A Study of Theatre Loud Speakers and the Resultant Development of the Shearer Two-Way Horn System*

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EDITOR'S NOTE

This remarkable paper brought together the ideas and craftsmanship of a unique team gathered during the heart of the Great Depression to scientifically solve problems in reproducing motion picture sound. Dr. John Hilliard led this team, having been given administrative guidance by Douglas Shearer, the head of MGM's Sound Department.

John's team included men like James B. Lansing, Robert L. Stephens, Harry R. Kimball, and used consultants such as Dr. Blackburn. John, when asked what part he had played stated "I was the ringleader," and indeed he was. The system was given an academy technical award in 1936.

The study was published in 1936. Yet 42 years later it is a text that needs to be studied:

It should perhaps be emphasized that lack of good distribution cannot be corrected by equalization in the electrical circuits . . .

Or, in the discussion on directivity,

. . . since for the best illusion the ratio of direct to reflected sound should be as high as possible.

And the prophetic,

Probably the maximum slope (of filters) that can be tolerated is of the order of 20 dB per octave, or roughly, that of a single-section constant-k filter.

These giants literally founded the so-called West Coast loudspeaker industry and developed what today is thought of as the professional loudspeaker line of products.

I have the 1938 edition of Motion Picture Sound Engineering put together for the Research Council of the Academy of Motion Picture Arts and Sciences. "A Study of Theatre Loud Speakers and the Resultant Development of the Shearer Two-Way Horn System" is the major part of the chapter of "Headphones and Loudspeakers." In the book, the "new" (1938) Lansing 285 driver is illustrated with the original version of a slit-type phasing plug, currently under rediscovery by the industry.

When the knowledgeable observer considers that the systems these men designed and the concepts they developed are essentially still state-of-the-art in a competitive professional sound marketplace, one is aware of the power of a leader such as John Hilliard. Literally tens of thousands of jobs in manufacturing, distribution, contracting ranging through motion picture sound, recording, commercial sound, musical sound, and high fidelity have sprung from this early work at MGM.

This paper is the footprints left by the passage of giants on whose shoulders we stand today.

Don Davis

INTRODUCTION: The present investigation was undertaken with a twofold purpose in mind: first, to study thoroughly the more important types of extended-range loudspeaker systems in current use, and second, to develop if possible a system which would combine practicability for theater use with as great an improvement in quality and efficiency as could be obtained without greatly increased cost. The first objective necessarily involved an effort to secure as much as possible of the "why" as well as the "how" of the systems and individual speakers

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studied, while the second led to considerable investigation of certain aspects of loudspeaker design, some of which—at least in the literature of the subject—seem not to have been sufficiently emphasized in the past.

Any investigation of as wide a scope as the present one inevitably furnished many facts not pertinent to the main issue, but useful in other fields. The main body of the paper, however, has been written with the problem of the reproduction of sound for motion pictures ever in mind, and should be read from that viewpoint. It is felt, however, that the results referred to may form a definite contribution to other fields, such as public address work and home radio.

1. SOUND REPRODUCTION SYSTEMS FOR MOTION PICTURE THEATERS

The art of modern reproduction of sound in motion picture theaters is now about eight years old. During this time there has, of course, been considerable improvement, but there has been only one major change in the standard theater installation. This change was the adoption of the "wide-range"[1] and "high-fidelity" systems after 1933. The principal modifications involved were: first, a partial fulfillment of a greatly needed increase in amplifier carrying capacity; second, the adoption of speaker systems which provided for the division of power between two or more groups of speakers, each operating over a limited frequency range; third, improvements in the sound head which reduced flutter. While these improvements considerably raised the standard of reproduction in the theater, it was felt that the loudspeaker system still constituted the principal limitation to naturalness of reproduction. An investigation was accordingly made to determine whether a speaker system could be developed which would economically replace the present systems while providing the much needed increase in fidelity. This was found to be the case, and it is the purpose of the present paper to describe this system and the results obtained with it, and to compare it with previous systems.

Since it was not known how great a departure from a full-range linear response could be tolerated for the purpose in hand, it was considered advisable to start with a system as near this as so far achieved, even though the form of apparatus available by its size and cost would prohibit its use for theater installations. From this it was determinable how much deviation was allowable and necessary in order to obtain a commercially practical system. Such a linear system was made available [2], and a series of tests led to the following specifications which were found to be adequate for theater reproduction, taking into consideration further developments in recording which may be expected within the next few years.

2. SPECIFICATIONS

Flat Overall Frequency Characteristic. The system shall not deviate by more than plus or minus 2 dB, from 50 to 8000 Hz, over the entire angle of distribution within 10 ft (3 m) of the mouth of the horn.

High Electroacoustical Efficiency. It shall approach 50% in order that the required amplifier capacity may not be too great.

Volume Range. The volume range shall be at least 50 dB and preferably 60 dB.

Reasonable Cost.

Absence of Transient Distortion and "Fuzziness." The electroacoustical transducer shall be of such construction that it shall not generate objectionable harmonics up to the peak power required, and the phase delay between units shall be such that the sound will be equivalent to that coming from a single source.

Suitable Angular Distribution Characteristics. The sound shall be radiated through a horizontal angle as great as 110 degrees and a vertical angle of 60 degrees with nearly uniform response at all positions.

Reasonable Compactness and Portability. Low weight.

Amplifier Capacity. The installed amplifier capacity shall be such that 1 acoustic watt per 1000 ft^2 (92.9 m^2) of floor area each can be delivered when the auditorium is adjusted for optimum reverberation time.

A system which will conform to or exceed these specifications has now been developed, and can be constructed at moderate expense.

In order to take advantage of these characteristics it has been found that when film is reproduced over a system such as this, it is necessary to keep the flutter from the sound head no greater than 0.1%. Although the problem of flutter has been satisfactorily solved, and heads are commercially available which will pass the 0.1% flutter specification, it should be pointed out that by far the largest majority of heads in use today will not meet this specification.

3. POWER AND FREQUENCY REQUIREMENTS

The history of the electrical reproduction of sound has been one of continual increase in amplifier carrying capacity, and in this respect, the theater installation is no exception [3]. Originally, output powers from 2.5 to 12 watts were considered adequate for most houses. With the advent of the later systems now in use, these powers were recommended to be increased from 3 to 6 dB, depending upon the size of the house. It has been found from this investigation that is both practical and eminently desirable to make a further increase of at least the same amount. The figure given of 1 acoustic watt per 1000 ft^2 (92.9 m^2) of floor area is felt to be the minimum which will do justice to the advanced conception of reproduction with modern recording technique. It is of interest to note that this figure can be achieved allowing for considerable latitude above this point without danger of mechanical damage to the units.

The advisability of extending the frequency range of a reproducing system must be determined by balancing the gain in naturalness obtained by the extension, against the resulting increase in noise and extraneous sounds. In the present state of the recording art, a characteristic flat to 6000 Hz is the least that will do justice to the film; an extension to 7000 or even 8000 Hz is advisable, and a further extension is not. This is so because a further extension becomes of less and less value, due to the decreasing sensitivity of the ear and the small amount of energy in this region, and especially because above 8000 Hz noise, flutter, and harmonics due to recording deficiencies become decidedly the limiting factor. Incidentally, since practically all recording systems include a low-pass filter with a cutoff in the neighborhood of 8000 Hz there is nothing on the film at high frequencies to be reproduced.

Once the high-frequency limit is chosen, the low-frequency limit is automatically fixed. It has been found that for ideal balance the product of the two cutoff frequencies must be fairly close to 400 000, so that for an 8000-Hz upper cutoff, the lower becomes 50 Hz.

4. HIGH-FREQUENCY HORN

One of the principal limitations of present theater installations is bad directional characteristics. The plain exponential horn has a directivity which varies with frequency; low-frequency sound is projected fairly uniformly over a wide angle, but as the frequency is increased, this angle decreases rapidly until at frequencies of several thousand hertz practically all of the energy is emitted in a narrow beam. The result of this is that the reproduction becomes very "drummy" or "bassy" for that portion of the audience whose seats lie well off the axis. In the present system this effect is eliminated by using a radiating system for the high-frequency unit which is composed of a cluster of small exponential horns, each having a mouth opening of approximately .60 in^3 0.0387 m^2). These individual units are stacked in layers to form a large horn, the mouth opening of which is spherical in shape. The principle of this high-frequency unit can best be likened to a further compacting of the typical cluster of loudspeakers, as customarily used in auditoriums and stadiums for public address systems and announcing, except that the whole array is fed from a common header and driven by two dynamic units. This type of high-frequency radiation is also a feature of the aforementioned reference system [2]. However, the reference horn having been developed to a very limited angle and being driven by a single mechanism, was not adaptable to theater use as more than one horn became necessary for full coverage. This would result in nonuniform distribution as well as complete loss of coverage for a large part of the auditorium should one unit fail during a performance.

One of the features of the reference system is the use of a single diaphragm to reduce phase distortion. Inasmuch as theaters require parallel operation as protection in the case of failure of one unit, experiments were made with a Y throat (Fig. 1) and two units. As a result of these experiments, it is now recognized by all concerned that any increase in phase distortion which may be introduced by the Y throat is negligible.

The diaphragms are made of duraluminum 0.002 in (0.05 mm) thick and have an area of 6 in^2 (3871 mm^2). The diaphragm is mounted on the back of the assembly and by the use of an annular opening [2], the sound that is admitted to the throat within the unit has a minimum phase distortion (Fig. 2). This is still further reduced by having this throat exponential beginning at the annular opening and avoids a sharp discontinuity that may exist with a tubular throat. Two units are connected by means of a Y throat to the multichannel horn which tends to reduce the distortion of high throat pressure. The field excitation requires 25 watts per unit.

The directional characteristics of the resulting unit are very satisfactory as found in theater installations. It should perhaps be emphasized that lack of good distribution cannot be corrected by equalization in the electrical circuits, since for any given adjustment, the overall response is a highly varying function of position in the house. Although the characteristic can be made flat for any given position, it cannot be made so for all or even a large part of the house by this method.

5. LOW-FREQUENCY HORN

In the case of a low-frequency unit, a suitable driving mechanism was not available, and it became necessary to develop one. The unit finally adopted consisted essentially of an exponential horn with a mouth area of 50 ft^2 (4.65 m^2) and an axial length of 40 in (1.02 m), driven by four 15-in (0.38-m) dynamic units of special design. The mouth opening was extended laterally to form a flat baffle 10 by 12 ft (3.05 by 3.66 m). The paper cones are dipped with lacquer to prevent them from absorbing moisture, which would vary their response. They are connected in series–parallel to give a desirable impedance characteristic as well as providing insurance against complete failure of the system in the event any individual unit would fail. The angle of distribution is uniform through an arc of 50 degrees on each side of the axis. The use of a horn instead of a flat baffle board for low frequencies has several advantages. The efficiency is raised from 10 or 15% to better than 50%, which effects an enormous reduction in amplifier capacity. Undesirable radiation from the rear of the unit is considerably reduced, and as a result the usual objectionable back-stage low-frequency "hangover" is decreased to a negligible amount [1]. For purposes of further compactness and rigidity the low-frequency horn may advantageously be folded and in this form retains the same characteristic, if the air path length is maintained

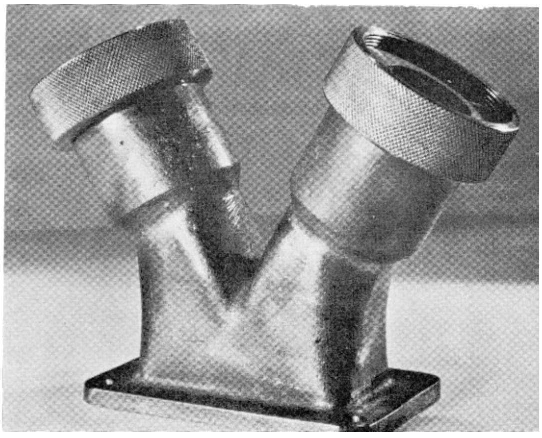

Fig. 1. Y throat.

unchanged. This modification was contributed by Dr. H. F. Olson of RCA Manufacturing Co. The loading provided by the air column of the horn decreases the excursion of the diaphragms as compared to the excursion necessary to produce equivalent output from a flat baffle array, and distortion is correspondingly reduced (Fig. 3).

With the low-frequency horn length as specified in the design under discussion maintained approximately equivalent to the length of the high-frequency horn, there is no time delay between the component sounds from the two horns.

6. HORN ASSEMBLY

The folded horn is assembled in sections, each section containing two driving mechanisms. They may be stacked one upon the other, depending upon the number required. Each section is adequate for an output from the amplifier of 25–30 watts for the required minimum harmonic content. If it is desired to secure a wide lateral distribution, the sections may be placed side by side. Section A–A of Fig. 4 shows the construction of the horn.

The entire horn is assembled so that the center of the high-frequency unit is approximately 50–60% of screen height. This position has been found by years of use to be the center of activity or "presence" on the screen, and since the high frequencies are responsible for determining the presence, the unit was so arranged. In order to keep the sound as near a point source as possible, the low-frequency horn is maintained at a position near the high-frequency horn (Figs. 5 and 6).

The complete assembly is a unit so that it can be moved away from the screen or raised and lowered with the screen with a minimum effort. The use of sections for the low-frequency horn allows the horn to be shipped and moved into spaces which have standard size doors.

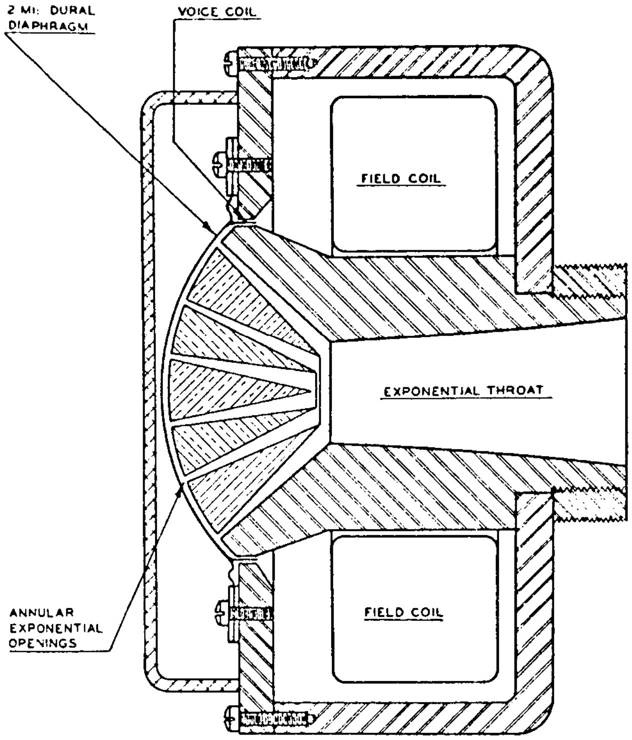

Fig. 2. Lansing no. 284E high-frequency unit.

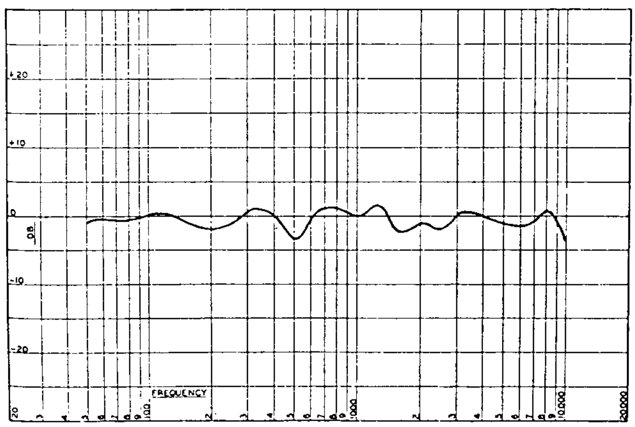

Fig. 3. Output characteristic of Shearer horn system measured on normal axis and 10 ft (3 m) from horn.

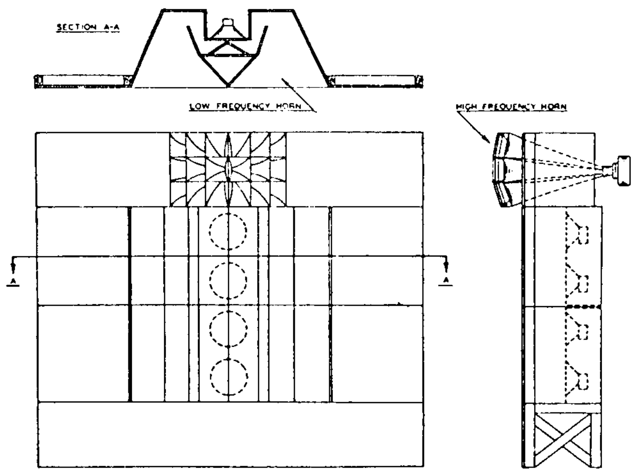

Fig. 4. Shearer two-way horn system, folded type.

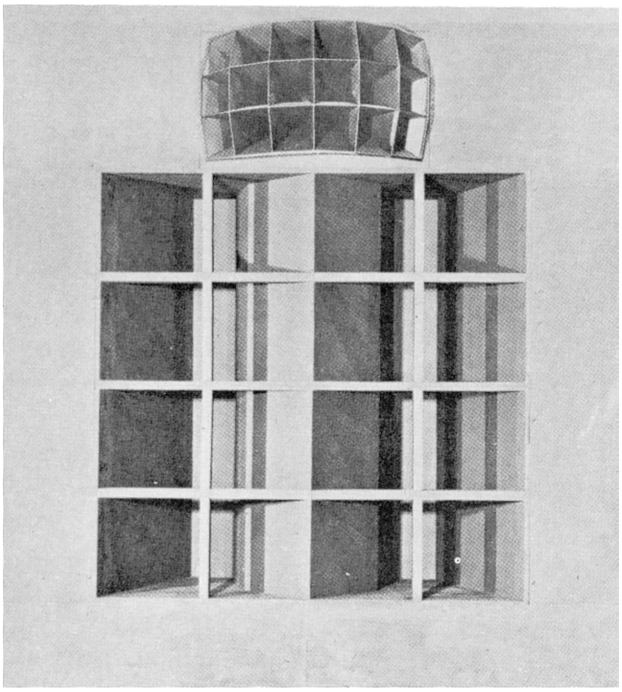

Fig. 5. Folded horn assembly.

7. DIRECTIVITY

For both the low- and the high-frequency units a certain amount of directivity is desirable. For most houses there should be but little energy radiated at angles greater than about 45 degrees from the axis, since such energy will be reflected from the walls, and since for the best illusion the ratio of direct to reflected sound should be as high as possible.

There is one additional consideration with regard to directivity which should be mentioned. Knudsen [4] has shown that at the higher frequencies, for example, at 10 000 Hz, absorption of the atmosphere may become very serious, being as great as 0.2 dB/ft (0.3 m) under certain conditions of humidity and temperature. In large and deep houses this would result in a serious loss of high frequencies in the rear seats. This effect can be considerably reduced by increasing the high frequency radiated from those horns of the unit which serve these seats. It may be done by putting a suitable amount of absorbing material in the other horns and re-equalizing to bring the overall response up to standard for the front seats. These artifices will probably not be required in most houses.

8. HARMONIC CONSIDERATIONS

One major defect of commercial loudspeakers is their large amplitude distortion. One of the striking improvements in the new system is its cleanness of reproductions at low frequencies. The measured harmonic content is less than 4% for 30-watt output. This is due in large part to the use of a thick and comparatively soft cone which can be driven to full excursion without breakup, and consequent harmonic production. It was found by actual listening tests that with a pure tone of 40 Hz impressed, most of the cone speakers investigated gave a greater apparent loudness than the speaker finally adopted. However, when a direct comparison was made by keying the amplifier from the new unit to the unit under test, it was at once obvious that the output of the new one was fairly pure 40-Hz tone, while that of the other speakers consisted of, in most cases entirely, the second and higher harmonics. Direct measurement of the acoustic output showed that in spite of its low apparent loudness, the fairly pure output of 40 Hz was actually about 6 dB higher than that of the other speakers.

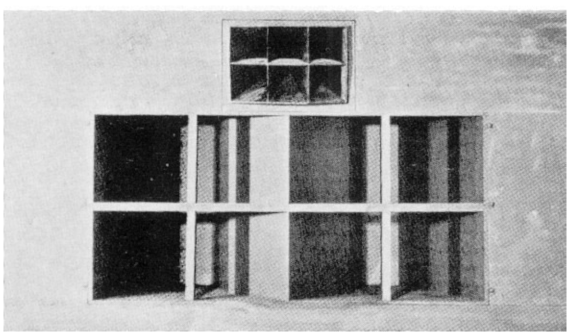

Fig. 6. Single-section low-frequency horn with 52-degree high frequencies for use in studio viewing rooms and small theaters.

This great increase in apparent loudness due to transferring part of the fundamental power into harmonics in the conventional speaker is very striking, and is undoubtedly the explanation for the alleged high efficiency of many present-day speakers of all types. The loudness of the harmonics is not due to the rapid change in the sensitivity of the ear at low frequencies which would favor the harmonics at the expense of the fundamental, since it also occurs at fairly high frequencies where the sensitivity of the ear is varying in the opposite way with frequency. With one particular pair of units tested, the effect was more striking at 1000–2000 Hz than at any other frequency. It is equally great with complex sounds, such as speech and music, although here the change in quality is somewhat less with respect to the change in apparent loudness than in the case with pure tone.

9. PHASING

Another important advantage of the new system is that it can easily be made to fulfill the requirements that the virtual sources of all the components of the reproduced sound shall coincide in the vertical plane. This condition is impossible to obtain with divided frequency range systems now in use in which the axial length of the several types of horns in a given system are widely different. In this respect, a two-unit system is much easier of adjustment than a three-way system [1]. It might be thought that since the time delay is so small, of the order of a few milliseconds, the effect would be inappreciable. This is true for certain types of sound such as sustained music passages, but on dialog and especially certain types of sound effects which are of the nature of short pulses, a very objectionable distortion is usually noticeable. A striking demonstration of this fact was obtained by recording a tap dance. When this was reproduced it was found that the system with a very small time delay gave a naturalness of reproduction, but that systems which had an appreciable delay reproduced the scene with far less realism. In fact, the sound did not appear to come from the screen, and, in addition, the tap was fuzzy in character with a decided echo.

This effect sounds somewhat like that of transient distortion due to the use of a filter with too sharp a cutoff, but it is actually more analogous to the echo effect often observed on long lines and with certain types of phase distortion networks.

A recent paper [1] discusses the features of the three-way system including some of the limitations which require special installation techniques for the setting of horns, back stage draping, phasing of various horn positions, position of horns for distribution, and setting of volume between horns. Familiarity with these data will assist in appreciating the principles of the present system.

It should be pointed out that the overall frequency response curve of the system should not fall off too rapidly beyond the cutoff frequencies, or objectionable transient distortion will result. Probably the maximum slope that can be tolerated is of the order of 20 dB per octave, or roughly, that of a single-section constant-k filter.

10. DIVIDING NETWORK

The frequency chosen for the critical frequency of the dividing network is governed by several factors. If this frequency is too low, it leads to uneconomically large values of capacity in the network, and to impracticably large horns for the high-frequency unit. If too high, there is danger of running into the characteristic dip which seems to be always present in large cones, and also, it would result in dividing the prime energy of speech sounds between the two units, which is objectionable from the standpoint of good presence. If the critical frequency is chosen as approximately 250 Hz, a good compromise results (Fig. 7).

A dividing network was chosen which gave fairly rapid attenuation, 12 dB per octave, in order to keep any appreciable low-frequency energy out of the high-frequency unit, and to minimize the effect of irregularities encountered in the response curve above the designed range of the low-frequency cones. This lies somewhat above 400 Hz for an efficient low-frequency unit. Certain dividing networks in current use have attenuation curves of such gradual slope that at some frequencies the irregularities in the response curves of the speakers are actually greater than the attenuations of the network.

The network is designed so that the reflected impedance of the horn on the amplifier is approximately 2.5 times the amplifier impedance. The loss in the network is less than 1 dB in order that the full capacity of the amplifier may be utilized.

11. MEASUREMENTS

While it is recognized that indoor response measurements do not have the degree of precision that may be had in free space, they nevertheless do represent conditions under which the loudspeakers must actually be used for motion pictures. Also, for the purpose at hand, comparative measurements are sufficient and were verified by listening tests, which in the end is the final criterion. (Fig. 3 shows average response.)

Irregularities in the sound pressure at the microphone due to standing-wave patterns in the room are minimized by the use of a conventional warble frequency, varying ± 25 Hz at a 10-Hz rate. Tests have been run which indicate that the warble is only effective below 2000 Hz. Above this point, the standing waves do not interfere with the correct interpretation of the response curve.

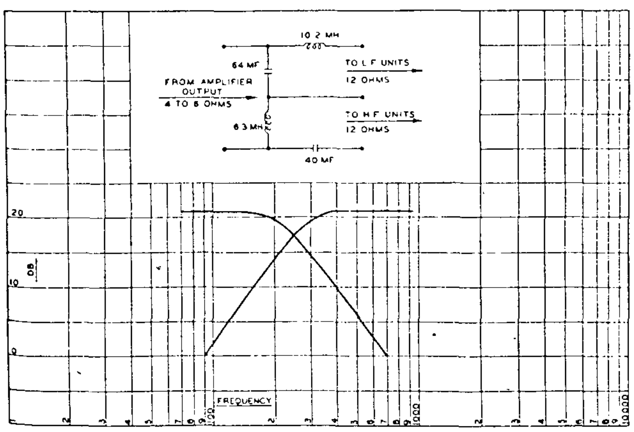

Fig. 7. Series-type dividing network, Shearer horn system.

The measurements were taken in a stage 100 by 70 by 35 ft (30.5 m by 21.3 m by 15.7 m), having a reverberation time of 1 second at 512 Hz. By making these measurements indoors, tests could be made rapidly on a large number of units without the interference from outside noises due to a 60-dB insulation between inside and outside provided by the building.

The response curves were measured using a high-speed level indicator [5] capable of responding to a change in level as rapid as 300 dBs.

ACKNOWLEDGMENT

Douglas Shearer, head of the Metro-Goldwyn-Mayer Sound Department, brought about and directed this project. This development was engineered by the writer and contributed by Metro-Goldwyn-Mayer Studios. The cooperation of the following companies is gratefully acknowledged: Electrical Research Products, Inc.; R.C.A. Manufacturing Co.; Lansing Manufacturing Co.; and Loew's, Inc. These companies assisted by making available test equipment, the reference system, staff, and theaters, which greatly facilitated the work and produced a coordinated result not otherwise possible. The writer also wishes to acknowledge the contribution of the Metro-Goldwyn-Mayer Sound Department, and in particular Robert L. Stephens, who has carried out the mechanical design.

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APPENDIX

A1. LOW FREQUENCY EXPONENTIAL HORN

Fundamentally, the design of a low-frequency exponential horn follows the same treatment as that accorded a horn for high-frequency response. There is, however, a greater tolerance allowable in deviating from theoretically calculated values, namely, expansion rate (governing value of cutoff frequency), mouth size, and nature of crosssection. Discontinuities which would be out of the question in high-frequency design may be permitted with little loss in a low-frequency horn. Numerous tests have borne out the above statement. A horn of folded crosssection has been chosen for general use in this system, because it permitted a compactness of design not possible with a straight exponential horn. Sufficient loading has been obtained in a small space to permit the cone-driving units to operate at their optimum efficiency.

For the purposes of illustrating the method of computation, a brief summary of the calculations involved in the design of a straight exponential horn will be given (Fig. 8).

The cutoff frequency was chosen at 50 Hz. A 50-Hz wave has a length of 271 in (6.88 m). The distance across the mouth of the horn should be at least equal to one quarter the wave length of the lowest frequency it is desired to transmit. This value for the horn in question gives a minimum mouth size of 68 in (1.73 m). The size of the throat must be sufficient to accommodate four 15-in (0.38 m) cone speaker units. A throat size of 30 by 30 in (0.76 by 0.76 m) was chosen.

The following statement is repeated from the section on high-frequency horn design.

It has been found that an exponential horn whose area doubles every 12 in (0.3 m) will have a cutoff frequency of 64 Hz; one whose area doubles every 6 in (0.15 m) a cutoff frequency of 128 Hz. From the above relationship the length for the area of the present horn to double may be found by simple proportion:

$$\frac{64}{X} = \frac{50}{12}$$

from which $X = 15.36$ in (0.39 m).

From the general horn equation

$$A_x = A_0 e^{MX}$$

where

A_x = area at any point X
A_0 = area of throat, chosen above as 900 in^2 (0.58 m^2)
e = 2.7183
M = flare constant of horn
X = distance along horn axis from throat

M can be computed by substituting known values in the above equation:

$$1800 = 900 \times 2.7183^{15.36M}$$

from which $M = 0.045$.

Then the equation for the present horn becomes

$$A = 900e^{0.045X}$$

from which the sectional area at all points X may be computed.

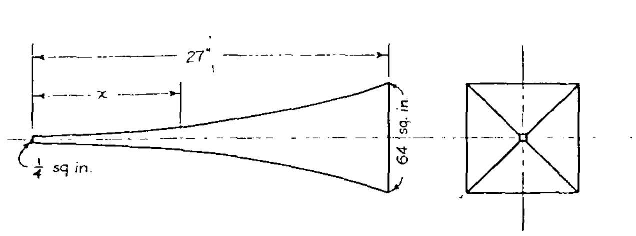

Fig. 8. Typical individual channel.

For a minimum distance across the mouth of the horn of 68 in (1.73 m) or a minimum mouth area of 4624 in^2 (2.98 m^2), the length is determined:

$$A = 900e^{0.045X}$$

$$4624 = 900 \times 2.7183^{0.045X}$$

where $X = 36\frac{1}{4}$ in (0.92 m).

It has been found, however, that while the sizes above are satisfactory from a theoretical standpoint, an increase in loading will result in a higher efficiency. An increase in length to 44 in (1.12 m) with a corresponding mouth size of 80 in (2 m) or 6400 in^2 (4 m^2) has, as a result of tests, proven to be perhaps the most desirable size. The overall length inclusive of units then becomes approximately 55 in (1.40 m). This length is considerably more than is desirable for the majority of installations.

The above analysis applies to the straight type horn rather than the folded type.

Fig. 4 illustrates a horn of folded cross section. Here is is possible to retain optimum loading conditions in a minimum of space. It is, however, in this case mechanically impractical to construct a horn of true exponential shape.

The mouth, throat size, and flare constant are determined as in the case of the straight exponential horn. Intermediate cross-sectional areas are approximated to those of a true exponential horn as closely as is feasible without involving constructional difficulties.

It has been found that the difference in response is sufficiently slight as to justify this deviation from the theoretical.

A2. HIGH-FREQUENCY EXPONENTIAL HORN

The specifications require that the overall depth or length of both low- and high-frequency assemblies do not exceed 44 in (1.12 m).

This limitation of length brought about the selection of a theoretical cutoff frequency of 220 Hz. This value of cutoff allowed the design of a horn which fulfilled the desired requirements, such as a spread of either 90 degrees or 105 degrees with a maximum of six separate channels and a sufficient mouth size to present a reasonably small amount of discontinuity.

A brief summary of the design calculations follows.

It has been found that an exponential horn whose area doubles every 12 in (0.3 m) will have a cutoff frequency of 64 Hz; one whose area doubles every 6 in (0.15 m) a cutoff frequency of 128 Hz. Then by simple proportion the length for the area of the present horn to double may be found:

$$\frac{64}{X} = \frac{220}{12}$$

from which $X = 3.5$ in (88.9 mm).

From the general horn equation:

$$A_X = A_0 e^{MX}$$

where

A_X = area of any point X
A_0 = area of throat, chosen as ¼ in² (16.1 mm²)
e = 2.7183
M = flare constant of horn
X = distance along horn axis from throat

M can be computed by substituting known values in the above equation:

$$\tfrac{1}{2} = \tfrac{1}{4} \times 2.7183^{3.5M}$$

from which $M = 0.2$.

Then the equation for the present horn becomes

$$A = \tfrac{1}{4}\, e^{0.2X}$$

From which the sectional area of the horn at all points X may be computed.

Dividing Networks for Loud Speaker Systems*

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EDITOR'S NOTE

Hilliard and Kimball's writings and a careful look at the very real systems they designed for the motion picture industry should be a required discipline for the electronic circuit designer with crossovers in his plans. Electronics expertise minus the acoustic know-how of these pioneer giants continues to seriously mislead contemporary crossover investigations.

System designers must consider simultaneous and occasionally conflicting criteria in the design of crossover networks: 1) role of directivity factor, 2) inversion of coverage angles at a given frequency, 3) power distribution of program material in addition to standard transfer function characteristics of amplitude, phase and impedance. Most current articles on the subject cause a sigh of pain.

Not since John Hilliard and Harry Kimball's work on the subject have any writings appeared that considered more than one or two of the variables at a time and usually the author of a crossover article flogged one argument to death to the exclusion of all others.

Attenuation, phase, impedance and that lump-all term "loudspeaker characteristics" are all considered in their writings. The one legitimate "improvement" since their articles might be the proposal to start at one attenuation rate for the first octave and steeper rate for subsequent octaves.

Don Davis

INTRODUCTION: In the design of linear sound-reproducing equipment where it is desired to faithfully reproduce tones from about 50 Hz to about 8000 Hz it is common practice to divide the frequency range into two or more parts and provide one or more loudspeakers for each of these frequency ranges. The speakers employed for the different bands are, of course, differently designed, each speaker being particularly suitable for its own band. Since it is not possible to design speakers which will faithfully and efficiently reproduce frequencies in one preassigned band and sharply attenuate frequencies outside of the band, it is necessary to supply an electrical network between the final power amplifiers and the speakers to deliver the correct frequency band to each of the sets of loudspeakers. These networks have acquired the name of "dividing networks."

It is the purpose of this paper to discuss the theoretical and practical design of such networks and give data from which the electrical constants may be easily selected. Only two-way speaker systems, that is, systems dividing the frequency band into two parts, are discussed. The theoretical information given, however, is fundamental in nature and may be easily extended to cover three-way speaker systems.

For the two-way system the speakers handling the lower frequencies are termed the low-frequency speakers or low-range speakers. In like manner the speakers having the job of reproducing the higher frequencies are called the

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