-mm equipment. The writer believes that manufacturers have made and are continuing to make serious effort to improve the quality of performance of their products.

Although this Circular is intended primarily for persons with some technical familiarity with 16-mm equipment, it is hoped that sufficient general discussion is included to make the Circular of some interest and value to other readers. Additional information may be found in a report of the SMPE Non-Theatrical Equipment Committee [1][1] and in Bureau Circular C437 [2].

[1] Figures in brackets indicate the literature references at the end of this paper.

II. DESCRIPTION OF SOUND-REPRODUCING SYSTEM

It is assumed that the reader is acquainted with the general construction and operating functions of silent-motion-picture projectors. The following description is given to familiarize the reader with the components and functions of 16-mm projector sound-reproducing systems discussed in this paper.

In sound-on-film type of equipment the sound signal is recorded and retained on the film by a photographic process. The sound track, which is in the form of a continuous narrow band, is placed alongside the picture area. There are two types of sound-on-film recording in general use, the "variable area" and the "variable density." In the variable-area type the record consists of a transparent area adjoining an area of uniform density, with the boundary between the two areas having the wave form of the recorded signal. The variable-density type consists of transverse parallel striations of varying density corresponding with the frequency and intensity of the signal. The variable-area type is more commonly used in the 16-mm projector

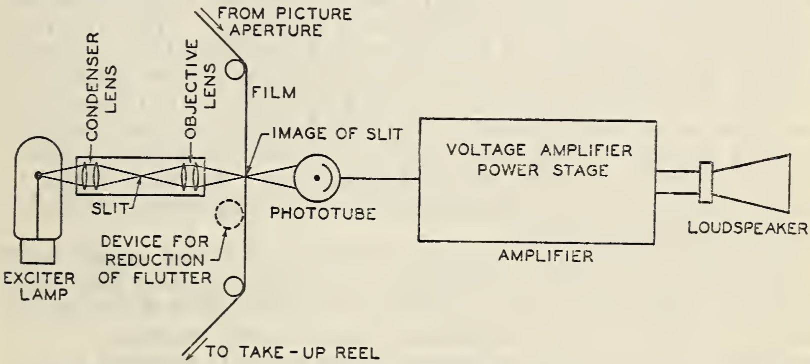

FIGURE 1.—*Schematic diagram of 16-mm projector sound-reproducing system.*

field. Since the sound track is carried along on the same film with the picture, synchronization of picture and sound becomes automatic in the reproducing process.

To reproduce the signal from film record it is necessary to scan the moving sound track with a light beam, transform the light modulations into electric current by a photoelectric device, and deliver the signal as an amplified fluctuating current to the loudspeaker. Figure 1 shows this extended process in schematic form. The light source for the scanning beam is known as the exciter lamp and consists of a small low-voltage lamp similar to an automobile headlamp. Current to the lamp may be supplied by the amplifier rectifier system, by 60 c/s alternating current direct from the line, or by a vacuum-tube oscillator operating above the range of audio frequency. The latter type of source for current is coming into common use because of greater signal-to-noise ratio, stability, and ease of control.

The image of the filament of the exciter lamp is focused by a condensing lens on the scanning slit, which may range from several ten-thousandths to about one-thousandth of an inch in width. The light from the illuminated slit is then focused by the objective lens to a very narrow beam on the sound track of the moving film. The optical system consisting of the condensing lens, slit, and objective lens is sometimes referred to as the sound optic. The entire system from the exciter lamp to the phototube is known as the sound-optical system.

The modulated light beam is then passed on to the phototube. Because of their greater sensitivity, gas-filled phototubes are used. The small changes in electric current caused by the fluctuating light falling on the light-sensitive cathode of the phototube must be greatly amplified.

The amplifier in 16-mm equipment is usually of conventional design. There may be additional features that will allow the operator to shift the frequency response through rather wide ranges and to reduce background noise to a minimum. The last stage, or power stage, is usually of the push-pull type and is terminated by the loudspeaker. If the loudspeaker is of the electromagnetic type, the current to the field coil is obtained from the amplifier rectifier system.

An important function must be performed by the film-moving mechanism in a sound projector. It is essential that the film pass the scanning beam at a very uniform speed if variation in pitch (flutter) of the reproduced signal is to be kept at a minimum. When it is considered that the motion of the film must be changed from an intermittent movement of 24 frames per second at the picture aperture to a constant speed at the scanning beam, it is obvious that the mechanism must be of excellent design. Various devices have been designed to keep the film moving uniformly as it passes the scanning beam. Such devices range from simple flywheels and damping rollers to rather elaborate mechanisms which aid in smoothing out the inevitable fluctuations in film travel.

Although the several processes through which the signal must course as it changes from one kind of energy into another may seem relatively simple, to approach perfection in reproduction of the original signal it is vital that each of these processes be well engineered. Any one link in the chain of components which is poorly designed or is in maladjustment can cause an otherwise superior projector to be rated as poor.

III. PERFORMANCE CHARACTERISTICS AND TEST METHODS

1. GENERAL

Of greatest interest in the performance of the sound-reproducing system is over-all performance, which may be described briefly as the characteristics of the sound output from the loudspeaker in terms of a known and specified film record. It is the final result that reaches the listener as an audible signal from the loudspeaker when a signal is impressed upon the sound-reproducing system by the sound film.

By over-all performance we refer, in particular, to frequency response; harmonic distortion; volume of sound; signal-to-noise ratio, or dynamic range; freedom from flutter; and noise of the operating mechanism of the projector, all measured under specified operating conditions and from a specified film record.

Unfortunately, at the present time it is difficult to specify the desired over-all performance for several reasons. First, we are none too sure what is desirable, although we do have information available from related fields, such as the performance of 35-mm equipment in theaters, of radio-broadcasting equipment, and of equipment for high-quality reproduction of phonograph records. Second, because of the decided lack of uniformity in the recording and printing processes, it is difficult to prescribe performance characteristics for projectors that will produce uniform and generally acceptable results. Third, there are few, if any, accurately made 16-mm sound-test films available. Fourth, it is difficult to specify loudspeaker performance, and fifth, the acoustic test measurements are not easily made. Because of this situation, only a few direct measurements of over-all performance are given in this report. Because of these existing conditions it is necessary to specify the performance and make tests of each of the several components of the sound-reproducing system. It is possible then to compute some of the over-all characteristics.

The following information has been prepared to form a background for suggested performance characteristics and proposed requirements for high-quality sound-reproducing systems on 16-mm projectors. These suggestions are intended to serve as a guide in making tests of recent models of 16-mm projectors that have been sold to school boards and other educational groups. However, since 16-mm sound-test films are not available at present for many kinds of tests, it is somewhat difficult to state simple and yet rigid requirements that would obtain equipment with the highest quality performance.

Practical test methods and necessary facilities are outlined. Most of the tests conducted in this investigation could be duplicated by a large school organization that has the facilities of a physical or electrical engineering laboratory, particularly one equipped to make measurements of radio equipment. Objective measurements of the loudspeaker require the use of a sound-level meter, an instrument which is coming into wide use today for noise-level measurements.

2. OVER-ALL PERFORMANCE

It has been found advisable to introduce the subject of over-all performance at the beginning of this discussion and then follow with the characteristics of the several components. With this approach, the reader may familiarize himself with the general requirements for reasonably good reproduction of speech and music and the specific requirements for 16-mm projectors. Wherever possible, practical testing methods have been devised and are described.

(a) RESPONSE-FREQUENCY CHARACTERISTIC

It is considered that the response-frequency characteristic of the complete system is the most important single measurement to be made in determining over-all performance. However, sound-pressure measurements are involved with accompanying difficulties. In this investigation, the response-frequency characteristics of the loudspeaker and of the remainder of the system have been measured separately, the over-all performance calculated from the two sets of data and shown as a single curve.

In view of the somewhat limited frequency range of 16-mm projectors compared with 35-mm equipment or other sound-reproducing systems, the question arises as to what the specified limits of frequency range should be. It is well known that a high-quality reproducing system should cover a frequency range of at least 60 to 10,000 c/s. Fletcher [3, 4] has shown that between 90 and 95 percent of spoken syllables may be understood by using a range of 500 to 5,000 c/s. This corresponds to a geometric mean frequency of approximately 1,600 c/s. Intelligibility of reproduced speech is much more dependent upon the middle and the higher ranges of frequencies than on the lows. However, the lower frequencies lend naturalness to the reproduction.

Reproduced music requires a much greater frequency range than speech. Snow [5] has shown that 75 percent of the original quality is retained if the frequency range of the system is 125 to 5,000 c/s, 83 percent for a range of 100 to 6,000 c/s, and 92 percent for a range of 80 to 8,000 c/s. These frequency limits, or what may be termed the cutoff frequencies, when multiplied give a product of approximately 625,000, or a geometric mean frequency of 790 c/s. Hilliard [6] has stated that for ideal balance the product of the two cutoff frequencies should be close to 400,000, or a geometric mean frequency of 630 c/s. The difference in these somewhat empirical numbers, 400,000 and 625,000, is probably due to several causes, one of which might well be personal preferences on the part of a jury that has been conditioned to listening to reproduced music [7]. If the range is extended toward lower frequencies without extending the high-frequency range (this is the effect if a balance is made giving a product nearer 400,000), the effect is to produce a "mellow", or less brilliant tone. If greater prominence is given to the high frequencies, the tone is "thin" and "lacks body." In either case, the resultant effect does not sound natural.

To summarize, the frequency range should be as great as possible and the extreme high and low regions should be in some balance. In many sound-reproducing systems, including 16-mm projectors, the decrease in response near these extreme regions is usually quite gradual and is not marked by sharp cutoff. Nevertheless, the response-frequency characteristic can be specified, with approximation, in definite limits of response and frequency.

Since reproduction of speech is given first consideration in this discussion, another factor should not be overlooked. Greater intelligibility is possible if there is a gradual decrease in response of the system below 300 to 500 c/s and even more so if the response begins to fall off below 1,000 c/s. In the latter case, the loss in naturalness becomes very apparent, and for best results a compromise must be made. In many transmission systems where intelligibility is of prime importance, naturalness is usually sacrificed, particularly if low-frequency background noise is high. It is of doubtful value, however, to adjust the response of a 16-mm system to the extent that much of the naturalness is lost. The observer senses the loss and is usually quite conscious that something is lacking in the equipment. Moreover, naturalness of music is affected to even a greater extent than is speech by loss in response below 1,000 c/s. At present there is no common opinion among designers of 16-mm equipment as to the permissible or desirable extent of the reduction in response in the low-frequency range.

At present it is difficult to extend the frequency range of 16-mm equipment much above 5,000 c/s, and since this allows for good reproduction of speech, it probably represents a practical specified upper limit. To balance the reproduction of music against this upper limit, it is suggested that a frequency of 150 c/s be used as a specified lower limit. Using Snow's data, a frequency of 125 cycles would be the optimum low-frequency limit for music, but is not easily obtained because of the larger baffling necessary on dynamic speakers. (It should not be overlooked that there are methods of increasing the response at low frequencies other than merely increasing the size of the baffling.) Other properties of the radiation of low frequencies from a loudspeaker are discussed in the section on loudspeakers.

No mention has been made of variation and limits of response within prescribed frequency limits. It is generally accepted that uniform or flat response within certain frequency limits is the most desirable response of a sound-reproducing system. This assumes, of course, that harmonic distortion is low, that the signal-to-noise ratio is high, and that acoustical conditions are satisfactory. For projection equipment, the quality of recordings must also be taken into consideration. Since some of these conditions cannot easily be kept under control, provision is made in projection equipment for altering the response-frequency characteristic of the system. This subject is discussed at greater length in the section on tone control.

Except for high-frequency loss caused by the scanning beam, practically all other variations in response that may and usually do occur are caused by the loudspeaker. This phase of the subject can be treated best under the subject of loudspeaker performance and the reader is referred to that section.

It is the opinion of the writer that within the frequency limits of 150 to 5,000 c/s the over-all response-frequency characteristic of the sound-reproducing system should not show variations greater than 10 decibels (db) under certain specified test conditions. With a tone control having the characteristics described in this paper, it should be possible to reduce the response below 300 to 500 c/s to increase the intelligibility when operating under adverse acoustical conditions. However, as an additional measure, it is suggested that the response decrease gradually below 300 to 500 c/s.

In addition to the total variation within the frequency range considered, the smoothness of the response curve is important. It is the opinion of the writer that, within the frequency range of 150 to 5,000 c/s, variations of the response-frequency characteristic greater than 5 db should not occur within frequency intervals of one-half octave or less. Variations of the response-frequency characteristic greater than 7 db should not occur within frequency intervals of one octave or less.[2] The above characteristics are considered to be determined by measurements taken on the axis of the loudspeaker (0° azimuth angle) and at a 15° azimuth angle.

The over-all response-frequency characteristic was not obtained by direct measurement. Because of the lack of suitable test film for making such measurements, it was necessary in this investigation to determine the over-all response-frequency characteristic in terms of the response taken separately of the loudspeaker and the amplifier, including phototube and scanning beam.[3] A power-input level of 1 watt to the loudspeaker at 1,000 c/s was used as a reference level. Pressure-level measurements were made with the microphone placed

[2] The reader is referred to the section on loudspeakers for a discussion of the smoothness of response.

[3] It is necessary to introduce the response-frequency characteristics of the amplifier and loudspeaker at this point. The reader is referred to the sections on amplifier and loudspeaker for a detailed account of these characteristics.

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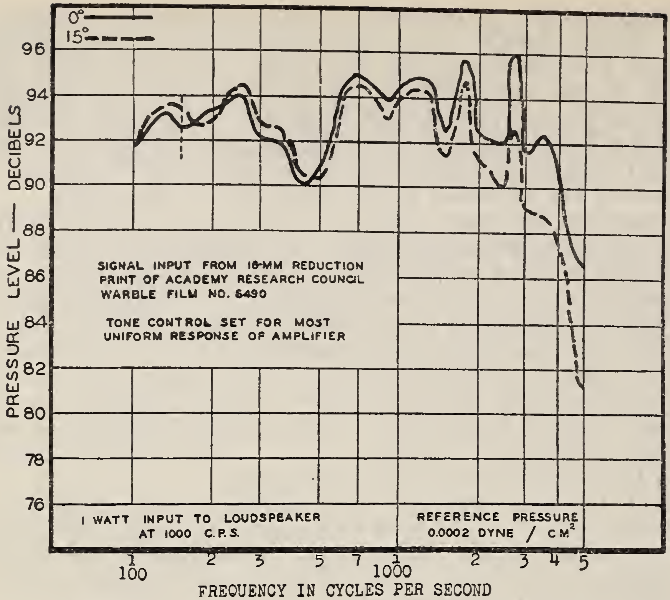

FIGURE 2.—*Over-all response-frequency characteristic of projector sound-reproducing system.*

Projector *A*.

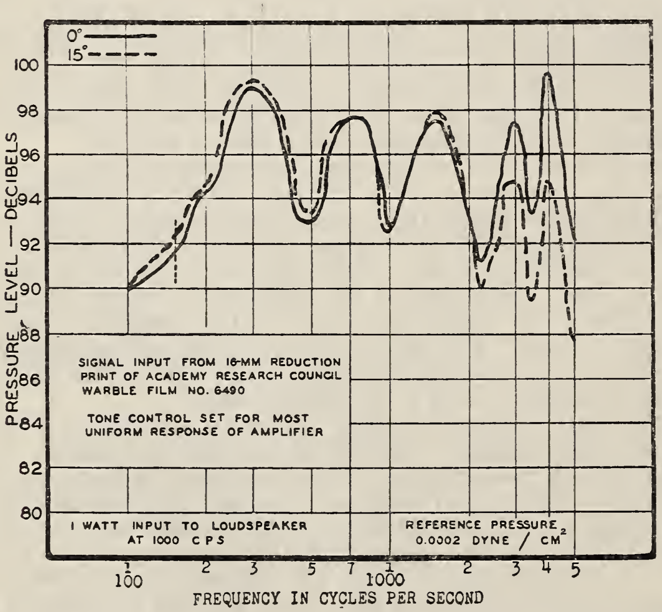

FIGURE 3.—*Over-all response-frequency characteristic of projector sound-reproducing system.*

Projector *B*.

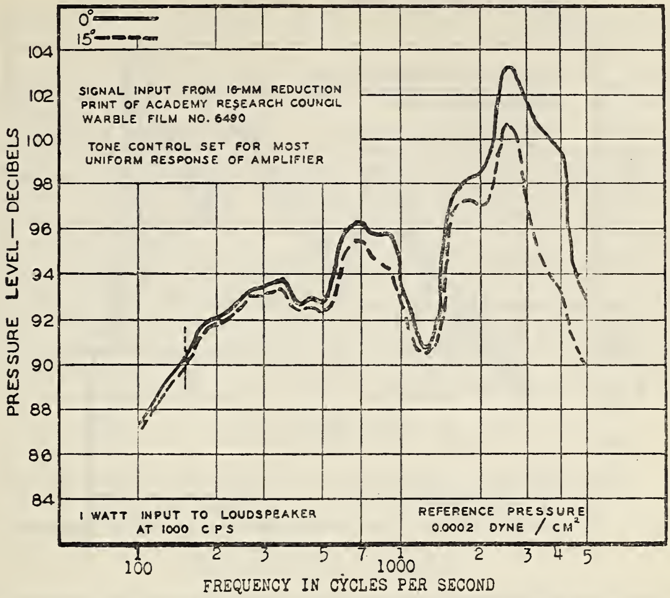

FIGURE 4.—*Over-all response-frequency characteristic of projector sound-reproducing system.*

Projector *C.*

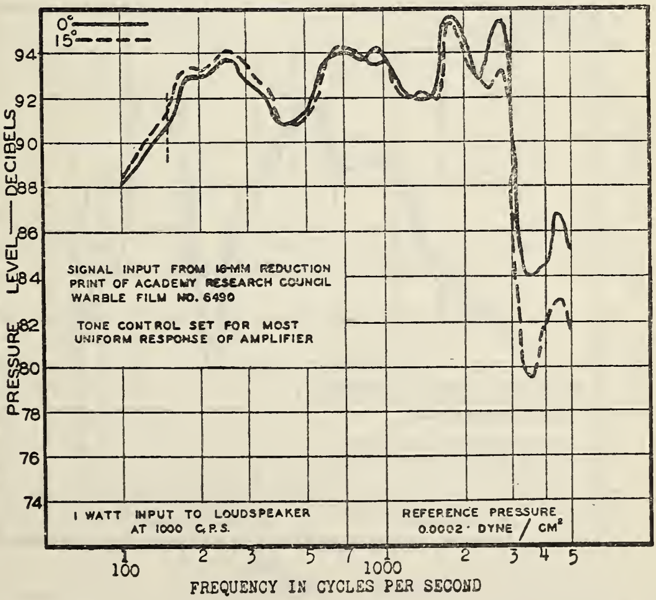

FIGURE 5.—*Over-all response-frequency characteristic of projector sound-reproducing system.*

Projector *D.*

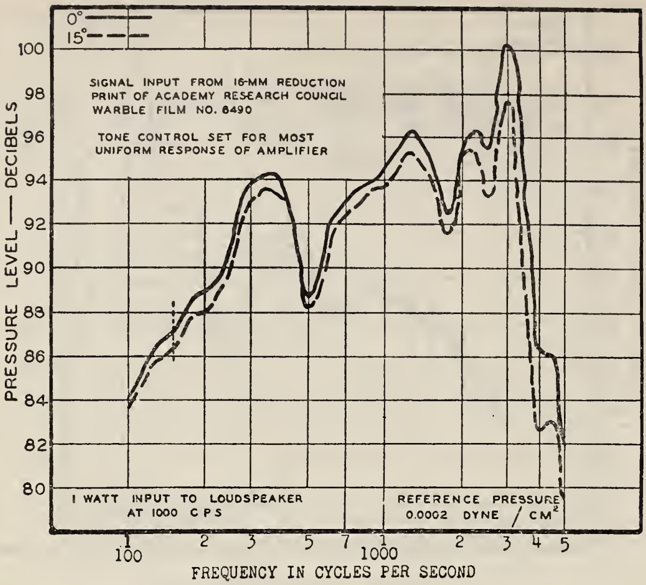

FIGURE 6.—*Over-all response-frequency characteristic of projector sound-reproducing system.*

Projector *E*.

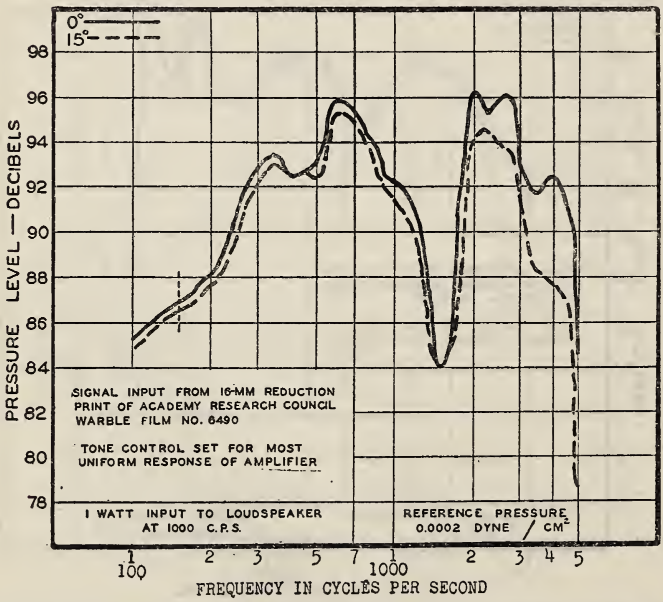

FIGURE 7.—*Over-all response-frequency characteristic of projector sound-reproducing system.*

Projector *F*.

5 feet in front of the front grille of the loudspeaker. The results for six projectors tested during this investigation are shown in figures 2 to 7.

Two features of the response curves should be studied—first, the total variation within the frequency range considered, and second, the smoothness of the response.

To simplify the process of reading the curves to determine wherein the response did not comply with the above proposals of performance, three pieces of bristolboard were cut with windows of varying size. The first was cut large enough so that when laid on the response curve the edges parallel to the ordinate permitted the curve to be viewed just within the frequency limits of 150 and 5,000 c/s, whereas the edges parallel to the abscissa were exactly 10 db apart. Thus if the response curve did not come within the window area, the equipment did not meet the proposed recommendation. The second and third pieces were of such sizes that the edges parallel to the ordinate

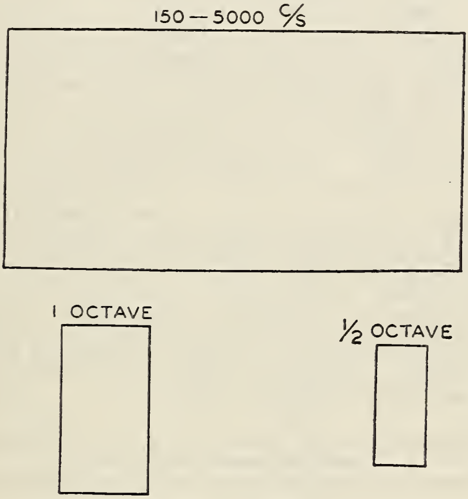

FIGURE 8.—*Suggested form of windows for observation of loudspeaker response-frequency characteristic.*

were one-half and one octave apart, respectively, and the edges parallel to the abscissa were 5 and 7 db apart, respectively. Thus if the response curve within these frequency intervals crossed the upper and lower edges of the window area, the curve was of such shape that the equipment did not meet the proposed recommendation. Drawings of these window areas are shown in figure 8.

Only two of the six projectors met any of the proposed requirements of the over-all response-frequency characteristic. However, it is believed that the requirements are not too severe. It should be remembered that two important functions are involved which affect the over-all response to a greater or lesser degree. These are the scanning beam and the radiation of sound by the loudspeaker, and in combination their effects may be augmented or diminished.

In some cases the loss at high frequencies is very pronounced and is definitely due to loss of high frequencies by both the loudspeaker and the scanning beam. There is much room for improvement in the increase of response at high frequencies ranging up to 5,000 c/s. Four out of six of the projectors showed a marked decrease in response beginning at about 3,000 c/s. Several of the projectors showed pronounced irregularities in the middle frequency range from 500 to 3,000 c/s. These were due entirely to the characteristics of the loudspeaker.

(b) HARMONIC DISTORTION

In many systems, when energy is transmitted through a medium, or when a signal is amplified (or attenuated) or is changed from one form of energy into another, the system may give rise to distortion due to nonlinear response. That is to say, the output or response is not directly proportional to the input, or driving, force. When energy is transmitted through such a system in the form of sinusoidal variations, the result is to produce multiples of the impressed frequency and is commonly known as harmonic distortion. If present to any considerable extent, these extraneous frequencies will sound unpleasant, and the signal will lose much of its original quality.

For any given harmonic frequency the distortion is defined as the ratio, expressed in percent, of its amplitude to the amplitude of the fundamental frequency. Total harmonic distortion is defined as the ratio, expressed in percent, of the total harmonic amplitude (root-mean-square value) to the amplitude of the fundamental frequency.

Establishing a criterion for permissible harmonic distortion in a sound-reproducing system has been for the most part a rather arbitrary procedure. Few investigations have been made to determine the subjective elements of harmonic distortion. Several years ago Massa [8] studied the several detectable changes in quality of reproduced speech under controlled conditions of harmonic distortion. Table 1 of Massa's paper is given here.

Table 1.—*Percentage of harmonic necessary to produce a detectable change in the quality of reproduced speech*

Cutoff frequency of system	Directly comparing distorted reproduction with undistorted reproduction		Without comparison against undistorted reproduction	
	Single-tube overloading (2d harmonic predominant)	Push-Pull overloading (3d harmonic predominant)	Single-tube overloading (2d harmonic predominant)	Push-Pull overloading (3d harmonic predominant)
	%	%	%	%
14,000	5	3	10	5
8,000	5	5	10	7
5,000	12	>10	17	>10

Note 1.—The measurements were made on several speakers (3 male and 2 female). The values given above represent the minimum distortion required to produce a noticeable change in quality and are representative of 1 speaker rather than an average value for several speakers.

Note 2.—The percentage of harmonic distortion for speech or complex audio signals in the system is defined as the amount of harmonic distortion produced by a pure tone having a peak value equal to the peak value of the complex wave.

It will be noted that even under conditions of direct comparison of distorted reproduction of speech with undistorted reproduction and with a wide-range frequency channel, harmonic distortion in any form is not easily detectable when less than 5 percent. Therefore, as an over-all performance, it would be very satisfactory if the total harmonic distortion did not exceed 5 percent, and even 10 percent would not be noticeable under many conditions. Harmonic-distortion measurements of an amplifier are easily made if working from an electric oscillator as a source of audio-frequency current. Since the scanning light beam (sound-optical system is a source of considerable harmonic distortion, it is very desirable to make tests, using film as a signal source. However, no satisfactory film is now available for this purpose. Harmonic-distortion measurements of loudspeakers present a formidable problem. The subject is discussed further in the section on loudspeakers.

No attempt was made to measure the over-all harmonic distortion. Harmonic-distortion measurements of the amplifier are included in this report.

(c) VOLUME OF SOUND

Reproduced sound in a classroom or small auditorium must be great enough in volume so that all persons with normal hearing can listen without effort. This implies further that sound is well distributed throughout the room. In many instances the masking effects of room noise must be overpowered to make the reproduced speech intelligible without undue effort on the part of the listener. For this purpose it is necessary to have a reserve of undistorted sound output available in the system.

Tests made over a period of several years indicate that recent models of 16-mm projectors will give a reasonably undistorted sound output of speech and music at sound levels ranging from 85 to 95 db above a reference level of 10^{-16} watts per cm ^{2} when measured 10 feet in front of and on the axis of the loudspeaker. Such tests should be conducted in a room with negligible wall reflections or in an open space out-of-doors. Measurements should be made at least at frequencies of 300, 500, 1,000, 2,000, and 3,000 c/s, and the arithmetic mean of the several sound levels in decibels taken as the indicated sound level. To determine the operating level, the volume control is set just below the threshold of noticeable harmonic distortion or other evidences of overloading as determined by listening, using all parts of a 16-mm reduction print of a standard SMPE 35-mm sound-test reel.[4] Such a test probably leaves much to be desired, since it is dependent upon a subjective determination of harmonic distortion. Since no measurement of harmonic distortion, either subjectively or by instrument, was made of the loudspeakers, therefore no data were obtained in this investigation on the volume of sound as an over-all performance. The subject is worthy of careful consideration in the future.

Such a test as outlined above would, however, be indicative of the power output or power-handling capacity of the complete sound-reproducing system, including sound radiation from the loudspeaker as determined by limits of noticeable or objectionable distortion. The test would minimize the importance of power output of the amplifier and efficiency of the loudspeaker and give more weight to over-all performance, which is considered to be more significant than performance of individual components. However, this should not imply that performance of the components is to be ignored, since some of the

[4] This is the only film generally available that is suitable for this test. It is believed that a film could be produced which would be more suitable.

operating characteristics of these parts of the equipment must, by necessity, be measured as separate items.

Results of previous investigations have shown that, in general, the loudspeaker rather than the amplifier has been the limiting factor in the resultant distortion at high operating levels. Very few, if any, 16-mm projectors are equipped with loudspeakers designed to operate without production of considerable harmonic distortion and other extraneous sound at the higher operating levels of the associated amplifiers.

(d) SIGNAL-TO-NOISE RATIO, OR DYNAMIC RANGE

Although the signal-to-noise ratio as an over-all characteristic more nearly represents actual listening conditions, the measurement presents a difficult problem, since sound-pressure measurements are involved. At present, the only practical method is to determine the signal-to-noise ratio of the amplifier, including the scanning beam. The method of measurement is discussed in the section on amplifiers.

(e) NOISE OF OPERATING MECHANISM

It is a general observation that all 16-mm projectors are quite noisy, and some may be rated as being objectionable. Seldom is a 16-mm projector placed in a booth, as is 35-mm equipment, and it is difficult to insulate against the operating noise produced by the projector mechanism. Attempts have been made to reduce the noise by using "blimp" cases or the regular carrying case, but the results have been none too good. Not until an intensive effort is made by manufacturers to reduce materially the noise at all sources will there be any marked reduction in the operating noise of portable 16-mm projectors.

In the usual situation a 16-mm projector is placed in such a position that the audience surrounds it or is just in front of it. Often a part of the audience will be not further removed from the projector than is the operator. Under such conditions the noise level of the projector will approximate the sound level of the less intense speech sounds emitted by the loudspeaker and will have a decided masking effect upon the very important consonant sounds which make for intelligibility of speech. Thus arises the importance of reducing the operating noises.

Examination of projectors indicates that the principal sources of noise are the fan, or blower, blades, rapid movement of air through small openings or across sharp edges, gears, drive motor, the intermittent, and the various parts of the film-moving mechanism. It cannot be overemphasized that no great improvement will be obtained until each of these sources of sound is reduced to a common noise level, which is very much lower than the noise level of present-day projectors.

Strictly speaking, another factor must be taken into account with reference to the general term of noise level. The quality of a noise as determined by the relation and distribution of frequency components, variations with time, and such other characteristics as identify a specific noise is not, at present, a measurable quantity. It has been called the annoyance factor, and is that quality which one ascribes to a noise which makes it seem more objectionable than another noise. As yet this annoyance factor has not been evaluated in terms of comparison data, nor have objective methods of measurement been feasible. Experience has shown that most 16-mm projectors produce noise levels that fall within a narrow range, and to differentiate between these narrow limits on the basis of noise levels only may not always be a fair evaluation of the operating noise of projectors. Only judgment by an experienced jury would be fair under these circumstances. A maximum noise level with liberal tolerance and measured under specified conditions must suffice for the present. Noise-measurement technique is relatively new and is in a state of development.

For noise-level measurements of projectors it is suggested that the recommended practice given by the American Institute of Electrical Engineers [13] be followed as far as practicable. Many pieces of apparatus, however, require special consideration and this is true for projectors. After due consideration, it is proposed that the picture gate, or aperture, be used as a reference position for determination of microphone placement. This particular part of the projector is selected because it is common to all projectors, is in a well-defined position, is somewhat centrally located, and is adjacent to the intermittent, which is a primary source of noise. It would be difficult to specify microphone placement relative to the face of large surfaces, since projectors have very irregular surfaces except when mounted in a carrying case. Although the choice of microphone distance may be somewhat arbitrary, there are certain limitations which must be observed. If the distances were too small, it might be impracticable to place the microphone at some locations because of an obstruction on the projector. Too short a distance from a source of noise would give measured noise levels much higher than experienced by a person in the immediate vicinity of the projector. Also, there may be a very pronounced sound pattern just adjacent to the surfaces of the projector. At too great a microphone distance the measured levels may be affected by wall reflections, particularly if the measurements are not made in an acoustically dead room. Considering all of these factors and following the A.I.E.E. Test Code, a microphone distance of 3 feet from the picture aperture is suggested.

The choice of exact microphone positions is dependent upon the symmetry of sound pattern around the projector, which, in turn, will determine the fewest possible number of positions necessary to obtain a statistical average. Experience shows that eight positions separated by intervals of 45-degree angles in a horizontal plane passing through the picture aperture is satisfactory. A reference position can be taken in front of the projector on a longitudinal axis through the picture aperture.

The choice of the response curve to be used on the sound-level meter [14] is subject to argument and will not be discussed in this paper. However, the 40-db response (curve A) probably has several advantages.

Results have indicated that if the noise level of a projector is measured in accordance with the above suggestions, a maximum level of 65 db would include all projectors tested in the investigation. On the basis of present-day performance, the operating noise of none of these projectors would be considered objectionable by most observers. On the other hand, none can be called quiet in operation. In view of some of the foregoing discussion, a maximum limit of 65 db is proposed for the present.

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(1) *Test method.*—The measurements were made in a room 16 feet by 16 feet by 12 feet high with negligible wall reflections. The projector was mounted on a small stand near the center of the room in such a manner that it could be turned about a vertical axis which passed through the picture aperture. The microphone was placed 3 feet from this vertical axis and in a horizontal plane passing through the picture aperture. Eight microphone positions in this horizontal plane were chosen, separated by intervals of 45 degrees from a reference position in front of the projector and on a longitudinal axis which passed through the picture aperture. This reference position was called microphone position 1.

A sound-level meter meeting the requirements of the American Standards Association [14] was used to make the noise measurements. All measurements were made at the curve *A* setting of the meter, corresponding to an equal loudness contour of 40 db.

The projectors were operated with a 1,600-foot reel of film. All projectors were operated at sound speed of 24 frames per second. One projector was also operated at silent speed of 16 frames per second to compare the noise levels at the two operating speeds. If the projector was housed in a carrying case, all doors but the small control door and projection-lens door were closed.

A very limited number of frequency analyses were made of the projectors to study the frequency distribution of the noise. The noise levels of projectors *B*, *C*, *E*, and *F* are given in table 2.

TABLE 2.—*Noise of operating mechanism*

Projector	Noise level, in decibels, above reference level of 10^{-16} watts per cm² at different microphone positions								
	0° (front of projector)	45°	90°	135°	180° (rear of projector)	225°	270° (operating side of projector)	315°	Average noise level
B	61.4	61.8	62.8	64.1	64.6	63.4	64.4	62.4	63.1
C:									
(Control door open)	62.6	63.8	63.8	63.8	61.1	62.1	62.8	62.1	62.8
(Main door open)	61.1	61.6	62.6	62.8	63.4	64.6	65.6	63.8	63.2
(Operated at 16 frames per second, control door open)	57.6	58.6	60.1	59.1	58.1	58.1	57.8	57.1	58.2
E	62.8	62.8	62.8	63.4	63.8	63.8	63.8	63.8	63.4
F	61.1	61.6	61.4	62.1	61.8	62.4	60.8	60.6	61.5

It was surprising to find that the noise levels of the projectors tested came within the narrow range of 2 db. The range of operating noise level was found to be so limited that one would hardly be justified in differentiating between the relative degrees of quietness (or noise) of the several projectors on the basis of sound-level-meter measurements only. It is from this viewpoint that the suggestion has been made that a maximum limit of 65 db be set for the operating noise level of projectors measured under conditions described herein. All projectors tested were found to have noise levels more than 1.5 db below this maximum. Until further developments are made in the field of noise measurements, it will hardly be possible to specify anything else than a maximum limit of 65 db.

As might be expected, the noise level differs to some extent at the eight microphone stations. The greatest difference was found for projector *C* (designed for operation in a carrying case) when the main door of the case was opened. Here the noise level on the operating side was 4.5 db greater than on the opposite side, which was shielded by the carrying case. No great difference in the noise level averaged over the eight microphone positions was found when the main door was open or closed, the difference being only 0.4 db. One might expect the difference to be greater, since opening the main door allowed sound to radiate from an open area as large as the side of the carrying case. To an observer on the operating side the noise seems to increase noticeably as the door is opened. A frequency analysis showed a marked change in distribution of sound energy as the door was opened, thus confirming an observed change in quality of the noise. With the main door closed, the high-frequency components of the projector noise were reduced considerably, although measurements with a sound-level meter indicated very little reduction in the total noise. It is, to a great extent, the reduction of high-frequency components of a noise that makes for reduced annoyance and for better listening conditions. Any measures taken to reduce the high-frequency components, such as surrounding the mechanism with a case, reduction of air speed or smoother operation of the moving parts, will produce the effect of quieter operation.

A change of speed of projector *C* from 24 to 16 frames per second showed a decrease of 4.6 db in the average noise level. No measurements were made of other projectors, but it is believed that the reduction would have been approximately the same amount.

3. FLUTTER

A factor of importance in the recording and reproducing processes of speech and music is uniform speed of the record material or sound track, whether it is a phonograph disk, film record, magnetic tape, or any other type of recording. Many unique mechanical and electrical devices have been designed to attain uniform speed of the recording material. The problem is particularly difficult in projection equipment, where, within a very short distance, it is necessary to change from an intermittent movement of the film of 24 frames per second at the picture aperture to a uniform speed at the scanning beam.

The variation of film speed allowable to reduce noticeable variations in pitch of recorded pure tones to a negligible amount is a function of the rate of change of speed, of the frequency of the tone, of the loudness level, of the acoustical environment, and of other listening conditions of the reproduced tone. This has been shown by Shower and Biddulph [9] and others. Wente, Biddulph, Elmer, and Anderson [10] have referred to an unpublished memorandum by W. A. McNair, which gives the minimum perceptible speed variations for sustained tones. Although the values given are extremely small, being only 0.0045 percent for a flutter frequency of 9 c/s, the comment is made that "it is known that, for complex tones ordinarily recorded when reproduced in a moderately dead room, these minimum perceptible speed variations can be exceeded without detection." Albersheim and MacKenzie [11], in referring to the work of Shea, McNair, and Sebriz [12], showed that trained observers listening to pure tones in live rooms were able to notice speed variations as low as 0.005 percent in a 3,000-c/s tone at the rate of 1.5 c/s. However, if the same tones were heard through headphones, the speed variations, or flutter, could be increased one-hundredfold before being perceptible. Fortunately, the ear is quite tolerant of variations in pitch (flutter) caused by variation in film speed of speech recordings. Thus the requirement for extreme constancy of film speed is lessened for ordinary use of projector equipment.

Albersheim and MacKenzie [11] have given as criteria for good performance the following flutter limits for sound heard in a theater: 0.25 percent at flutter rates above 25 c/s, 0.15 percent at flutter rates between 25 and 1 c/s, and an allowable increase in the amount of flutter inversely proportional to the square root of the frequency for frequencies below 1 c/s. Rates of flutter below 1 c/s are associated with a sense of "drifting" of the pitch.

Experience has shown that if the flutter is less than 0.3 percent as measured on an RCA flutter indicator, the performance is quite acceptable if the observer is not too critical of flutter that would be noticeable only in sustained passages of music. However, very few, if any, 16-mm projectors will operate consistently within a limit of 0.3 percent. For the present, a more liberal requirement of flutter will be necessary and a maximum limit of 0.5 percent as determined on an RCA flutter indicator is suggested. As the art advances it may be desirable to specify maximum limits of flutter for several ranges of flutter frequency, since the limit of tolerance by the ear is dependent upon the flutter frequency or rate of flutter.

(a) TEST METHOD

The RCA flutter indicator is a commonly used instrument for measuring the magnitude of flutter. It consists essentially of a bridge circuit which is tuned to balance at 3,000 c/s. The instrument is furnished with a 35-mm test film of 3,000 c/s, which is recorded with extreme care. For this investigation a 16-mm reduction print was obtained which showed but little evidence of irregularities due to the reduction process.

In use, the impedance terminals of the flutter indicator are connected to the output terminals of the amplifier, and the test film is run through the projector. Certain adjustments must be made of the indicator before a reading can be taken. The film-moving mechanism should be operated for about 5 minutes before making the tests, since any mechanism tends to run more smoothly after a few minutes of operation.

The pointer on the indicator meter does not remain at rest during a measurement. This is due not only to variations in film speed, or flutter (sometimes called frequency modulation), but may also be due to actual amplitude modulation. Amplitude modulation may be caused by lateral weave of the film as it passes the scanning beam and irregularities in the density and other properties in the film. If these irregularities are present, amplitude modulation will occur even when the film is moving with absolutely constant speed. It can be read when the indicator is set to the "calibrate" position. Usually the effect is not large, and can be ignored. If amplitude modulation should be large, it may mask, at least in part, the reading of flutter.

Measurement of flutter taken with the RCA flutter indicator is indicated as the total magnitude of change in frequency above and below 3,000 c/s, and is expressed in terms of the percentage change in frequency.

As one observes the irregular movements of the pointer when measuring flutter there is usually a well-defined minimum limit to the excursion of the pointer which, more often than not, is an indication of the percentage of flutter due to high-frequency flutter caused by sprocket-hole modulation. There is a less-defined maximum limit as the pointer is thrown up at irregular intervals. These violent fluctuations may be attributed to several causes. It is also possible to estimate an average position of the pointer. All three of these positions were recorded for the tests. The difference between the maximum and minimum positions gives an approximation of the percentage of low-frequency flutter.

It is not only possible to measure the magnitude, or percentage, of flutter, but to a limited extent to determine the frequency at which low-frequency flutter, or "wow," occurs. This can be done by observing the frequency of fluctuations of the pointer. Readings or estimates can be made only for frequency of flutter somewhat less than one-half of the resonance frequency of the pointer and moving coil. Because of the design characteristic, the frequency of flutter is one-half the frequency of changes in the pointer position. Aural observations can also be made by listening to the reproduced tone. Critical listening by an experienced observer to regular film recordings will often yield an approximation of the magnitude of flutter, and the quality of the sound may indicate the source of the variation in film speed.

Table 3 gives the results of flutter measurements or an indication of the constancy of film speed at the scanning beam.

All the projectors showed slight variations in amplitude as the test film traveled through the projector. Since the magnitudes of variation were very nearly the same, it was possible that the disturbance was caused by irregularities in the film.

TABLE 3.—*Flutter measurements*

Projector	Amplitude modulation (measured on 2% scale)	Percentage of flutter			Frequency of flutter and aural observation
		Lower limit	Upper limit	Average	
A	1.55 to 1.65	0.4	1	0.6	Noticeable flutter by aural observation. Rather violent fluctuations of various periods on occasion.
B	1.55 to 1.65	.3	1.2	.45	Noticeable flutter by aural observation. Violent fluctuations of various periods on occasion.
C	1.55 to 1.65	.25	.45	.33	Long period fluctuations of approximately one second.
D	1.55 to 1.65	.7	1.4	.85	Noticeable flutter of various periods by aural observation.
E	1.55 to 1.65	.4	1.2	.7	Noticeable flutter by aural observation.
F	1.56 to 1.62	.45	.62	.53	Noticeable flutter by aural observation.

Only projector *C* gave readings of flutter that were consistently less than 0.5 percent, the average being 0.33 percent. Although this was the lowest reading of flutter encountered in the investigation, the flutter was, nevertheless, noticeable by aural observation. The period of noticeable flutter was approximately 1 sec, which was rather long as compared with that of the other projectors.

Although projectors *A* and *B* gave average readings of flutter around 0.5 percent, they showed violent fluctuations at times, reaching upper limits of 1 percent or more. These fluctuations had no particular periodicity, and were quite noticeable by aural observation.

The results of these flutter measurements indicate that an average reading of 0.5 percent is not unreasonable. Two projectors came within this limit, and another was but slightly in excess of the limit.

4. AMPLIFIER AND SCANNING BEAM (SOUND-OPTICAL SYSTEM)

As stated previously, until better test procedure is available, it will be necessary to make several of the tests of over-all performance in terms of the performance of the amplifier and associated equipment. The various operating characteristics of an amplifier are determined by introducing an alternating-current signal of known properties at the input terminals of the amplifier and measuring the voltage or power developed across the output, which is usually terminated with a resistive load. The properties of the scanning beam or sound-optical system may be obtained by several experimental methods.

(a) GENERAL

(1) *Scanning Beam.*—When consideration is given to the over-all response-frequency characteristic of 16-mm projectors, it is found that the properties of the scanning beam are a definite "bottleneck" in the system. At some point along the film-moving mechanism the film must pass a stationary light beam which scans the sound record. Several methods have been used to accomplish this, but, in short, they amount to using a beam of light very narrow in width at the point where it passes through the emulsion side of the sound record. The narrow width of the beam is produced by a slit which is 0.0013 inch in width in the case of 35-mm equipment, and approximately 0.001 inch in most 16-mm projectors.

In theory, the light beam as it scans the sound record should be negligible in width in comparison with the high-frequency modulations of the sound track if it is desired to reproduce high frequencies without loss and to reduce harmonic distortion to a minimum. In practice, this is, of course, difficult to approach. Furthermore, consideration must also be given to the signal-to-noise ratio in the phototube circuit, since this ratio decreases for smaller widths of the slit image, all other factors remaining the same. Unfortunately, the loss of high frequencies caused by the finite width of the scanning beam is aggravated in 16-mm projectors by the slower film velocity (36 feet per minute compared with 90 feet per minute for 35-mm projectors).

Several methods of reducing the loss of high frequencies by the scanning beam suggest themselves. A moderate decrease in loss can be obtained by using smaller widths of the slit or focusing to a narrower slit image, thereby obtaining a smaller width of the scanning beam (other factors being taken into consideration). The use of ultraviolet light or monochromatic light would improve the situation to some extent. Warping of the response-frequency characteristic of the amplifier by increasing the response of the high frequencies suggests itself, but this is accompanied by greater noise levels in the high-frequency range. Probably the best result would be obtained by recording the high-frequency components of the signal at higher levels than is the present practice. This latter method has the advantage of increasing the signal-to-noise ratio in the high-frequency range.

A combination of these methods would certainly be an improvement over the present situation, although some degree of standardization of procedure would be necessary for uniform results.

(2) *Amplifier.*—The amplifier will be considered to consist of the phototube and accompanying circuit, voltage amplifier stages, power-output stage, rectifier circuit, and all accompanying controls. Today the exciter lamp and its power supply are an integral part of the amplifier circuit, and should also be considered a part of the amplifier. Since the amplifier incorporates many parts and serves several functions, it will be necessary to explain the detailed requirements. Inasmuch as test films are not available today to make all desired tests, and since loudspeaker testing presents difficulties, we must resort to making at least some tests on the amplifier, treating it as a separate unit.

The writer has found on numerous occasions when testing amplifiers in 16-mm equipment that the test procedure was complicated by lack of information on the intended operating conditions. For certain tests it is necessary to specify the exact position of the tone control and other adjustments which affect the operating characteristics. Another important item is the value of the resistive load which is used to simulate the loudspeaker load for test purposes. Measurement of the impedance of the loudspeaker voice coil will give an indication of what the resistive load should be, but the result is not always in agreement with the manufacturer's design load. Two factors which cause this disagreement are variation in impedance of the voice coil among individual loudspeakers of otherwise identical construction, and the change in ohmic resistance of the voice coil as it is heated by the voice-coil currents during operation or by the field coil when an electromagnetic field is used. The increase in d–c resistance due to temperature rise was found to be as high as 10 percent.

For the tone-control adjustment, it is possible to determine by experiment the position for obtaining the most uniform response-frequency characteristic, but this entails extra work. It is suggested that when tests of equipment are to be made, the manufacturer should state the exact position of the tone control and other adjustments to give such operating characteristics as may be specified. Usually the amplifier is tested for the condition of most uniform response. For tests that require the use of a resistive load, it would be well for the manufacturer to state the resistance of his design load.

Amplifier performance is affected to a limited extent by the individual properties of vacuum tubes. This is particularly true of the power stage. No one method of controlling this situation is universally used. At least two methods suggest themselves. First, the manufacturer could supply vacuum tubes that are selected to have rated values. The selection would depend, of course, upon prescribed tolerances. Second, the person making the tests could use several sets of tubes which have known characteristics. The first method is probably the better, particularly if all parties involved agreed upon rated values and tolerances of the tubes. It might also be well for those conducting the tests to check the characteristics of the tubes supplied with the amplifier against rated values.

Since amplifier performance is dependent upon the supply voltage, consideration must be given to its choice. The value of 117 volts has come into common use during the past several years as a testing and operating voltage for equipment of this nature, and it is recommended for this purpose.

(b) SIGNAL INPUT TO AMPLIFIER AND PHOTOTUBE CIRCUIT

The choice of signal input, both as to type of source and method of application, is dependent upon the test under consideration. If the amplifier, exclusive of the phototube circuit, is being tested, an audio-frequency oscillator of low harmonic content suitably coupled to the input circuit of the first stage will be satisfactory. Inasmuch as the phototube circuit is an essential component of the sound-reproducing system, and today is actually built as an integral part of the amplifier, it should receive careful consideration.

The ideal source of signal for sound projectors is naturally a test-film record. It is relatively low in cost, simple to use, and simulates exactly the actual operating conditions. However, certain contingencies, such as variation in film speed and spurious harmonic distortion, reduce the effective quality of film record and make its use, at least for the present, somewhat difficult for certain types of testing. Furthermore, test films, particularly in the 16-mm size, are not generally available at the present time. Because of these conditions, it is necessary to resort to the use of a signal generator, such as a beat-frequency oscillator, for the source of audio-frequency signal.

In coupling an audio-frequency oscillator to the phototube circuit with the phototube removed, it is desirable to simulate as nearly as possible the electrical properties of the phototube under average operating conditions and at the same time to make the coupling circuit as simple as possible. There has been a practice of coupling one terminal of the oscillator to that part of the circuit leading to the grid of the first amplifier stage by means of a resistor ranging from about 2 megohms upward to 20 megohms, the other oscillator terminal being connected to ground. The frequency characteristics of the amplifier are changed but little within this range of coupling resistors. For the usual type of phototube-circuit, measurements showed a slight decrease in gain at the high frequencies as the coupling resistor was increased in resistance, accompanied by a slight increase in gain at the low frequencies. For many types of measurements these slight shifts in the response-frequency characteristic due to different values of the coupling resistor (ranging from 2 to 20 megohms) are negligible. Other contingencies, such as control of hum pick-up, might govern the choice of resistance for the coupling resistor.

Other methods of introducing a modulation into the phototube circuit have been used. These include a neon lamp or other form of "light chopper" which is modulated by an oscillator. With these devices it is possible to introduce modulations directly into the phototube itself. Use of test films as a means of signal input has been mentioned above and will be discussed in greater detail under the test of response-frequency characteristic of the amplifier.

(c) RESISTIVE LOAD FOR TESTS OF AMPLIFIER (INCLUDING MEASUREMENT OF VOICE-COIL IMPEDANCE)

Although it has been suggested earlier in this paper that the resistive load should simulate the design load of the amplifier, it was not possible to obtain this information in one instance; and, further, it was found desirable to make tests of the equipment using the particular components the manufacturer had assembled. It is doubtful if any of the measured results have deviated to any appreciable extent from the results that would have been obtained by using a resistive load corresponding to the design load.

It is the usual practice to specify or design an amplifier with the output impedance equal to the impedance of the loudspeaker at a frequency of 400 c/s. For dynamic cone-type loudspeaker the impedance at 400 c/s is usually not much greater than the d–c resistance of the voice coil.

A simple method of determining the impedance of a voice coil is by the substitution method, using a pure resistance as the known quantity. The method does not yield values for the resistance or reactance components, but this is not necessary in the determination of the impedance only. An electrical-power input of approximately 1 watt was chosen as the level at which the measurements of the loudspeaker response were to be made, and the impedance of the voice coil was determined at this operating level. In making the measurements a beat-frequency oscillator was used as the source of signal, in conjunction with an amplifier capable of delivering considerable audio-frequency power with harmonic distortion less than 2 percent.

It was noted during the course of these measurements that the impedance and the d–c resistance of a voice coil was dependent upon the temperature of the field magnet wherever an electromagnetic field was used in the assembly. The impedance would increase by nearly 10 percent in the extreme cases before temperature equilibrium was reached, which required several hours. In this investigation the initial value of the impedance was used to determine the resistive load.

As a resistive load to simulate the voice-coil impedance an Ohmite model *R* variable resistor was used. This type of resistor has no inductive effects throughout the audible-frequency range, and is well suited for this purpose.

(d) MAXIMUM UNDISTORTED POWER OUTPUT AND HARMONIC DISTORTION

The maximum undistorted power output of amplifiers has been given too much emphasis in many quarters. Far more important and fundamental than maximum undistorted power output from an amplifier is the undistorted acoustical output at reasonably high levels from the complete system. One element that has brought about this condition is that the amplifier measurements are fairly easy to make and the performance easy to specify. This is not the case for loudspeakers.

It is admittedly difficult to specify and measure the maximum undistorted power output or state of harmonic distortion at a prescribed level of the complete system. This being the present situation, it is believed that at least some type of test should be made of the undistorted power-output characteristic of the amplifier. It has been men-

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tioned before that the equipment should be able to reproduce speech and music with low harmonic distortion at specified sound levels, and reference had been made to the approximate levels that are obtainable at present. Since the efficiency of loudspeakers varies considerably, and, in turn, determines the power-output requirement of an amplifier, it is believed that a specified maximum undistorted power output for an amplifier is not essential, but that the manufacturer should at least comply with his own statement of the power-output properties of his equipment.

The following is proposed as a requirement for power-output performance of an amplifier. The amplifier should comply with the manufacturer's stated maximum undistorted power-output rating at a test frequency of 400 c/s with volume control set at maximum position and tone control at a position to give most uniform response. The maximum undistorted power output is defined as the maximum power developed through a resistive load (considered in another section) with total harmonic distortion equal to 5 percent. The total harmonic distortion is defined as the ratio, expressed in percent, of the total harmonic voltage (root-mean-square value) to the corresponding value of the fundamental frequency component.

Several parts of this proposed requirement deserve discussion. The choice of a test frequency of 400 c/s is to conform with present practice. Both 400 and 1,000-c/s test frequencies are used today, but the former is in more common use. Use of the 400-c/s test tone usually makes for a more severe test. It is also more representative of the frequency region that contains the greater amount of acoustical energy, both in music and speech. Since the tone-control setting for most uniform response should be the usual setting of the control, and since this setting can be considered as a reference position of the tone control on all makes of projectors, it is suggested that the setting at this position be standard practice for amplifier power-output tests.

It will be noted that only the total harmonic distortion is considered, and no differentiation has been made between even- and odd-order harmonics. Although there are perceptible differences by listening tests [8] between predominating even- or odd-order harmonics, it is doubtful if the difference is great enough to warrant the measurement of each separate type. The measurement becomes difficult when account is taken of the condition that a determination is often made of the harmonic distortion at a specified limit of distortion rather than the harmonic distortion at a specified power output. This makes the work more laborious, particularly if differentiation is made between the even and odd harmonics. Also, with available methods of measuring harmonic distortion it is much easier to measure total harmonic distortion than the sum of each of the even- and odd-order harmonics.

No mention is made in the proposed requirement for power output of the source of signal to be used for making the test. Ideally, the source should be from film record, but at the present writing no precision type of test film is available, at least in quantity, for this purpose. As a second choice, it is possible to introduce an alternating current from an oscillator of low-harmonic content (less than 0.5 percent) into the phototube circuit.

Several methods are available by which harmonics in an electrical circuit can be measured. These include an arrangement with a high-pass filter, which can be used for measurement of total harmonic distortion only and at a definite fundamental frequency, a wave analyzer of the General Radio Co. type having a very narrow band width, or of the Electrical Research Products, Inc. type which may be fitted with a much wider band width. With the two latter types, it is possible to measure each harmonic component. Another type, known as the RCA Distortion and Noise Meter, Type 69–B, is useful for measuring total harmonic distortion over a wide range of frequencies and can be used also for measurement of signal-to-noise ratio, etc. The latter instrument was used to make the harmonic distortion measurements in this investigation.

The power developed across the load resistor was measured in terms of the voltage across the resistor and the power was calculated by the familiar formula of $W=E^2/R$, where W is the power in watts; E, the root mean square value of the voltage across the load resistor; and R, the resistance in ohms. The voltage was read with a thermocouple-type voltmeter, which eliminated errors due to wave form of the distorted signal at high output levels.

Table 4 gives the power output at 5 percent total harmonic distortion measured across a resistive load equal to the impedance of the voice coil at 400 c/s. The amplifier was operated at 117 volts. Comparison is made with manufacturer's undistorted power-output rating.

TABLE 4.—*Comparison of measured undistorted power output with manufacturer's rating*

Projector	Measured undistorted power output (5 percent total harmonic distortion)	Manufacturer's rating of undistorted power output
	Watts	*Watts*
A	19.4	25
B	13.2	15
C	11.2	12
D	(a)	10
E	9.6	10
F	11.8	10

[a] Total harmonic distortion exceeded 6.4 percent at all power-output levels.

It will be noted that only one amplifier delivered an undistorted power output that was equal to or greater than the manufacturer's rating, although several were within 10 percent of the rated values. It can be said without reservation that but few 16-mm-projector amplifiers are rated conservatively.

The reader is advised that although good quality of the reproduced sound will depend, in part, upon low harmonic distortion in the amplifier, there are many and possibly more important factors that need to be taken into account.

(e) RESPONSE-FREQUENCY CHARACTERISTIC

The response-frequency characteristic of an amplifier will be discussed in this paper from the viewpoint of over-all performance of the complete sound-reproducing system. It has been stated previously that uniform response for the whole system is probably the most desirable characteristic under favorable conditions of operation, including use of high-grade film recordings. This is difficult to attain, but uniform response of the amplifier is easy to obtain. However, for conditions that exist, such as high-frequency loss due to the scanning beam and possible loss in efficiency of the loudspeaker at high and low frequencies, it may not be desirable to design the amplifier for uniform response.

Another consideration should be given to the response-frequency characteristic of projector amplifiers that has received little or no attention by the manufacturers. Because of the very rapid loss of signal with frequency above 5,000 c/s in 16-mm equipment, particularly in the reproducing equipment, it appears to be unwise to extend the frequency range of the amplifier much beyond 5,000 or 6,000 c/s in the present state of art. If the amplifier and loudspeaker should reproduce, effectively, tones above 5,000 or 6,000 c/s, there would be an apparent decrease in signal-to-noise ratio due to loss of signal by the scanning beam, which in turn would reduce the quality of reproduction. This apparent increase of noise background to the listener would be particularly noticeable near and on the axis of the loudspeaker, due to the pronounced beam effect of high frequencies from the conventional type of dynamic speaker. In view of this situation, it is suggested to the manufacturer that a low-pass filter of rather sharp cutoff above approximately 6,000 c/s be incorporated within the amplifier to reduce high-frequency background noise.

(1) *Test Method.*—The common method of determining the response-frequency characteristic of an amplifier is to introduce a constant voltage at the input terminals and measure the voltage developed across the output load which may be the voice coil of a loudspeaker or a resistor. The response may be plotted as a curve with the response at any frequency expressed as a deviation in decibels from the response at a reference frequency. With projector equipment, not only is the response-frequency characteristic of the amplifier and phototube circuits of interest, but of greater interest is that of the scanning beam. The properties of the latter may be determined with film record.

For measurement of the response-frequency characteristic of the amplifier and phototube circuit and the scanning beam, it is necessary to have a film record with a number of test tones properly spaced throughout the frequency range to be studied. Moreover, the film must be calibrated in terms of its capability of delivering constant-amplitude light modulations to the phototube at different frequencies. The film used for this purpose was a special reduction print made and calibrated by the Precision Film Laboratories, of New York City. The print was made from a 35-mm Secondary Standard Frequency Test Reel—ASFA–1, of the variable-area type, produced by the Research Council of the Academy of Motion Picture Arts and Sciences. Corrections must be made for each reduction print.

The output voltage was measured across both a resistor and the voice coil of the loudspeaker. The voltage was measured with a Ballantine Laboratories, Inc., electronic voltmeter. The voltmeter was also fitted with a scale calibrated in decibels, which made it easy to read directly the deviations in the response of the system from the response at a reference frequency of 1,000 c/s. Measurements were made with the controls set to give a power-output level of 1 watt at 1,000 c/s.

The position of the tone control for measurement of the response-frequency characteristic, using film record as a source of signal, was determined from several response curves taken at different settings of the tone control. These measurements were taken across a resistive load, with a beat-frequency oscillator as a signal source, using a 2-megohm resistor as the coupling element. The setting of the tone control which produced the most uniform response of the amplifier under the conditions just mentioned was taken as the position of the tone control for making response measurements, using film as the source of signal.

The response-frequency characteristic of the amplifier, including the scanning beam, of the several projectors are shown in figures 9 to 14.

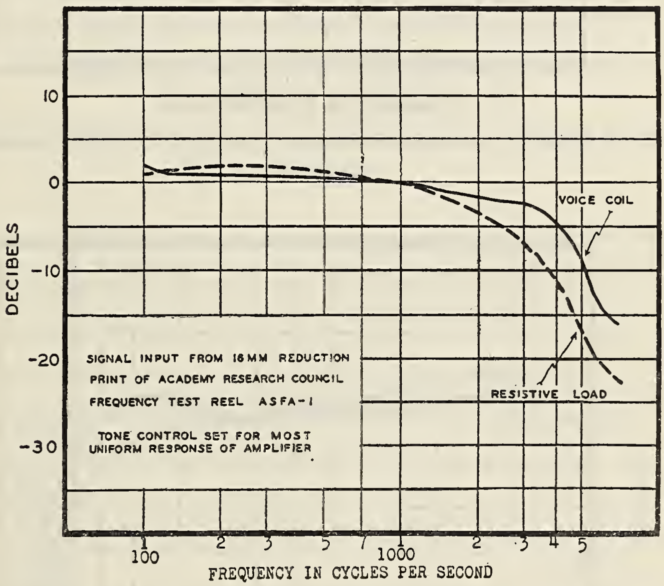

FIGURE 9.—*Response-frequency characteristic of amplifier, including scanning beam.* Projector *A*.

All the equipment tested with a resistive load had one prominent feature in common, that is, a marked falling off in response above 3,000 c/s. This is due almost entirely to the properties of the scanning beam. There are individual variations of this falling off of the response, but the general pattern is the same. Under actual operating conditions, with the voice coil as a load, the response is built up somewhat at the higher frequencies. It would appear to overcome, at least in part, the loss due to the scanning beam, but the effect is usually accompanied by a decrease in efficiency of the loudspeaker.

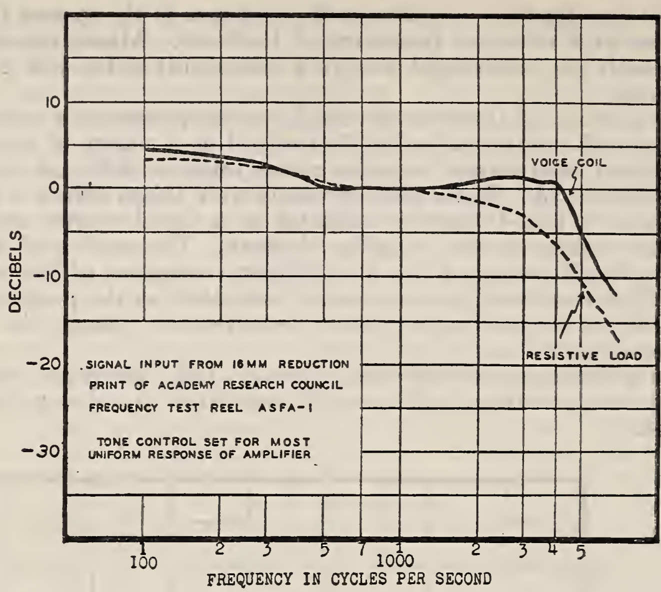

Figure 10.—*Response-frequency characteristic of amplifier, including scanning beam.*

Projector *B*.

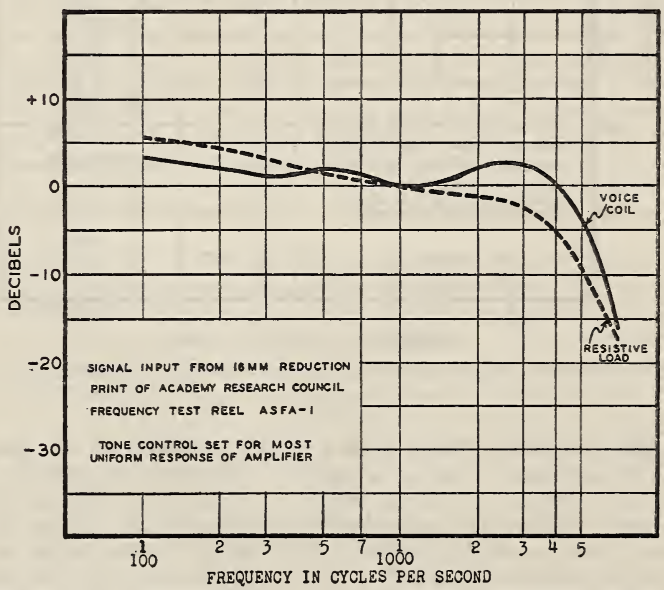

Figure 11.—*Response-frequency characteristic of amplifier, including scanning beam.*

Projector *C*.

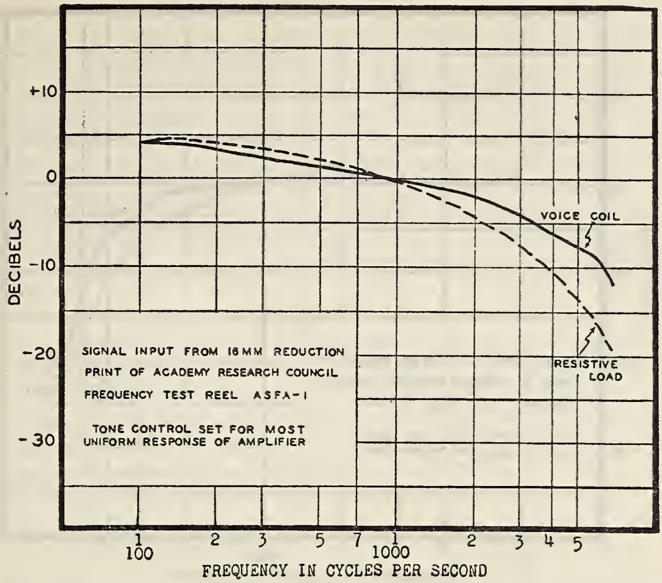

FIGURE 12.—*Response-frequency characteristic of amplifier, including scanning beam.*

Projector *D.*

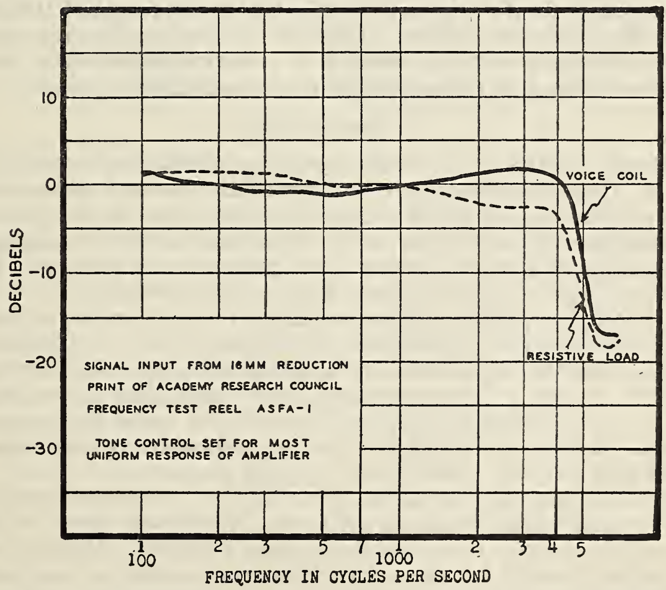

FIGURE 13.—*Response-frequency characteristic of amplifier, including scanning beam.*

Projector *E.*

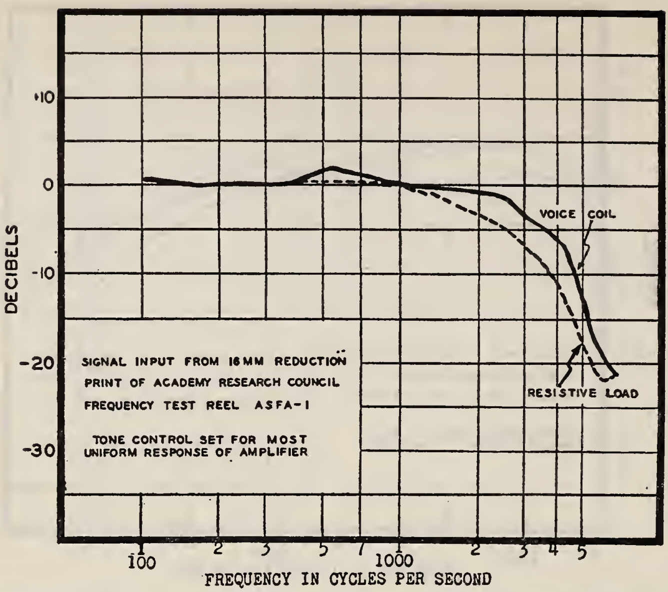

FIGURE 14.—*Response-frequency characteristic of amplifier, including scanning beam.* Projector *F*.

The variation in response as measured across the voice coil was approximately 10 db or greater in the frequency range of 100 to 5,000 c/s for all projectors tested. This lack of uniformity in response of the amplifier and scanning beam has a marked effect upon the over-all response-frequency characteristic of the complete system.

(f) TONE CONTROL

The tone control on a 16-mm projector should serve one principal function, that of minimizing the undesirable effects of room reverberation by reduction of the low-frequency response of the system. It may also have a limited use in the reduction of noise background or harmonic distortion by altering the high-frequency response, but this use should be discouraged, since quality of reproduction is impaired. With the better quality of films available today there seems but little need for altering the high-frequency response if all other requirements of a good reproducing system are fulfilled. Moreover, if the suggestion made previously of incorporating a low-pass filter of rather sharp cutoff in the amplifier circuit is adopted, the noise background and harmonic distortion should be reduced without resorting to the tone control that may be mishandled by many people.

Since 16-mm projectors of the portable type are under consideration in this paper many different acoustical conditions may be encountered as the projector is taken from place to place. If the reverberation period should be excessive, listening conditions are impaired, particularly for speech reproduction. Reduction of the low-frequency response of the system by means of a tone control will usually increase the intelligibility of speech when reproduced in unfavorable acoustical surroundings caused by excessive reverberation.

An observed fault of the tone control on some projectors has been the tendency to shift the apparent level of reproduced speech as the control was changed through the various positions. This often makes it necessary to readjust the volume control. Sivian [15] has shown that the greater amount of speech energy lies between 300 and 600 c/s. Thus the often-used test frequency of 400 c/s might be chosen as a single frequency at which the energy would remain approximately constant regardless of tone-control setting. It is the opinion of the writer that the effect of change in volume with tone-control setting is minimized if the response of the system (or output of the amplifier) changes no more than 5 db at 400 c/s at any position of the tone control.

As ordinarily designed, 16-mm projectors have a decreasing over-all response below about 300 cycles, and this tends toward increased intelligibility of speech in reverberant rooms. This decrease in response shortens the necessary range of reduction of low-frequency response by the tone control and simplifies the electrical design of the control. Experience shows that if the response of the amplifier, using 1,000 c/s as a reference frequency, can be reduced by 10 db at 100 c/s, that the system will reproduce speech quite satisfactorily under fairly adverse conditions of room acoustics.

Two positions of the tone controls are of primary interest. They are, first, the position producing the most uniform response of the amplifier, and second, the position giving the greatest reduction at low frequencies. Any compensating circuit which would increase the very high frequencies to overcome scanning beam loss should be considered apart from the circuits giving a normally uniform response to the amplifier. No such compensating circuits were encountered in the projectors tested. All projectors tested had but one tone control and this was of the rotary type. A uniform system of designating the position of the control knob was adopted, and was simply that the position of the arrow, or pointer, corresponded to the hour-hand position on a clock. Thus the 9:00-o'clock position indicated that the pointer was horizontal in the left direction and 12:00 o'clock indicated that the pointer was vertical in an upward direction.

The method of measuring the characteristic of the tone control was identical with that of measuring the response-frequency characteristic of the amplifier, except that the beat-frequency oscillator was coupled to the phototube circuit by means of a 2-megohm resistor. The results of the measurements are given in figures 15 to 20.

It is apparent from the measurements that a variety of tone-control characteristics exists in the design of projector amplifiers and probably represents varied opinions of the purpose of such a device. With the exception of projector *D*, the projectors were fitted with tone controls producing a fairly wide range of shift in response at the low frequencies. Shift in response at the high frequencies has probably been introduced by the designers to minimize harmonic distortion and to reduce extraneous noise caused by dirt on film, phototube hiss, and other sources of high-frequency disturbances.

It was found that projectors *B*, *C*, and *E* had tone-control characteristics that would have the properties proposed in the above discussion. These proposals were, first, that for any setting of the tone control, the response of the amplifier should not change more than

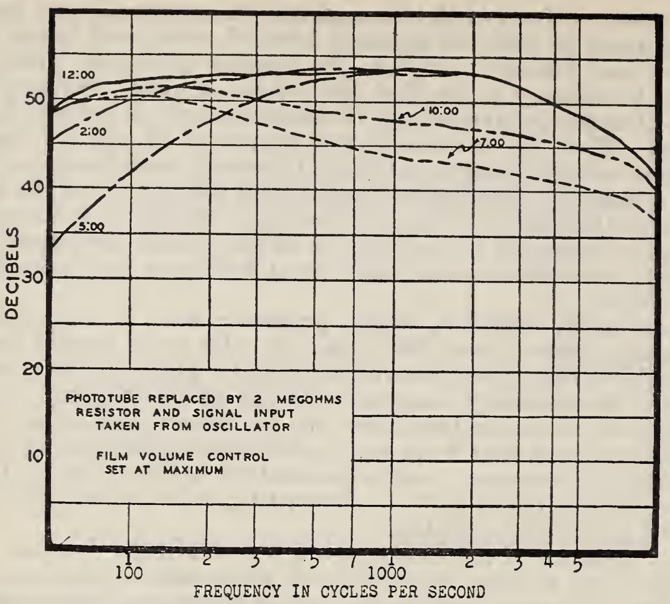

FIGURE 15.—*Response-frequency characteristic of amplifier for various settings of tone control.*

Projector *A*.

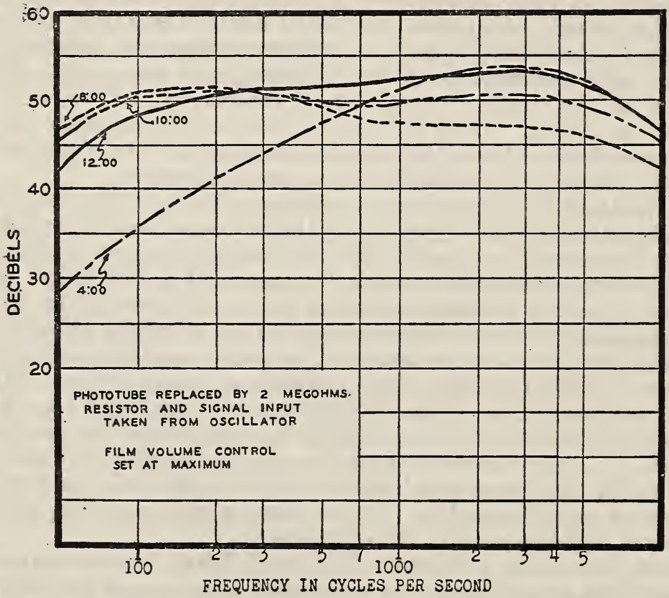

FIGURE 16.—*Response-frequency characteristic of amplifier for various settings of tone control.*

Projector *B*.

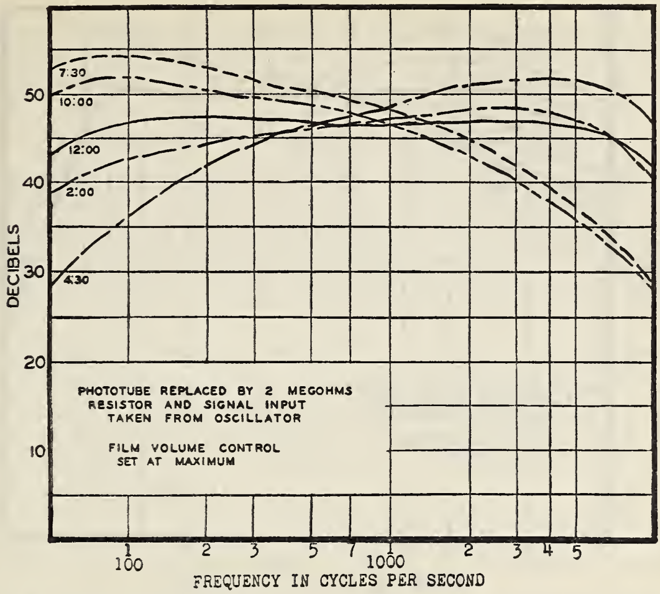

FIGURE 17.—*Response-frequency characteristic of amplifier for various settings of tone control.*

Projector *C.*

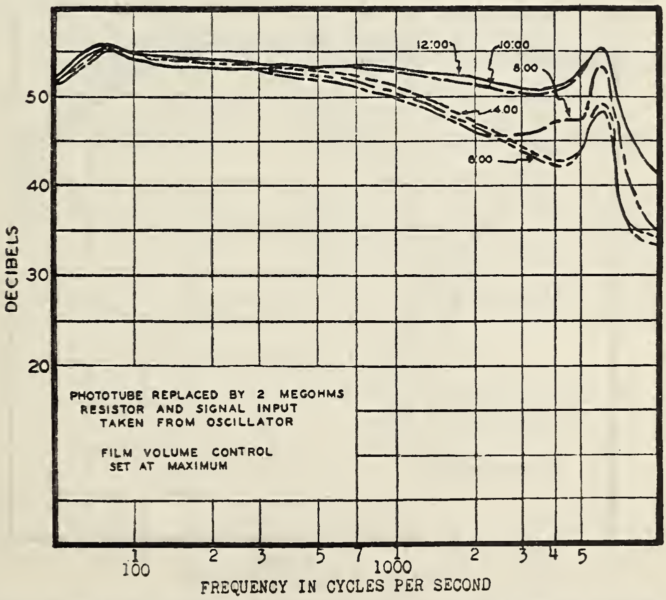

FIGURE 18.—*Response-frequency characteristic of amplifier for various settings of tone control.*

Projector *D.*

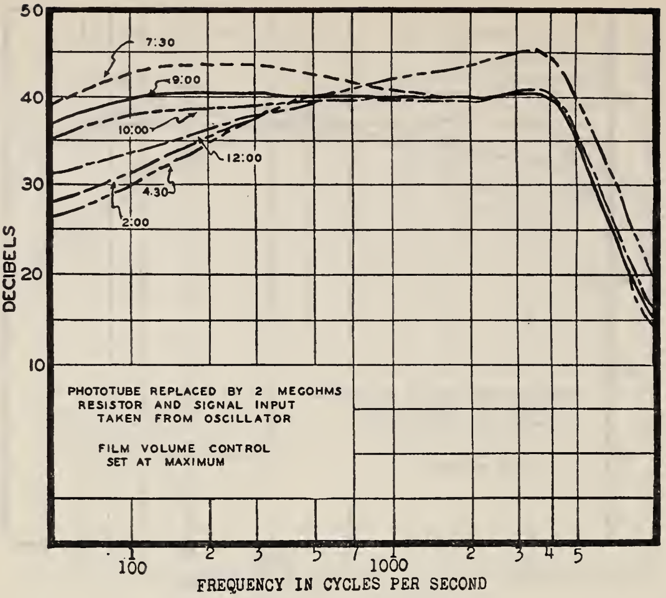

FIGURE 19.—*Response-frequency characteristic of amplifier for various settings of tone control.*

Projector *E.*

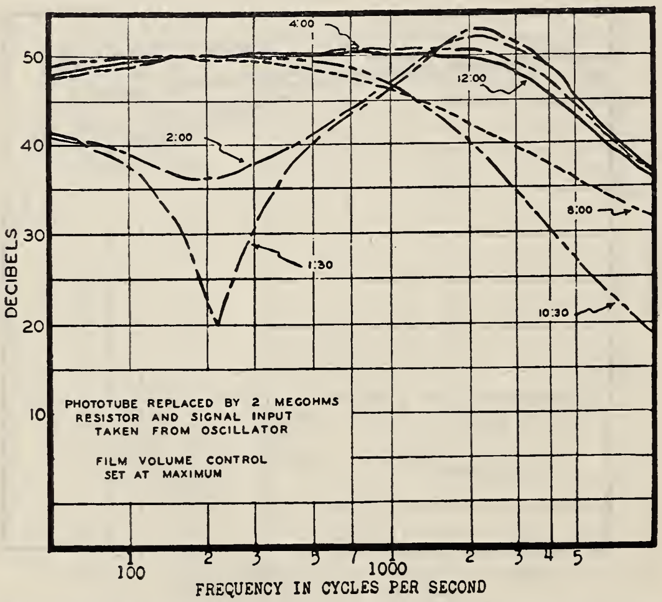

FIGURE 20.—*Response-frequency characteristic of amplifier for various settings of tone control.*

Projector *F.*

5 db at 400 c/s from the response at any other position of the tone control, and second, that the tone control should be capable of reducing the response at 100 c/s by at least 10 db from the response at 1,000 c/s.

(g) SIGNAL-TO-NOISE RATIO, OR DYNAMIC RANGE

The signal-to-noise ratio, or dynamic range, of an amplifier is fairly simple to measure. It is a much more difficult problem to measure the same as an over-all performance characteristic of a sound-reproducing system, since sound-pressure measurements are involved. Moreover, since the ear is a factor, attention must also be given to the characteristics of hearing when determining the over-all signal-to-noise ratio.

For satisfactory dynamic range it is believed that the signal-to-noise ratio should be at least 45 db under certain specified conditions of measurement. High-quality reproduction of music requires a much greater dynamic range, but this is not possible in the usual type of 16-mm equipment, nor is it necessary for the purposes under consideration in this paper.

To be more explicit, the noise level due to phototube hiss, hum in the amplifier and exciter lamp, microphonic noise of tubes, and other extraneous noises, should be at least 45 db below the maximum undistorted power output level of the amplifier.

In brief, the method of measurement is to operate the projector with a test film representative of average modulation. The signal-to-noise ratio is determined from readings taken across a load resistor at the amplifier output terminals of the undistorted power-output level and the equivalent noise level. The signal-to-noise ratio is the difference between these two levels, expressed in decibels.

It is emphasized that this particular method determines the signal-to-noise ratio at the output terminals of the amplifier. Strictly speaking, the method is not representative of actual listening conditions, since the performance of the loudspeaker has not been taken into account.

Nothing has been stated in the proposed requirement of a weighted observation of the signal-to-noise ratio. Because of the characteristics of the ear not all tones of equal intensity level are heard with equal loudness. This is particularly true of the very low frequencies. Thus noise due to low-frequency hum will be heard differently from phototube hiss and other amplifier noise. At this writing no recommendation is given for weighting the noise measurement.

Measurements of the signal-to-noise ratio do not give a true representation of the dynamic range of sound reproduction when the projector is operated from regular recordings. Accompanying the speech and music modulations is a noise background caused by scratches, dirt, and other irregularities in the film record. There may be also a background noise in the original program material or in the recording process. Furthermore, modulation peaks in the recording process may be purposely or inadvertently reduced. All of these sources tend to reduce the effective dynamic range of reproduced speech and music.

The signal-to-noise ratio will be dependent upon the choice of the state of distortion of the power output from the amplifier, since it is defined as the ratio, expressed in decibels, of the power output (at some defined level) to the background noise from all sources. In this instance it is judicious to use as the power output the measured power output at which the total harmonic distortion is equal to 5 percent.

Still another factor will affect the measurement of the signal-to-noise ratio. Most projectors are provided with a control which changes the voltage applied to the plate of the phototube, and this will shift the over-all gain or amplification of the system, which in turn affects the signal-to-noise ratio.

(1) *Test Method.*—It is, of course, very desirable to use film record as the signal source, thereby simulating actual operating conditions. For this purpose a test film [1] of the variable-area type with a recording at 400 c/s at 75-percent modulation may be used. This value of the modulation is a fair representation of the average level of recordings and determines the volume-control setting or necessary gain of the amplifier to obtain the required output under average operating conditions. In the tests here described a film of this exact nature was not readily available, and a recording of 500 c/s at 85-percent modulation was used. The modulation of 85 percent was reduced to 75 percent by a correction factor of 1 db. No correction was necessary for the difference in frequency.

It has been mentioned that some consideration should be given to the modifying effects upon the measured signal-to-noise ratio by the characteristics of the ear. Since a sound-level meter was at hand which could be modified and used to measure the signal-to-noise ratio, it was possible to weight the measurement in terms of present-day technique of noise-level measurement. The sound-level meter used for this purpose had three response curves known as A, B, and C. Curves A and B correspond to 40 and 70 db equal-loudness contours, and C corresponds to a flat response [14]. Measurements made with a sound-level meter set at the response for curve A are more nearly representative of actual listening conditions than are measurements with curve C (flat response), or with other instruments, such as the RCA Distortion and Noise Meter Type 69–B or a vacuum-tube voltmeter.

The procedure for measuring the signal-to-noise ratio was as follows: The output of the amplifier was terminated with the proper resistive load. The tone control was set to give the most uniform response of the amplifier. If present, the phototube plate-voltage control was adjusted until the phototube hiss was just perceptibly greater than other background noises existing in the amplifier as determined by instrumental measurement. The signal was obtained from the test film described above, and the film volume control was adjusted to produce a power-output level corresponding to the measured power output with a total harmonic distortion equal to 5 percent. A reading of the output level was then made on the sound-level meter (using the flat response). The equivalent noise level across the resistive load was then determined at each of the three response conditions with the projector running, but with the test film removed and a neutral density filter of 25-percent transmission factor placed in the path of the scanning beam. The 25-percent transmission factor [1] for the neutral density filter which is placed in the path of the scanning beam when not operating with the test film reduces any extraneous noise from phototube hiss or exciter lamp hum to an extent approximating the reduction of noise from the same source by the test film.

Another set of readings was taken with no neutral density filter in the path of the scanning beam. A comparison of the two conditions gives some indication of the source of the background noise. Hence, if but little reduction occurs with use of the filter, the principal noise is from the amplifier and not the phototube.

Table 5 gives the results of signal-to-noise ratio measurements made with the three response conditions of the sound-level meter, with and without the neutral density filter.

TABLE 5.—*Signal-to-noise ratio*

Projector	With neutral density filter			Without neutral density filter		
	Response A	Response B	Response C (flat)	Response A	Response B	Response C (flat)
	db	*db*	*db*	*db*	*db*	*db*
A	51.2	51.2	51.2	46.0	46.0	45.7
B	51.8	44.7	40.4	44.0	34.6	29.7
C	52.4	50.9	50.7	47.2	46.4	45.6
D	50.3	49.7	46.6	49.1	43.2	38.7
E	57.0	53.3	50.8	50.7	48.2	46.2
F	42.0	30.9	27.7	34.9	22.4	19.7

Measurements were also made with the film-moving mechanism not operating. A comparison of such measurements with those made with the projector in operation indicates the presence of microphonic noise in the system.

If the measurements are made with a sound-level meter, a comparison of the results obtained with the three response conditions of the meter will indicate the presence of hum and other low-frequency noise. For example, projector *F* showed a marked decrease in the signal-to-noise ratio when shifting from response A to response C. When using response A a great amount of the energy in the low frequencies is attenuated by a network in the sound-level meter. The current for the exciter lamp in projector *F* is obtained from a winding of the power transformer, and the light modulations from the filament due to the alternating current give rise to hum. There are, of course, other possible sources of hum in the amplifier system.

Projectors *A*, *C*, and *E* had signal-to-noise ratios greater than 50 db when measured at the flat response of the sound-level meter and with the neutral density filter. A signal-to-noise ratio of this magnitude is indicative of reduced background noise and represents good performance.

There is another manner in which the signal-to-noise ratio may be expressed, which is sometimes used to indicate the background or noise level in an amplifier or sound system. The noise level is expressed as a difference, in decibels, from a reference level. A reference level of 6 milliwatts (mw) has been used in the past, and more recently a reference level of 1 mw has been used. In the latter case, the difference in decibels is simply expressed as the value in *VU*. The results given in table 5 can be changed to conform with either of these two reference levels by subtracting from the value given in table 5 the difference in level, expressed in decibels, between the power output as given in table 4 and the reference level of 6 mw or 1 mw, as the case might be. As an example, for the signal-to-noise ratio of 51.2 db given for projector *A* measured at response C on the sound-level meter, and with the neutral density filter, the noise level would be minus 8.3 db from the reference level of 1 mw, or simply —8.3 *VU*.

(h) GAIN OF AMPLIFIER

More important than the actual voltage gain of the amplifier is maintenance of full power output under conditions of low power-supply voltage. It is hardly conceivable that a projector would be marketed if sufficient gain were not incorporated in the amplifier for operation from average recordings at normal line voltages. But on occasion it is necessary to operate from a power supply at a voltage considerably less than normal, yet under these unfavorable conditions it is desirable that full power output from the system be available.

For equipment designed to operate from a power supply of 117 volts, it is proposed that sufficient gain be available to produce a power output, with permissible harmonic distortion, equivalent to the manufacturer's stated maximum undistorted power output when operated at a power-supply voltage as low as 105 volts.

The procedure of making the measurement was quite similar to that outlined just above for signal-to-noise ratio. The tone control, phototube plate-voltage control, and film volume control were set as described previously, and the same test film (with proper correction) was used. During the course of the measurement as the gain of the amplifier decreased (and consequently the power output) with decreased power-supply voltage, the film volume control was gradually increased to maximum position. The power-supply voltage was reduced by decrements of 5 volts. Only two of the six projectors tested met the proposed requirement given above.

For further information on requirements for the available gain from the amplifier the reader is referred to the report of the SMPE Non-Theatrical Equipment Committee [1].

(i) OPERATING TEMPERATURES

Several components of the amplifier, such as tubes and the power transformer, are sources of heat which must be dissipated by conduction, radiation, or by convection currents of the air produced by natural ventilation or by a fan. In portable 16-mm equipment the necessity for light weight, compactness, and simplicity dictates use of amplifier components of small size and weight enclosed within a very small space. At best, the ventilation of a small, compact amplifier is none too good, and overheating of the components is quite possible.

The Radio Manufacturers Association and the Underwriters Laboratories have established standards for permissible temperature or temperature rise in amplifier and radio equipment. These standards should be adhered to by designers and manufacturers of projector amplifiers.

(j) RADIO MANUFACTURERS ASSOCIATION RATINGS OF VACUUM TUBES

The RMA Engineering Division has endeavored to set standards for maximum ratings such as plate and screen voltages, and plate and screen dissipation for vacuum tubes. If these ratings are not exceeded, a reasonably long life of the tubes can be expected, accompanied by a minimum of trouble and breakdown. It is recommended, therefore, that manufacturers of 16-mm projectors give attention to these ratings and design their amplifiers accordingly. This precaution has been ignored too frequently in the past. Actual tests of the amplifiers indicated but few instances of conformity with these ratings. Values for RMA ratings were taken from the RCA Manufacturing Co. Tube Handbook Series H3.

Tests were made with calibrated instruments, all measurements being made in accordance with the best engineering practice. The filament or heater voltage, the plate voltage and current and the grid-bias voltage were measured and the plate dissipation calculated with the condition of no signal applied to the amplifier. The screen voltage and current were measured and the screen dissipation calculated with the condition of the peak voltage of the signal across the input of the power stage equal to the grid bias.

It was noted in several instances that for the push-pull power stage where identical operation of the two tubes is expected, the plate dissipation of one tube exceeded the RMA rating, whereas the other tube was normal. This irregularity could be accounted for by the rather marked difference between the plate currents of the two tubes, although the applied plate voltage was the same for each tube. The difference can be traced to the marked nonuniformity in operating characteristics of tubes and particularly of power tubes.

It was very evident that in the design of the majority of the amplifiers RMA ratings had been disregarded by the designers, and, in particular, the plates and screens of the power tubes had been overloaded.

5. LOUDSPEAKER

(a) GENERAL

The loudspeaker has proved to be one of the most serious handicaps to the faithful reproduction of sound not only in 16-mm projectors but in radios and sound-reinforcing equipment as well. Not only do designers have their difficulties in developing an ideal loudspeaker for a particular purpose, but it has been difficult to state performance requirements and to determine the performance by instrumental methods. In view of these difficulties, it has been the purpose of this investigation to expand further the attempt to set up detailed performance requirements for loudspeakers and to work out simplified testing methods. Unfortunately, certain elements have entered the investigation which have not permitted the investigation to be carried out to the fullest extent that has been desired. It is hoped that more work will be carried out at some future time.

Probably the most comprehensive contribution to standard methods of testing of loudspeakers has been a report prepared by the American Standards Association Sectional Committee C16 [16]. Quoting from the Introduction to the report: "The purpose of this report is to outline briefly the apparatus which is now used in testing loudspeakers together with the procedure for obtaining the important characteristics which depict the performance of a loudspeaker." Since the report deals specifically with testing methods, there is no attempt made to prescribe definite performance of loudspeakers for particular purposes. Olsen [17] has presented much on loudspeaker measurements in his book on acoustical engineering. Others, including Kellogg [18], McLachlan [19], Olney [20], Ballantine [21], Wheeler and Whitman [22], and Massa [23] have contributed to the literature on loudspeaker testing.

Except for very sketchy statements, there appears to be very little information available on detailed performance requirements or specifications of loudspeakers. This can be explained, in part, as due to difficulties in experimental procedure.

There are many factors to be considered in the design of loudspeakers from an engineering viewpoint. For the purchaser who desires and may demand high-grade performance, several important operating characteristics need be known or determined. These include the response-frequency characteristic, directional characteristic, and harmonic distortion, and to a lesser degree, transient-response characteristic, efficiency, and power-handling capacity. In the design of the complete sound-reproducing system the impedance of the loudspeaker must be considered. Each of the above will now be treated in terms of desirable performance for 16-mm projection equipment.

(b) RESPONSE-FREQUENCY CHARACTERISTIC

Present-day limitations in the frequency range of 16-mm projectors have been discussed earlier in this paper. The practical frequency range has been set at 150 to 5,000 c/s, and within these frequency limits the response of the complete system should be within 10 db. Ideally, the response should be reasonably uniform throughout this range, with some falling off below 300 cycles. This characteristic minimizes "boominess" in reproduction of speech, and also compensates, to a greater or less degree, for the augmentation of low frequencies by a room, due to the nondirectional radiating characteristics of loudspeakers at low frequencies.

It is well known to sound engineers that no loudspeaker has an absolutely uniform response over an extended frequency range. For very high quality loudspeakers or those of special design the magnitude of this nonuniformity is quite small, but it may become very large in the usual type of dynamic loudspeakers used in radio equipment and portable 16-mm projectors. In the latter case variations as great as 20 or 25 db may exist within the range of frequencies where the manufacturer considers the loudspeaker as having a "substantially flat characteristic." It must not be overlooked, however, that the measured response-frequency characteristic is very much dependent upon acoustical environment, experimental procedure, and technique, and in the comparison of data, the test conditions must be indicated. Thus if the variations in response, within certain frequency limits, of a loudspeaker as given by one set of measuring conditions and presentation of data show an extreme range of 15 db, under a different set of conditions they may show a range of only 5 db. Therefore, great care must be exercised in presentation of the data, and in the preparation of a specification for response-frequency characteristics of loudspeakers the method of test should be stated.

A careful study of the measuring technique shows that the range of variation in response within any very narrow frequency band is dependent upon the time-average characteristic of the sound or tone within the band. Several kinds of tones are used to determine response-frequency characteristics of loudspeakers, namely, application of a number of tones at single, or discrete, frequencies, a sweep frequency or application of a number of "warble" frequencies. In the latter case the frequency of the tone is constantly shifting with time within a narrow frequency band. A full discussion of the use of these various tones and the effect upon the measured response-frequency characteristics is beyond the scope of the present paper. Briefly, however, the warble-frequency method will show smaller variations than will the single tones or the sweep-frequency method. Inasmuch as the ear is quite tolerant of lack of uniformity in response of sound-reproducing systems, it is believed that a determination by the warble-frequency method more nearly represents actual listening conditions. Moreover, the warble-frequency method is advantageous if measurements are made in rooms used for projection of pictures because of reduced standing-wave effects [17, 21, 22]. Because of these facts, all further discussion of response-frequency characteristics of loudspeakers in this section will be based upon the use of the warble-frequency method.

How nearly the flat response can be approached will be dictated largely by the economics of design and production. Just how great variations in response (resonance and antiresonances) within certain frequency limits are permissible without reducing materially the quality of reproduction is a moot question. So many factors are involved that experimental and subjective data are not easy to obtain without a great amount of work. Steinberg [24] has shown the effects of resonance in telephone transmission circuits upon the recognition of speech sounds, but quality was not a consideration. The writer has no knowledge of quantitative measurements of quality changes in reproduced music and speech as affected by sharp resonance or antiresonance regions in the response of the system. Ballantine [21] suggested a proposed specification for the permissible fluctuation in response of a radio receiver, but admittedly it lacked subjective verification.

Several years ago the writer was confronted with the necessity of preparing a specification for a high-quality sound-reproducing system for 35-mm equipment. As a part of that specification a requirement was written which defined certain limits of variations in response of the system within frequency bands of rather narrow limits. In other words, the "peaks" and "dips" or resonance and antiresonance regions of the response-frequency characteristic of the system were kept within certain well-defined limits. This was accomplished by stating the permissible variation within ½-octave intervals.

As requirements for 16-mm projector loudspeakers the following are proposed: First, variations of the response-frequency characteristic greater than 5 db should not occur within frequency intervals of one-half octave or less, and second, variations of the response-frequency characteristic greater than 7 db should not occur within frequency intervals of 1 octave or less. The frequency range is considered to be 150 to 5,000 c/s and the response taken on the axis of the loudspeaker.

Actual performance of the loudspeaker will depend upon the conditions of test. The above requirements are based on a determination with warble-frequency tones.[5] The response of the loudspeaker will

[5] Suggested characteristics of warble-frequency tones are given in the section on loudspeaker measuring technique.

depend, of course, on the nature of the input. When the loudspeaker alone is considered, it is convenient to express the response in terms of constant-voltage input to the voice coil. In practice, a loudspeaker is usually coupled to a power tube (or tubes) by means of a transformer, and the response may then be expressed in terms of constant-voltage input to the grid of the power tube. In any case, the input conditions must be given. These requirements are applicable without modification to the over-all response-frequency characteristic of the complete sound system, in which case it would be considered that the test film had constant modulation at all frequencies.

Experience has shown that the suggested requirements can be met with some of the present-day 16-mm projector equipment. It is believed that equipment meeting these requirements will give acceptable reproduction of speech and music, all other aspects of performance being considered to be satisfactory, of course.

(1) *Test Method.*—The practical difficulties of making sound-pressure measurements of the characteristics of loudspeakers have been discussed. At the present writing, only two of these characteristics, the response-frequency characteristic and the directional characteristic, have been given any detailed study. The necessity of using an acoustical environment which approximates free-space conditions has been emphasized. This may be obtained by using a so-called dead room of fairly large proportions, or by making measurements out-of-doors at reasonably long distances from large reflecting surfaces. Although the writer had both of these facilities at hand to make loudspeaker measurements, it seemed advisable to make the measurements out-of-doors, since this condition of testing is more reproducible by others. Very few dead rooms suitable for loudspeaker measurements are available, and they are expensive to construct.

During the course of making the measurements a number of variations of the acoustical environment were tried. These included measurements made in a dead room; out-of-doors, with no nearby reflecting surfaces; and measurements made with large nearby reflecting surfaces placed at several different positions relative to the axis of the loudspeaker. A detailed review of these conditions of measurement and the data obtained are beyond the scope of this presentation. The measurements indicated that the actual set-up used to obtain the data given in this paper was entirely satisfactory.

Figure 21 shows the arrangement for mounting the loudspeaker and the microphone with their accompanying supports, all of which were placed on a 10-foot stepladder. In this instance the ladder was placed near the corner of the roof of a building. No reflections from the roof or from nearby trees were observed. The loudspeaker was placed on a small wooden platform which could be rotated in the horizontal plane. The microphone was placed on a supporting boom, so that it was 5 feet in front of the front grille and on the axis of the loudspeaker. To obtain the directional characteristic the loudspaker rather than the microphone was rotated. The microphone distance was maintained constant by rotating the loudspeaker about a vertical axis through the center of the front grille. A circular disk beneath the wooden platform, graduated in increments of 5 degrees, was used to determine the position of the microphone to the right or left of the axis of the loudspeaker. The mounting arrangement was designed for convenient

FIGURE 21.—*Experimental arrangement for outdoor testing of loudspeakers.*

anchoring of a loudspeaker of any common size to a definite position relative to the microphone.

A calibrated microphone of the nondirectional type was used. An Electrical Research Products, Inc. Type RA–277–B Sound Frequency Analyzer (sound-level-meter circuit only) was used with the above microphone to determine the sound pressures. Any other comparable type of sound-level meter would have served equally well. However, it is desirable that a calibration curve extending over the necessary frequency range be used to correct for variations in response of the measuring equipment. On occasion, a very low frequency background noise was present from several sources of disturbance, including wind noise, but was easily reduced to a negligible amount by means of a high-pass filter which had an insertion loss of 3 db at 100 c/s and 10 db at 75 c/s. The ambient noise was 55 to 60 db above the standard reference level [14], and occasionally ranged somewhat higher, because of intermittent traffic noise. Since most of the sound pressures that were measured averaged around 90 db, and but few below 80 db, a safe margin was held above ambient noise.

The use of a warble-frequency film as a source of signal for testing loudspeakers has been discussed. For this purpose a 16-mm reduction print was made by the Precision Film Laboratories, Inc. of an Academy Research Council Warble Film No. 6490. This 35-mm test film was developed for sound-pressure measurements in large theaters. In all, there are 41 test tones plus a reference tone on the film, but only the 28 tones between 100 and 5,000 c/s were used in this investigation. The characteristics of the warble are as follows:

Amount of warble from 100 to 1,000 c/s, inclusive	±12.5 percent.
Amount of warble from 1,250 to 5,000 c/s, inclusive	125 cycles.
Rate of warble from 100 to 175 c/s, inclusive	3.0 per sec.
Rate of warble from 200 to 450 c/s, inclusive	4.0 per sec.
Rate of warble from 500 to 5,000 c/s, inclusive	5.0 per sec.

A sound projector, not of the group under test, was used solely for the purpose of a film reproducer or film phonograph. The output circuit was coupled to an amplifier using No. 845 tubes in push-pull, and fitted with an output transformer with various combinations of low-output impedance. Across the 1.2-ohm output was placed a 2-ohm load resistor. With this equipment there was at hand a signal generator which was essentially a constant-voltage device. The loudspeaker voice coil was placed across the load resistor. Ordinarily the impedance of a voice coil is large enough to have no effect upon the internal impedance of such a generator. However, because of variations in the film record and the response of the projector, it was necessary to calibrate the entire equipment.

A reference power imput of 1 watt at 1,000 c/s to the loudspeaker was chosen as being representative of a power input somewhat above the average level for most purposes. This corresponded to approximately 4 volts across a voice coil of 16-ohm impedance at 400 c/s, and the voltage was kept constant at this value. Even at 400 c/s there is some inductive effect, which must be taken into account for an exact determination of power absorbed by the loudspeaker.

By making response measurements at different azimuth angles it is possible to determine simultaneously both the response-frequency characteristic and the directional characteristic. Measurements were made by taking sound-pressure levels starting at the axis and at each 5-degree interval out to 30 degrees. Measurements were taken at both right and left positions of the microphone from the axis of the loudspeaker. A comparison between measurements taken at the same angle in both the right and left positions showed some asymmetry, particularly at high frequency and at the larger azimuth angles. It was not great enough to be taken into account in the practical aspects of loudspeaker performance.

All measurements were repeated, but it is believed that this is not necessary, since the sound pressures never varied much more than 1 db in repeat measurements, and usually were within a few tenths of 1 db. To simplify the data, only those measurements at 0-, 15-, and

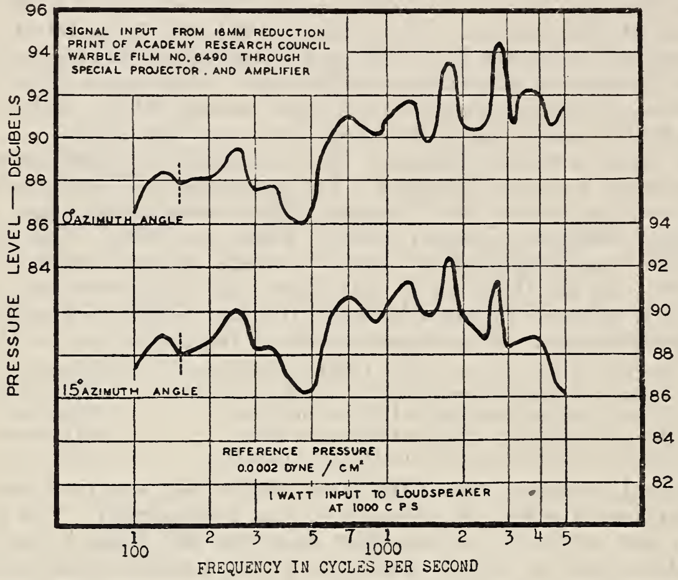

FIGURE 22.—*Response-frequency characteristic of loudspeaker.*

Projector *A*.

30-degree azimuth angles have been reported. If in a less comprehensive program of testing, single measurements on but one side of the axis be taken, the tests would be greatly simplified. Since the whole film, including the frequency ranges not used in this investigation, takes but 4½ minutes to travel through the projector, it can be appreciated that such a method of testing loudspeakers has much to offer, both from the amount of information gathered and the relatively short time in which it can be taken.

All the loudspeakers were operated with the hinged rear cover of the carrying case removed. None of the loudspeakers was designed to operate otherwise.

Figures 22 to 27 show the response-frequency characteristics taken at 0- and 15-degree azimuth angles of the loudspeakers accompanying the six projectors. Although the measured frequency range was 100 to 5,000 c/s, the region between 100 and 150 c/s is shown by a dashed line to differentiate it from the region between 150 and 5,000 c/s.

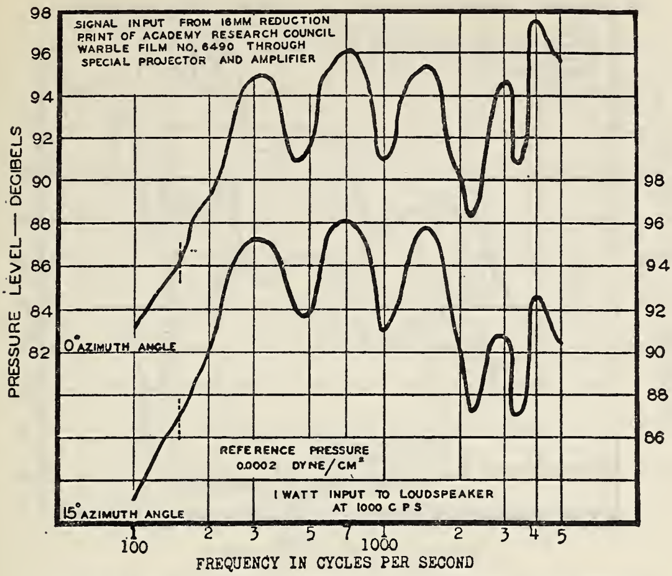

FIGURE 23.—*Response-frequency characteristic of loudspeaker.*

Projector *B.*

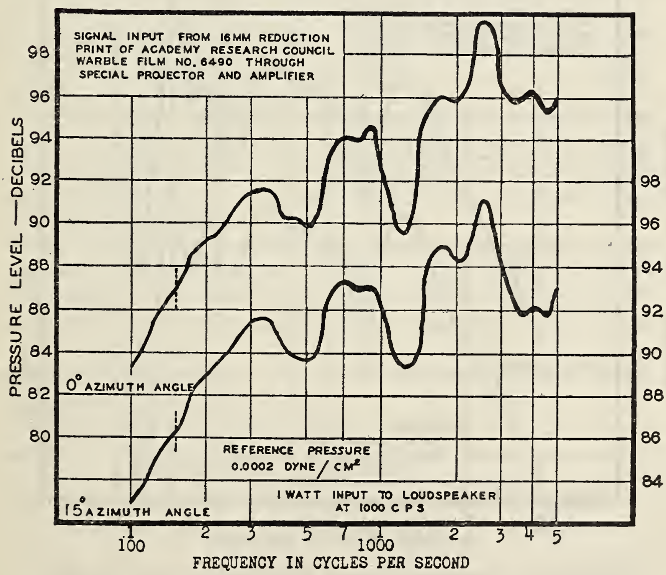

FIGURE 24.—*Response-frequency characteristic of loudspeaker.*

Projector *C.*

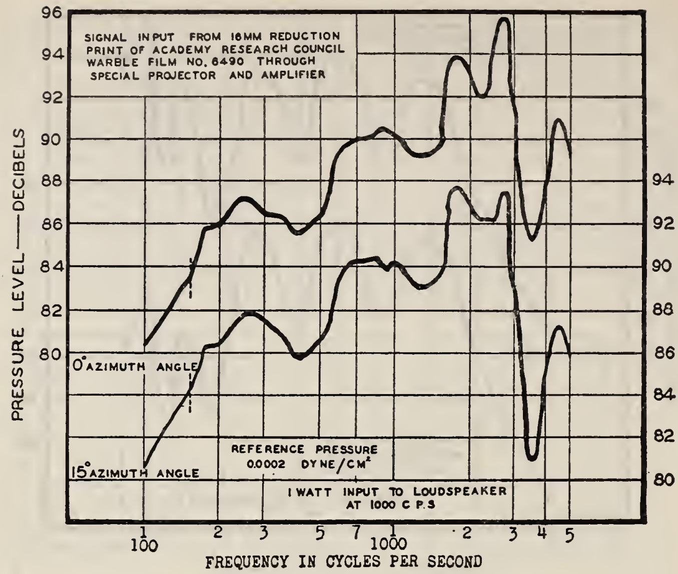

FIGURE 25.—*Response-frequency characteristic of loudspeaker.*

Projector *D.*

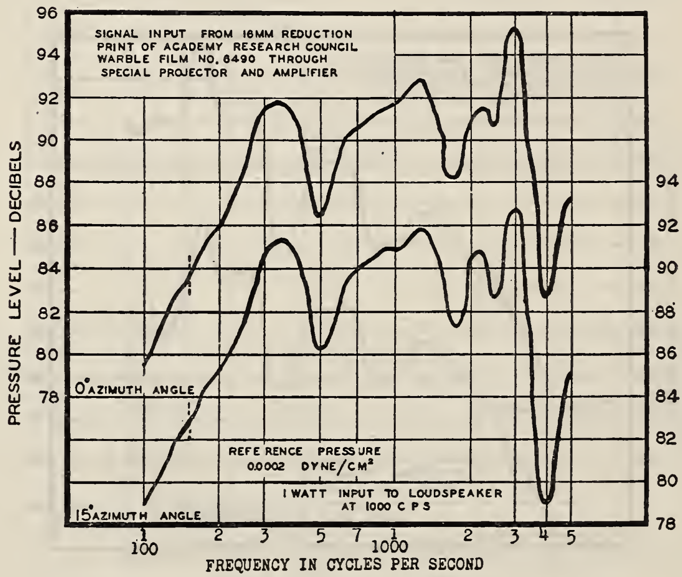

FIGURE 26.—*Response-frequency characteristic of loudspeaker.*

Projector *E.*

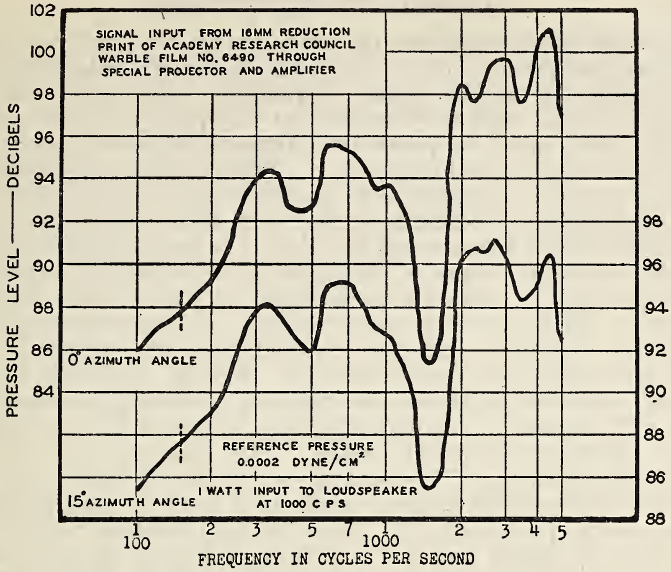

FIGURE 27.—*Response-frequency characteristic of loudspeaker.*

Projector *F*.

The purpose here is to lay stress upon that region in which a balance between high and low frequencies is desirable and within which it is desirable that the over-all response of the complete system should not vary more than 10 db. Most of the loudspeakers showed a very rapid decrease in response below 150 c/s.

In addition to showing the general form of the response-frequency characteristic of the loudspeaker, these curves indicate the lack of smoothness of the response of conventional dynamic speakers. The method of evaluating the over-all response-frequency characteristic described previously will be found useful in determining the performance of loudspeakers.

It should be borne in mind that these measurements were taken under the condition of constant-voltage input to the loudspeaker and do not represent actual operating conditions when used with an amplifier. It is, however, a convenient method of making measurements and presenting the data, and serves the useful purpose of delineating the performance of the loudspeaker, which in most cases must be treated as a separate item.

Furthermore, it must be taken into account that the measurements were made with warble tones and the variations in response shown by the curves do not indicate the extreme variations in response that will occur if single tones or a sweep frequency are used. The scope of this paper does not permit the inclusion of comparative data on these several types of test tones. To reiterate, the warble tones are probably more representative of actual listening conditions and also serve to smooth out violent fluctuations caused by standing waves if measurements are made with nearby reflecting surfaces or within a room.

(c) DIRECTIONAL CHARACTERISTIC

All sources of sound radiate the sound energy with varying intensity in different directions. For loudspeakers this is particularly noticeable out-of-doors and at the higher frequencies. The effect can be so predominating at high frequencies that the quality of sound changes radically from point to point even through relatively small angles directly in front of the loudspeaker. This is particularly true of the common dynamic cone-type of loudspeaker and of many of the horn-type loudspeakers. Sometimes the very high frequencies tend to concentrate into a beam much like that of a focused beam of light.

Under actual conditions of the projection of sound pictures within a room, the lack of uniform distribution of sound with consequent changes in quality are not as noticeable as out-of-doors or under dead-room testing conditions. Nevertheless, this phase of sound reproduction has been much neglected. Ideally, probably the sound pressure or intensity should be radiated uniformly throughout an angle of 30 degrees in the horizontal plane from the axis of the loudspeaker (30-degree azimuth angle). This assumes that the loudspeaker is placed near the vertical center line of the screen. The choice of the 30-degree angle is based upon recommended practice for 16-mm picture projection [1]. Probably the ideal loudspeaker should not radiate at angles greater than 30 degrees from the axis, particularly when used in a room. From fundamental considerations, it would not be possible to meet this latter condition.

It is of particular importance that the middle and high frequencies be radiated rather uniformly throughout this viewing angle, since intelligibility of speech and, to a less extent, retention of the original quality, or timbre, of music, are dependent upon faithful reproduction of middle and high frequencies. It can hardly be denied that for films relating to educational subjects, where effort toward grasp of content is far more important than effort expended in overcoming poor intelligibility of the reproduced speech, anything done to improve the reproduction is an advance in the art. Thus improvement in loudspeaker design toward more uniform radiation of sound of the higher frequencies would be a progressive step.

If greater uniformity in the directivity of high frequencies were obtained over wide and yet limited angle of propagation, there would be less need of dependence upon wall or ceiling reflections for reinforcement of speech sounds, and intelligibility should be improved. Moreover, there would be less concentration of high frequencies near the axis with accompanying over-all improvement in quality and naturalness.

Investigation has shown that most loudspeakers of the type used in portable 16-mm projectors begin to have directive effects at frequencies above 500 c/s for azimuth angles ranging up to 30 degrees. At frequencies between 3,000 and 5,000 c/s, the response near 30 degrees may fall off by as much as 20 db. from the response on the axis. This falling-off characteristic is usually quite regular and progressive as the angle is increased from the axis, but some loudspeakers show marked peculiarities.

As stated previously, the ideal loudspeaker for 16-mm projector purposes would probably have uniform response out to about 30 degrees and then cut off rather abruptly beyond that angle. Although this directional characteristic is difficult of attainment, nevertheless, it is believed that certain minimum requirements are desirable. Considered from the standpoint of possible improvement in present-day loudspeakers of the dynamic cone-type or combination types with two or more loudspeakers, and upon not too great a divergence from the ideal, the following is a proposed performance for the directional characteristic of loudspeakers. The response of the loudspeaker, measured 15 degrees from the axis in a horizontal plane (15° azimuth angle), should not vary more than 5 db from the response on the axis in the frequency range of 150 to 5,000 c/s. The response of the loudspeaker, measured 30 degrees from the axis in a horizontal plane (30° azimuth angle) should not vary more than 10 db from the response on the axis in the frequency range of 150 to 5,000 c/s. It is recommended further that such measurements be made at a distance of 5 feet or greater from the face of the loudspeaker, or from the front face of the loudspeaker system if more than one unit is in the assembly. This distance is chosen to reduce effects of sound pattern that might be caused by multiple sources if two or more units compose the loudspeaker assembly. Moreover, it is assumed that a warble tone is used and that tests are conducted in an acoustical environment with negligible reflections.

Although the response taken at 0- and 15-degree azimuth angles, shown in figures 22 to 27, give some indication of the directional characteristics, they can be shown more clearly by plotting the data as deviations from the response on the axis. This has been done for the response at 15 and 30 degrees, as shown in figures 28 to 33. Measurements were taken at 5 degree intervals out to 30 degrees, but for

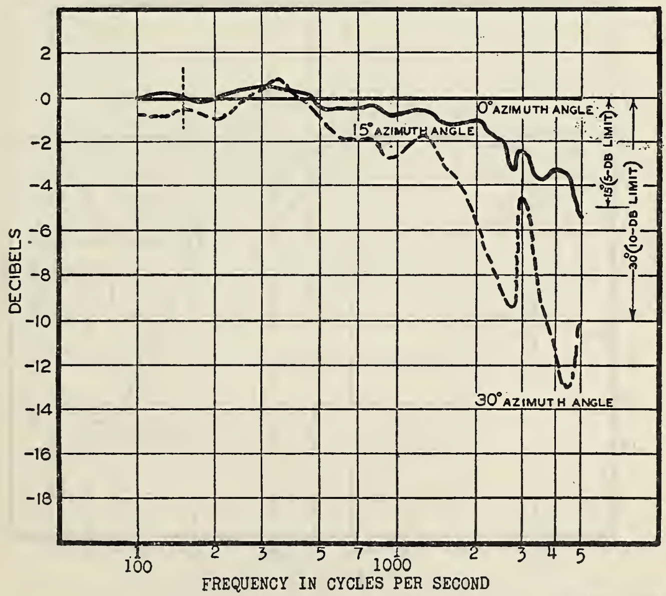

FIGURE 28.—*Comparison of directional characteristic at 15° and 30° azimuth angle with 0° azimuth angle.*

Projector *A*.

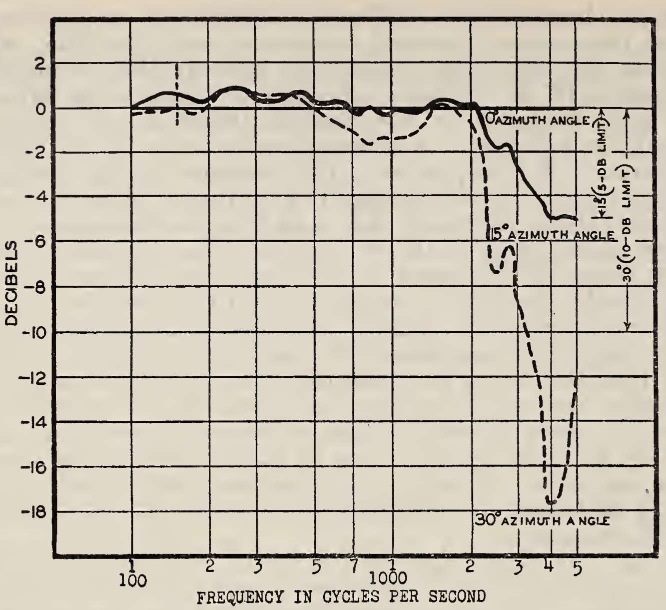

Figure 29.—*Comparison of directional characteristic at 15° and 30° azimuth angle with 0° azimuth angle.*

Projector *B*.

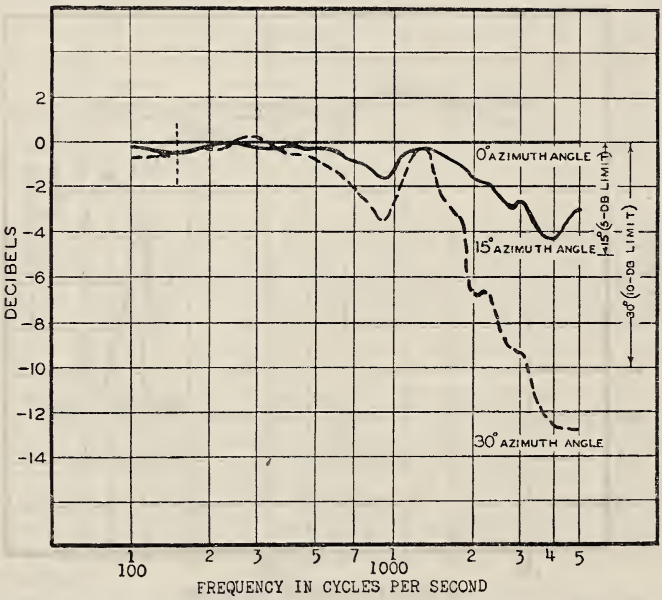

Figure 30.—*Comparison of directional characteristic at 15° and 30° azimuth angle with 0° azimuth angle.*

Projector *C*.

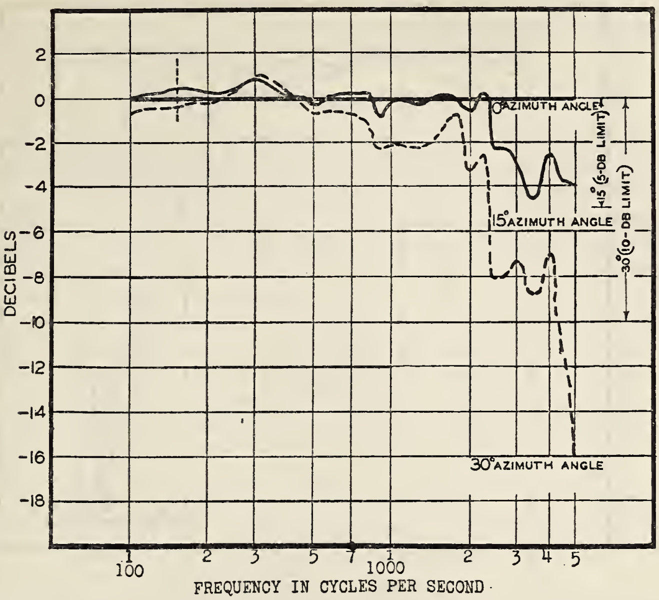

FIGURE 31.—*Comparison of directional characteristic at 15° and 30° azimuth angle with 0° azimuth angle.*

Projector *D*.

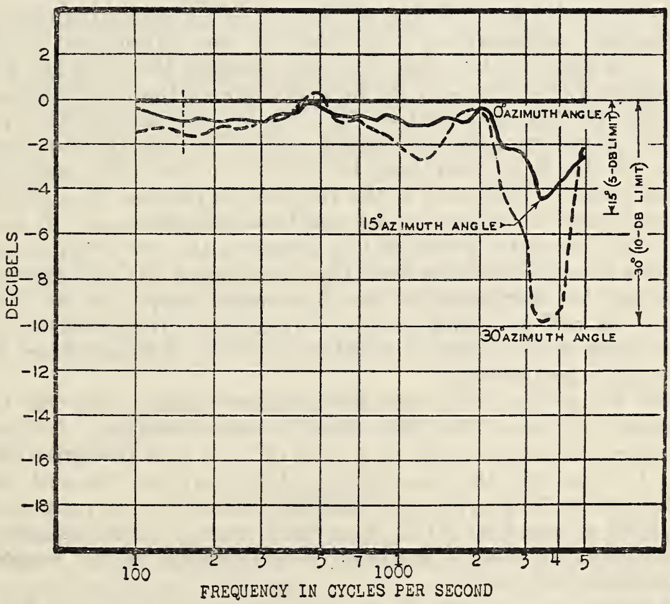

FIGURE 32.—*Comparison of directional characteristic at 15° and 30° azimuth angle with 0° azimuth angle.*

Projector *E*.

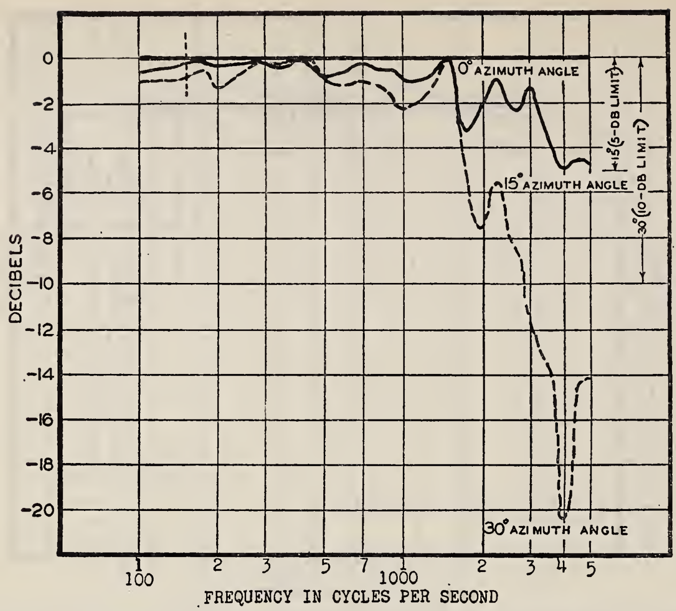

Figure 33.—*Comparison of directional characteristic at 15° and 30° azimuth angle with 0° azimuth angle.*

Projector *F*.

the sake of clarity in depicting the actual performance compared with the proposed performance, only the 15- and 30-degree curves are shown. At angles other than the axis position the data are given as the average of the right and the left positions of the microphone.

It might be supposed that at the very low frequencies the response curves at different azimuth angles would be exactly superimposed because of the large wavelength relative to the dimensions of the cone and baffle. However, if the response is plotted on a large scale, small variations in measurement will be noticeable and will probably account for the many irregularities found at the low frequencies. All deviations in excess of 1 db from the response on the axis above 300 to 500 c/s can be attributed to the directional properties of the loudspeaker. It will be noted that in several cases the deviation was as great as 20 db in the region of 4,000 to 5,000 c/s, and sometimes showed very peculiar properties.

It was found that only one loudspeaker would meet the two requirements suggested for directional characteristics. All but one would meet the requirement of a limit of 5 db at a 15-degree azimuth angle. In general, the directional characteristics showed decided irregularities at 30 degrees, the response exceeding the proposed limit of 10 db by as much as 10 db in several cases. There is much room for improvement toward increase of uniformity of the response at the larger azimuth angles.

As a means to simplify the measurements of response of a loudspeaker it is suggested that one measurement made at a 15-degree azimuth angle might suffice to give a general idea of the response-frequency characteristic averaged over a range of azimuth angles from 0 degrees to about 30 degrees.

(d) HARMONIC DISTORTION

Harmonic distortion in amplifiers is fairly easy to measure, but this is not the case with loudspeakers. Not only is an instrument for actual measurement of distortion needed, but a high-quality microphone and amplifier of known operating characteristics are needed as well. Naturally, the source of audio-frequency alternating current must be quite free of harmonics. Most important is an acoustical environment free from reflections.

So much for the equipment. Since the response of loudspeakers is not uniform, the magnitude of the harmonic components will change with the frequency of the fundamental. Moreover, in some loudspeakers the harmonic content will change considerably with power input to the voice coil due to nonlinearity of the magnetic field. This is particularly true at low frequencies, where the movement of the voice coil becomes large. Also, because of the varying patterns in the sectional vibrations of the cone at the middle and high frequencies (usually above 500 c/s), the harmonic content shifts considerably with frequency or power input. The directional characteristic of the loudspeaker must also be considered.

All in all, harmonic-distortion measurements of a loudspeaker present quite a formidable problem, not to mention the difficulties in application of a performance specification. At the present writing no attempt has been made to simplify this problem, but it is believed that there are possibilities of so doing. The only performance that can be suggested at the present time for a maximum limit of harmonic distortion is something like 10 percent at a required power input. This may or may not have to be qualified as being dependent upon the range of frequency of the fundamental tone. Consideration must also be given to production of subharmonics, buzzes, and other inharmonic sounds. The latter may be more annoying than the ordinary nonlinear type of distortion.

(e) TRANSIENT-RESPONSE CHARACTERISTIC

The loudspeaker is a source of transients, which may on occasion be objectionable. Good design of the loudspeaker and judicious use of amplifiers will minimize the production of transients. It must be said that the equipment used in portable 16-mm. projectors is none too free from these extraneous sounds.

No performance requirements are suggested at this writing, but the problem bears investigation. Certainly, transients can be reduced if proper steps are taken.

(f) EFFICIENCY

Today, loudspeakers range in efficiency from about 1 or 2 percent to 50 percent. Loudspeakers on most portable 16-mm. equipment probably have an average efficiency of about 5 percent. Because of high price and other factors it is not economical to use a highly efficient loudspeaker of the horn type, even though power amplifier requirements would be smaller.

As stated previously in the discussion of over-all performance, actual sound output is more important than efficiency of the loudspeaker or power output of the amplifier. Nonetheless, any extremes of very low efficiency of the loudspeaker or excessive power-output requirements of the amplifier would be considered poor engineering practice. Absolute efficiency of a loudspeaker is more of a problem for the designer than for the purchaser.

(g) POWER-HANDLING CAPACITY

The power-handling capacity of a loudspeaker is interrelated with the sound-level requirement (volume of sound) and the harmonic, or nonlinear distortion. It may be defined in terms of the electrical-power input or the acoustical-power output. The power-handling capacity will be dependent upon such factors as maximum allowable harmonic distortion and other extraneous noise, maximum allowable temperatures of the voice coil, and actual mechanical breakdown of the vibrating system. Thus a requirement of power-handling capacity is rather general and must be specific for any particular application.

The power-handling capacity of the loudspeaker can be made a correlating measurement of harmonic distortion, since, in general, specific limits of distortion will determine the power-handling capacity of the loudspeaker. Other features, such as actual physical breakdown of the vibrating system, may also be determining factors. In view of the fact that no measurements were made of harmonic distortion, no statement can be made of the power-handling capacity or overload characteristics of the loudspeakers tested in this investigation.

(h) SUBJECTIVE MEASUREMENTS

No matter how well a performance requirement might be written or upon how much experience it is based, it is conceivable that a loudspeaker may sound poor to an experienced jury of sound engineers and musicians, even though all the requirements of an objective nature are met.

Subjective tests of loudspeakers are best made by comparing the loudspeaker in question with a reference system. The same program material must be used in each case and the acoustical conditions must be identical. In the absence of a reference system, judgments of quality and other characteristics will be colored to a greater or less degree by previous experience of such testing by the observers, their knowledge of what constitutes good performance and upon personal preferences of reproduced speech and music. In case of the later, there is a wide divergence of opinion among people of just what constitutes acceptable quality.

IV. CONCLUSION

In this report emphasis has been given to certain tests which in the opinion of the writer were deserving of greater consideration. For example, a test of the over-all response reveals very much more of the performance of the sound system under actual listening conditions than does a test of the characteristics of the tone control.

There has been an effort on the part of several interested groups to weigh the requirements and tests for 16-mm projectors according to their relative importance. Certain tests should, of course, be given much greater weight than others. This weighting will be dependent upon individual judgment and experience.

Practical testing methods have been outlined. Most of the tests could be made by a laboratory equipped to make measurements of radio and amplifier equipment. Objective measurements of the loudspeaker and noise-level measurements require the use of a sound-level meter. Except for judgment tests, flutter can only be determined with some type of flutter indicator.

A real difficulty at present is the lack of proper test film to make some of the tests. For want of proper test film, some of the tests have to be made at present with an oscillator as a source for the test signal. Since a rather comprehensive sound-test film would be required to measure the many characteristics of a sound system, it would, of necessity, have several kinds of recorded signals. Suggestions for such a film have been reviewed by the SMPE Non-Theatrical Equipment Committee [1]. In addition, a warble-tone test film, much like that used in this investigation is necessary to make objective measurements of the loudspeaker and of the over-all response of the system. Until such a test film is generally available, many of the tests described in this report cannot easily be made. The SMPE 16-mm sound film available at present can be used to a limited extent for objective measurements, but it was made primarily for listening tests.

The following inprovements should be made on 16-mm projectors if they are to approach more nearly the performance of 35-mm projection equipment and other forms of sound-reproducing equipment. First, and probably most important, a decided improvement should be made in the extension of the over-all response to at least 5,000 c/s. Reduction of scanning-beam losses by one or more methods and improvement of the high-frequency response of loudspeakers are indicated as corrective measures to be taken. Second, a relatively low signal-to-noise ratio was obtained in some of the equipment tested. Reduction of hum and microphonic noise would improve the dynamic range. Third, more uniform film speed. Tests of one projector showed that a relatively uniform speed of the film at the scanning beam is not too difficult to obtain. However, the values of flutter obtained may represent a practical limit. Fourth, most of the loudspeakers should be improved. Some loudspeakers showed marked resonance and antiresonance regions. Fifth, a more uniform distribution of the high frequencies with angle from the axis of the loudspeaker should make a decided improvement in the listening conditions of a greater portion of the audience. Sixth, an effort should be made to reduce the noise of the operating mechanism of projectors. It is believed that much could be done if some of the moving parts were redesigned with careful consideration given to quiet operation. Seventh, the design of the amplifier should be such that the RMA ratings of the vacuum tubes are not exceeded. If these several improvements are made, it is believed that the manufacturer could place a far superior product on the market, and that educational groups would show a keener appreciation of projection equipment.

Acknowledgment is made to Peter Chrzanowski and Henry J. Leinbach, Jr. who assisted in the amplifier and loudspeaker measurements.

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