Development of Horn-Type Moving Coil Driver Unit*

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A driver unit with extended power, response, and reliability performance is described, with improvements resulting from new materials and techniques. The flexure of a new industrial material, polyimide, provides higher fatigue strength at high diaphragm displacement and high moving coil temperature. Aluminum ribbon anodized for insulation reduces the overall weight of the moving system. The method of coil termination and takeoff lead design allows higher power and reliability. Heat treatment of the aluminum diaphragm increases its fatigue strength.

INTRODUCTION

HORN-TYPE loudspeakers are used where wide frequency response, efficiency, and directivity are important.[1] They are superior at high frequency to combinations of direct radiators with cone shaped diaphragms. Differences in phase among a group of cones create irregular high-frequency response and directivity.[2] A single unit driving a horn, however, has more uniform response and directivity. A plurality of various direct radiators using a large spacing (compared to wavelength) generates a multiphase condition. The more simple and compact high-frequency radiator will provide the best reproduction.

This is the basic reason why the simplest configuration of a two-way system has achieved its reputation in the highest quality theater recording monitor and sound reinforcement applications.

The acoustic performance of a horn-loaded loudspeaker is a function of both the driver and the horn. In addition to the specific match between driver mouth and horn throat, the geometry of the horn is a factor.

It is desirable to design the horn with its frequency cutoff below the driver so it will be fully loaded in its operating range. To utilize the maximum high-frequency response of the driver, the horn should have the least possible length. Any folding or bending of the acoustic path will also reduce the high-frequency response where the dimensions of the bend or turn in direction are comparable to wavelength.

Moving-coil driver units are made for voice paging, auditorium sound reinforcement, theater projection, and high-fidelity home entertainment systems. Units for voice paging use 1½- and 2-in. voice coils in air gaps with magnetic flux densities of 8 to 13 kilogauss (kG). Frequency range is limited to 300 to 3000 Hz. A simplified loading plug in the throat serves as an acoustic transformer to match the diaphragm to the throat of the horn. These drivers have diaphragms of phenolic or similar material. The efficiency of voice-paging drivers is 10 to 20% at 1000 Hz and less than 5% at frequencies higher than 2000 to 3000 Hz. For extended frequency range, diaphragms are spun or drawn from 0.002-in. thick aluminum alloy. For the extended range, moving coils are 2 to 4 in. in diameter. The compliant portion, called a flexure or surround, is an annular or tangential member between the diaphragm and clamping ring. The coils are mounted on paper composition material cemented to a shoulder on the diaphragm. For highest efficiency, the coils are edge-wound of aluminum ribbon. (The ribbon has a conductor volume resistivity 25% smaller than that of round wire.) In some of the earlier units, coil leads were brought out across the flexure by cementing them to its surface.[3] In later models, arched takeoff leads of beryllium copper are employed. Gap flux densities up to 16 kG produce efficiencies approaching 30% over the octave interval from 500 to 1000 Hz. The mass of the moving system limits high-frequency response. For that reason, all practical ways of reducing the mass are used.

Low-distortion driver units for theater or auditorium sound reinforcement, and high-fidelity home entertainment systems have a frequency range from 400 to 15,000 Hz. The diaphragm radiates sound from its inner side through a series of annular rings in a conical phasing plug in the mouth of the driver.[4] The plug equalizes the path lengths from all portions of the diaphragm to the mouth of the driver. This arrangement reduces the destructive interference that would otherwise occur at the highest frequencies.[5]

The power required varies with the application. Indoor theater and sound reinforcement systems require outputs of 10 to 40 acoustic watts. In the open, 50 to 200 W are needed. For economy, driver units must operate at their maximum ratings for such high power.

With commonly available moving-coil drivers, a number of problems arise: *1.* Heat generated by high operating current can warp the voice coil. *2.* Large displacement amplitude of the diaphragm can cause early fatigue of the takeoff leads. *3.* Rupture in the flexure, usually near the attachment, and in the diaphragm itself, can be a major cause of failure. *4.* Iron filings and other particles of magnetic material in the air gap can cause scoring and consequent arcing of the voice coil because of short circuits. *5.* The 2000 g acceleration of the voice coil at high frequencies can cause relative movement of turns resulting in breakdown of coil structure. *6.* Sound power densities greater than 1 W/cm^2 (160 dB SPL re 2×10^{-4} dynes/cm^2) can result in excessive distortion. In the throat of a horn with a 300 Hz cutoff, distortion can be 5 percent at 1000 Hz and 1 W/cm^2.

The development program has been concentrated on these problems. An improved moving-coil driver for horn-type loudspeakers has resulted. The new driver unit, shown in Fig. 1, which develops 15 acoustic watts, has wide-band efficiency, high durability, and wide frequency range. The steps taken and the excellent results obtained will be discussed in the following section.

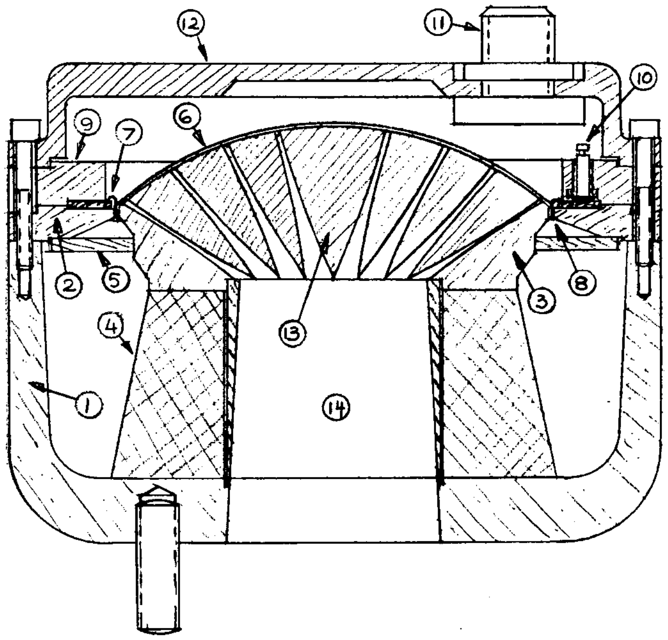


FIG. 1. Schematic diagram of the improved moving-coil driver. *1.* Case. *2.* Pole plate. *3.* Pole piece. *4.* Magnet. *5.* Centering ring. *6.* Diaphragm. *7.* Compliance. *8.* Coil. *9.* Clamping ring. *10.* Spring contact. *11.* Connector. *12.* Cover.

IMPROVEMENTS

Improvements over the past practice in four areas have resulted in a superior driver unit. These areas are: *1.* Diaphragm; *2.* Flexure; *3.* Moving coil termination and coil support; and *4.* Magnetic structure.

Diaphragm

The requirements for a good diaphragm are high stiffness and low mass, while the flexure requires low weight and high flexural strength. For this reason, the diaphragm is made as a separate unit. The material is 2024-0 aluminum foil, 0.002 in. thick. After drawing, the diaphragm is heat-treated to a T4 condition for improved stiffness and resistance to fatigue. Weight is 1.10 g, about half the total weight of the moving system. This construction results in extended frequency range and high output.

Flexure

A major change from previous designs results in a flexure of material different from that of the diaphragm. A 0.005-in. thick polyimide film is formed in a mold at a temperature over 600° F (polyimide operates up to 800° F). A single annular roll permits an excursion of 0.030 in. A rigid coil support forms an integral part of the flexure. Figure 2 shows the combined flexure and coil support. Light weight, high flexural strength, and a wide range of thermal dimensional stability results. These factors keep the moving coil in its optimum position.

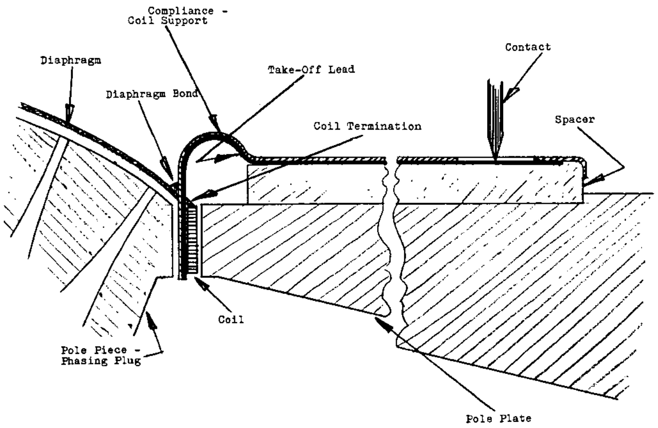


FIG. 2. Schematic diagram of the flexure and coil support.

Moving Coil

A 4-in. diaphragm provides the required sound pressure at low amplitude of displacement. The resulting 4-in. voice coil permits adequate heat dissipation. The coil has 30 turns of 0.0035×0.0158-in. aluminum ribbon wound

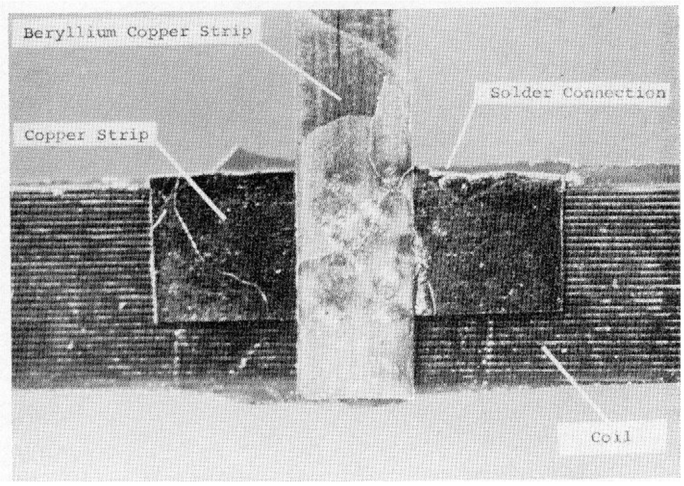


FIG. 3. Improved method of effecting connection.

edgewise; anodizing by a soft high-density process gives high turn-to-turn insulation and good adherence to the overall epoxy coating. A new method of coil termination and lead takeoff eliminates the weakness in this area. Figure 3 shows how a 0.002 × 0.06-in. beryllium copper strip connects to the aluminum ribbon. A copper foil strip, 0.001 × 0.06 × 0.250 in., crosswise spotwelded to the beryllium copper strip, provides a low-resistance termination and avoids the critical soldering to beryllium copper. A thin polyimide film strip bonded to the outer coil surface protects its soft surface from scratches and consequent short circuits. The voice coil, flexure, and diaphragm are held in position by an extruded outer rim which also positions the assembly on the spacer ring of the pole plate. A clamping ring holds the assembly in place.

Magnetic Structure

A carefully designed magnetic structure produces a flux density of 18 kG in the air gap. Three pounds of Alnico 5-7 provides the needed 6 lbs of force, producing the displacement and acceleration shown in Fig. 4.

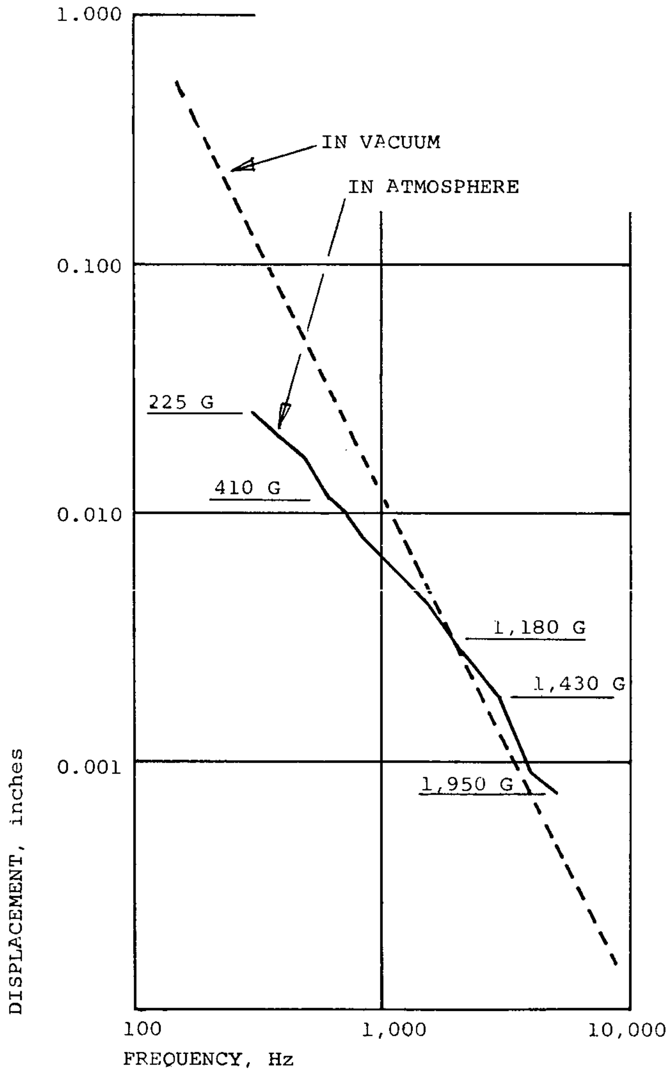


FIG. 4. Displacement and acceleration *vs.* frequency. (Diaphragm weight 2.3 g, force 6 lb.)

Performance

Careful design of the component parts of the driver results in excellent performance characteristics. Figure 5 gives the

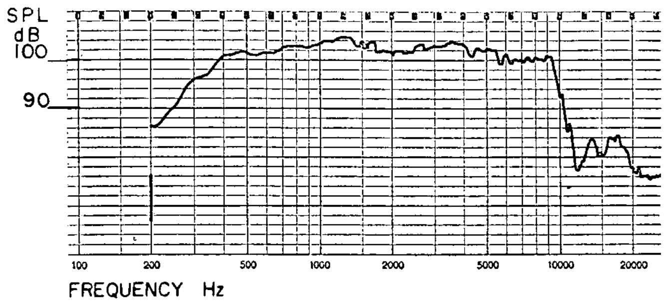


FIG. 5. Frequency response of the improved driver.

frequency response of the driver on a sectoral horn; the data were taken on-axis at 7 ft in an anechoic chamber. As can be seen, the driver has uniform response over a range of 400 to 10,000 Hz. Figure 6 shows efficiency meas-

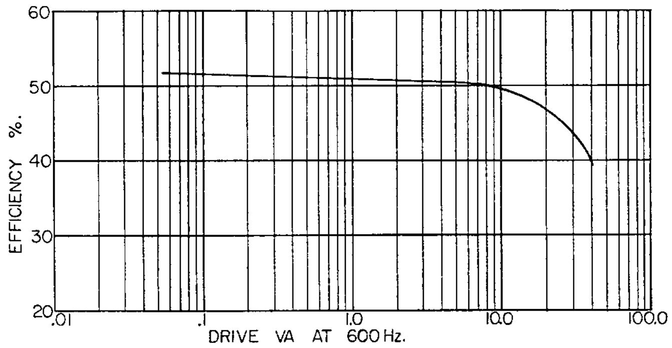
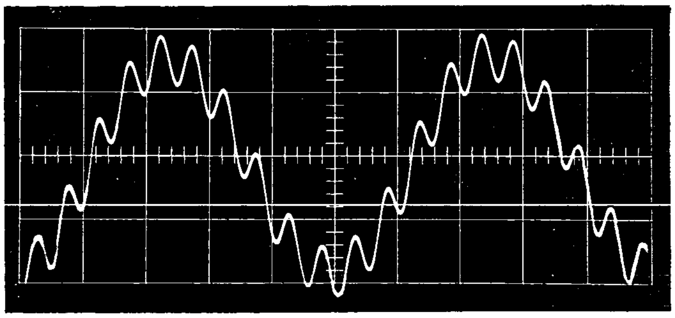
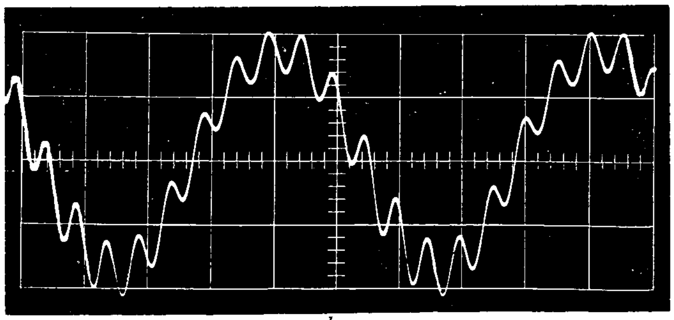


FIG. 6. Efficiency of the improved driver.



a.



b.

FIG. 7. Intermodulation distortion of the improved driver. *a.* At 1 watt. *b.* At 40 W.

ured in a 2-in. plane-wave tube for electrical inputs up to 40 W; measurements were taken after the moving coil had assumed a stable temperature. The efficiency is 50% over most of the useful frequency range.

Because of the 1.83 in.^{2} throat area, distortion is low. Intermodulation distortion measurements at 500 plus 5000 Hz with an amplitude ratio of 4:1 at 1 and 40 W input are shown in Fig. 7.

CONCLUSIONS

An improved moving coil driver for horn-type loudspeakers has been developed. Essential design principles, reflecting experience gained over a period of forty years, are unchanged. By applying new materials and techniques, however, a superior driver has been produced. The new unit has an efficiency of 50%, frequency range from 400 to 10,000 Hz, a maximum acoustic output of 20 W, and weighs only 14 lb—all with a high degree of reliability. The design principles that were developed apply equally to drivers of higher or lower power inputs. Additional refinements are also possible. If an extended high-frequency range is required, extra slits can be added to the phasing plug.

The original design objective of obtaining the maximum acoustic power output per pound of weight has been attained.

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John K. Hilliard was born in Wyndmere, North Dakota, in 1901. He received his BS degree in physics at Hamline University, St. Paul, Minnesota, in 1925, and followed it with graduate work in electrical engineering at the University of Minnesota.

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