A High Efficiency Receiver for a Horn-Type Loud Speaker of Large Power Capacity

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SYNOPSIS: This paper describes a telephone receiver of the moving coil type which is particularly adaptable to the horn type of loud speaker and which represents a notable advance over similar devices at present available. Its design is such as to permit of a continuous electrical input of 30 watts as contrasted with the largest capacity heretofore available of about 5 watts. In addition, measurements show that the receiver has a conversion efficiency from electrical to sound energy varying between 10 and 50 per cent in the frequency range of 60 to 7,500 cycles. Throughout most of this range, its efficiency is 50 per cent or better. This contrasts with an average efficiency of about 1 per cent for other loud speakers either of the horn or cone type. Combining the 50 fold increase in efficiency with a 5 or 6 fold increase in power capacity, a single loud speaker unit of the type here described is capable of 250 to 300 times the sound output of anything heretofore available.

This device is in commercial use in connection with the Vitaphone and Movietone types of talking motion pictures. As commercially produced in quantities numbering several thousand, an average efficiency of the order of 30 per cent has been realized.

BEFORE the advent of radio-broadcasting, practically the only loud-speakers in commercial use were of the horn type. In recent years this type has been largely supplanted by others of more compact des'gn. However, where appearance and size are not of prime importance, a loud speaker with a horn still has a large field of service, as, for instance, in public address equipment or in systems for reproducing speech and music in large auditoriums from wax or film records. For such uses, the greater directivity obtained by the use of a horn has in some respects definite advantages. In the design of the receiver about to be described we have had in view particularly the requirements for such services, where the following qualifications were deemed of the greatest importance: a good response-frequency characteristic up to at least 5,000 p.p.s., large power output without amplitude distortion, high efficiency, and constancy of performance.

As this paper is concerned with the design of a driving unit, or the receiver proper, and not with the horn, we shall confine our discussion to the operation of the receiver when connected to a tube of infinite length and of the same cross-sectional area as the throat of the horn. An ideal horn should have at its throat the same acoustic impedance [1]

[1] The term acoustic impedance as here used may be defined as the ratio of pressure to rate of volume displacement.

as a tube of this character, viz., $\frac{\rho c}{A}$ c.g.s. units, where ρ is the density of air, c, the velocity of sound, and A, the area.[2]

The Coupling Air Chamber and Diaphragm

In order effectively to make use of horns as sound intensifiers it is usually necessary to couple the throat of the horn to the diaphragm through an air chamber. We shall first consider the effect of this air chamber on the sound output of the loud speaker. This coupling air chamber is generally of an indefinite conical shape of the type shown in Fig. 1. If we assume that this air chamber is so proportioned that

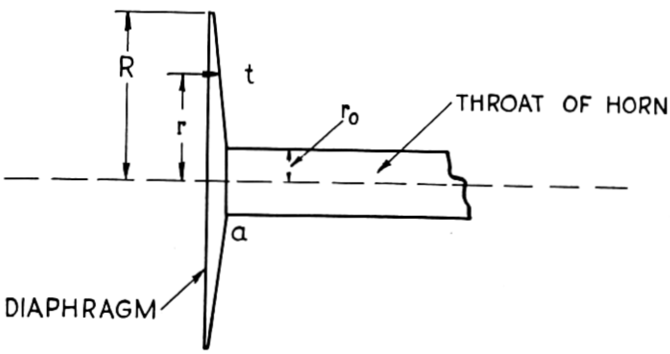

Fig. 1—Conventional type of coupling air chamber.

the annular area, $2\pi rt$, is equal to the throat area, and that the diaphragm is driven so that its displacement is paraboloidal, then, as calculated from formulæ developed in appendix A, the mechanical impedance imposed by the air chamber and horn on the diaphragm is shown in the curves of Fig. 2. Here the ordinates of the curves r_1 and x_1 are proportional to the resistance and reactance respectively, and the abscissæ are equal to the product of the frequency and the radius of the diaphragm. Of particular interest here is the large decrease in the resistance with frequency, for r_1, multiplied by the square of the velocity of the diaphragm, is the acoustic power delivered to the horn. For example, if the radius of the diaphragm were four centimeters, no sound would be emitted at 4,000 p.p.s. We have here one reason why most horn-type loud speakers fail to reproduce high frequency tones at sufficient intensity. Of course, in most cases the high frequency tones are further attenuated by the fact that the mode of motion of the diaphragm changes with frequency. The decrease in

[2] "The Function and Design of Horns," by C. R. Hanna and J. Slepian, *Journal of the A. I. E. E.*, March 1924.

resistance with frequency is largely due to the fact that the disturbances generated at different points of the diaphragm do not reach the throat of the horn in the same phase. To minimize this effect the air chamber should be designed so as to make this phase difference as small as

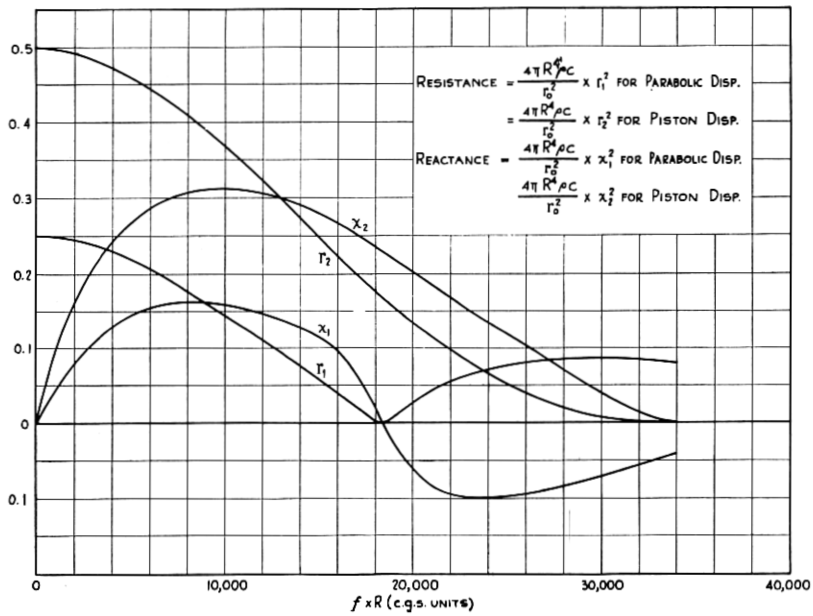

Fig. 2—Mechanical impedance of air chamber and ideal horn.

possible. In the same figure, r_2 and x_2 show the resistance and reactance respectively, if the diaphragm were moved as a plunger, i.e., with the same amplitude and phase over its whole surface. It is seen that the resistance is considerably larger and the cut-off frequency nearly twice as high. These curves show the superiority of the plunger type of diaphragm.

In order to cover the desired frequency range the method of coupling a diaphragm to the horn shown in Fig. 3 was adopted. Here the disturbances reach the horn more nearly in phase without having to pass through any restricted passages. The throat of the horn is flared annularly to the point A. The disturbances reach the throat of the horn from the inner and outer portions of the diaphragm approximately in phase up to comparatively high frequencies. With this type of construction it is possible to use a fairly large diaphragm so that large amounts of power may be delivered without a great sacrifice in efficiency at either the high or the low frequencies. An experimental test showed that with this type of coupling for a particular size of diaphragm and throat area the cut-off frequency was raised from approximately 3,500 to 6,000 cycles per second.

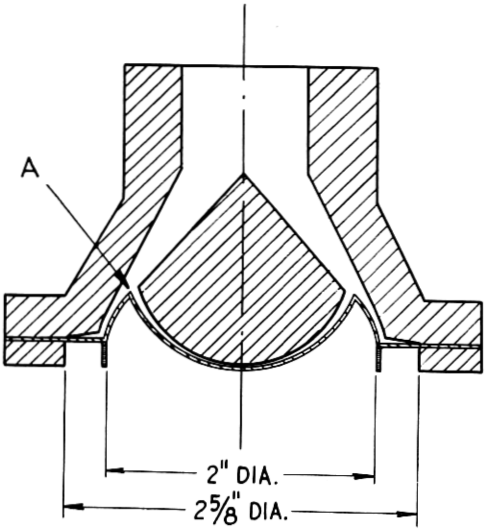

Fig. 3—Diaphragm and air chamber.

Principal Dimensions

Effective mass of coil and diaphragm = 1.0 gm.
Effective area of diaphragm = 28 sq. cm.
Area of throat of horn = 2.45 sq. cm.

$$\text{Stiffness constant} = \frac{\text{force}}{\text{static displacement}} = 6 \times 10^{6} \text{ dynes/cm.}$$

Resistance of coil = 15 ohms.
Length of wire in coil = 760 cm.
Average flux density = 20,000 gauss.

The diaphragm was made of a single piece of aluminum alloy 0.002 inch thick; metal was used in preference to other materials because of its superior mechanical properties. The form and principal dimensions are shown in Fig. 3. A driving coil is attached directly to the diaphragm near its outer edge. With this arrangement the diaphragm can be driven nearly as a plunger and it has little tendency to oscillate about a diametral axis, as there is great rigidity against a radial displacement of any part of the coil. The portion of the diaphragm lying between the coil and the clamping surfaces has tangential corrugations of the same type as described by Maxfield and Harrison [3] in reference to a phonograph sound box. The inner portion of the diaphragm was drawn into the form of two re-entrant segments

[3] *Bell System Technical Journal*, Vol. V, pp. 493–523, July 1926.

of spherical shells; this part was thereby made very rigid so that it should move as a unit up to high frequencies.

Construction of the Driving Coil

For the driving element of loud speakers either a moving coil or a moving armature is commonly used. The latter is in general satisfactory if driven at a small amplitude. However, where large powers are involved, the moving coil drive can be much more simply constructed so that it is free from amplitude distortion; it has the further advantage of having a resistance nearly constant with frequency and a practically negligible reactance. These were the primary reasons for our choosing this type of drive.

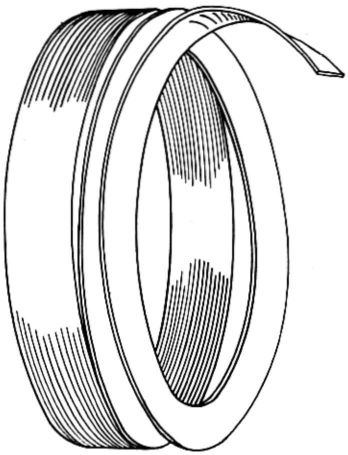

Fig. 4—Receiver driving coil.

The coil that was used in the receiver consisted of a single layer of aluminum ribbon 0.015 inch wide and 0.002 inch thick wound on edge as shown in Fig. 4. The turns were held together with a film of insulating lacquer about 0.0002 inch thick, thoroughly baked after the winding was completed. This type of coil has the following advantages. It is self-supporting, no spool being required; 90 per cent of the volume of the coil is occupied by metal; the distributed capacity between turns is small, giving a coil whose impedance varies only slightly with frequency; the metal is continuous between the cylindrical surfaces, allowing heat to be conducted rapidly outward from the center of the winding and diminishing the possibility of any warping of the coil; it can be accurately made to dimensions, thus permitting small clearances between the coil and the pole pieces. Small clearances not only permit the use of a comparatively small magnet but they facilitate the dissipation of heat. This latter effect is shown in the curves of Fig. 5. These curves give the temperature of the coil as a function of the power input for the coil in open air (A), and when it is placed between annular pole pieces with clearances of 0.010 inch between the cylindrical surfaces (B).

The Electromagnet

As shown in Fig. 6, the electromagnet is of conventional design except that the central pole piece has an opening through its center to

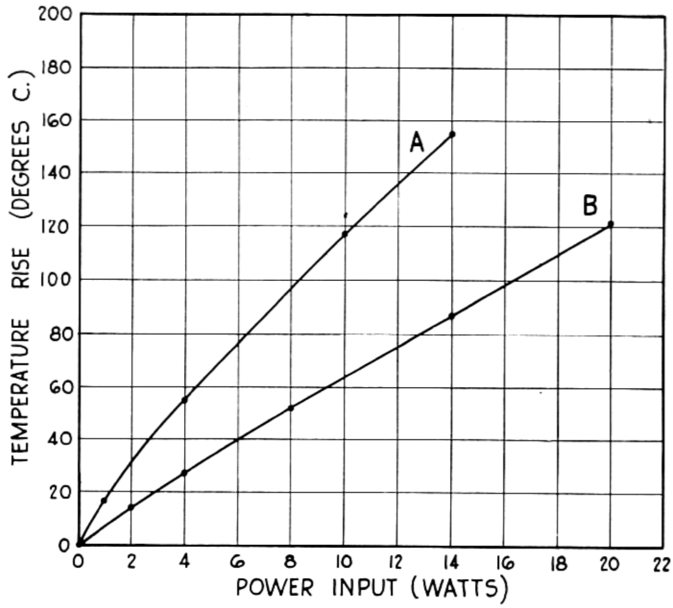

Fig. 5—Variation of temperature of coil with direct current input.

avoid a reaction of any air pockets on the diaphragm. This opening is widely flared to prevent tube resonance.

Experimental Results

It has already been pointed out that an ideal horn should have an acoustic impedance at its throat equal to that of a tube of infinite length and of the same cross-sectional area. In order to measure the

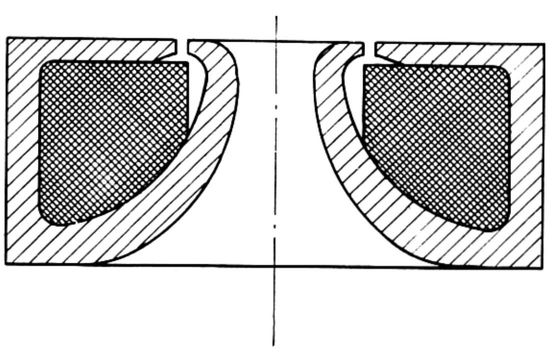

Fig. 6—Field magnet.