

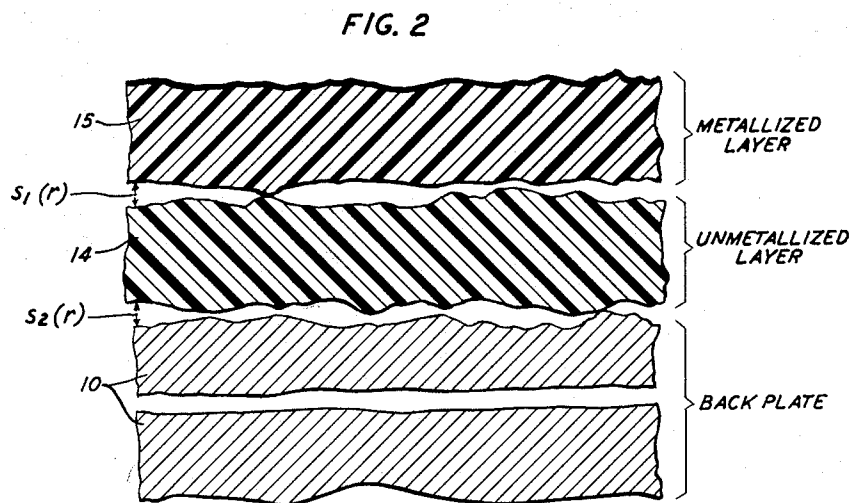
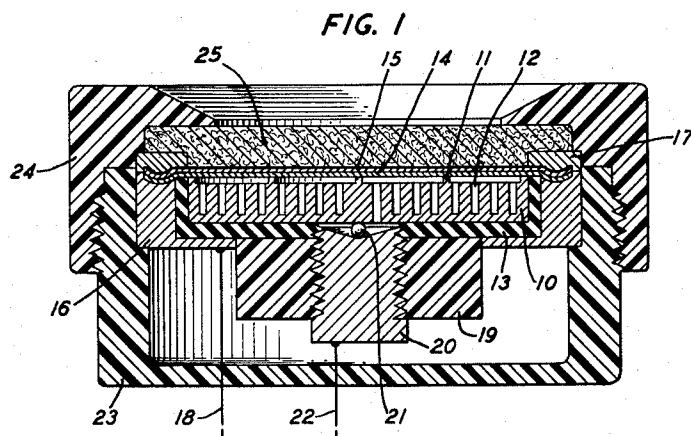
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G. M. SESSLER ET AL
ELECTROSTATIC TRANSDUCER

3,118,979

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2 Sheets-Sheet 1



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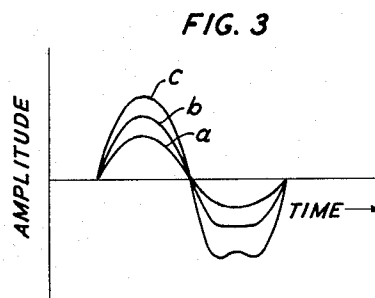
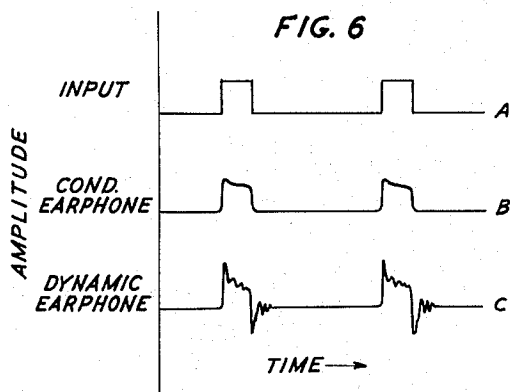
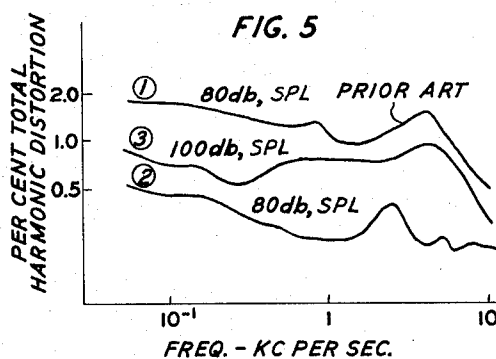
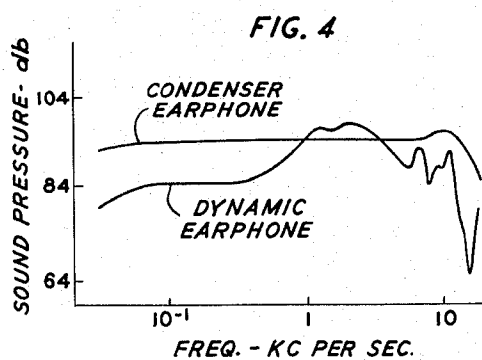
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1

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ELECTROSTATIC TRANSDUCER

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This invention relates to electroacoustic transducers and more particularly to such transducers of the electrostatic type.

General objects of this invention are to improve the performance and to facilitate the construction of electroacoustic transducers of the electrostatic type.

An electrostatic transducer, a condenser earphone, for example, normally comprises a rigid metal back plate and a thin conductive plate or diaphragm stretched or mounted by its edge in a plane parallel to the surface of the back plate and closely spaced and insulated from it. When a potential difference is applied between the back plate and the diaphragm the difference in potential therebetween alters the force manifested between the plates thus to cause the diaphragm to move toward or away from the back plate substantially in proportion to the magnitude of the applied electric potential. Movement of the diaphragm produces sound pressure wave counterparts of the applied electrical signal.

In order to maintain high efficiency and to regulate the frequency response of a condenser earphone or the like, it is necessary to control closely the spacing between the movable diaphragm layer and the rigid back plate. Further, the dielectric between the two should be reasonably constant and sufficiently thin to permit the desired spacing to be obtained. If the spacing is too small, large signals produce excessively large excursions of the diaphragm and it may physically contact the back plate. Such a contact interrupts the normal mode of vibration of the diaphragm. In effect, it stops all vibration at the point of contact and gives rise to a number of secondary vibrations in the diaphragm. As a result, second and higher order harmonic distortion is produced.

Various attempts have been made to circumvent this in prior art transducers. For example, the spacing has been made sufficiently large that diaphragm contact is avoided altogether, with a resulting loss of efficiency. Alternatively, a layer of flexible material, e.g., sponge rubber, has been spaced between the diaphragm and back plate to impede large excursions thus to prevent abrupt contacts. Here, too, the spacing must be of substantial proportions so that high efficiency is difficult to achieve.

The transducer of the present invention avoids many of these difficulties. It employs a thin sheet of flexible metallized dielectric material stretched across a perforated back plate to form a capacitor in which the thin sheet of flexible material acts as a solid dielectric. Ordinarily, considerable care must be exercised in positioning the metallized sheet in juxtaposition with the back plate so that the air gap, which is inevitably present even although a spongy filler is used, is reasonably thin and uniform over the entire back plate surface. In accordance with the present invention, an additional thin layer (or layers) of dielectric material is inserted between the metallized sheet and the back plate to form a multilayer diaphragm. Because of surface irregularities in the metallized layer, in the auxiliary layers of dielectric material, and in the back plate, a close sandwiching of the several elements traps minute air bubbles between the various layers. With this construction, the several air layers are of random configuration such that the total air gap along a given line normal to the quiescent plane of the diaphragm is virtually a constant from point to point along the surface of the diaphragm but distributed unequally from point to point.

2

Thus, although an extreme excursion of the diaphragm may conceivably compress one of the gaps to produce a contact of the metallized layer with a point of the auxiliary layer, or a contact of the auxiliary layer with the back plate at another point in the surface, it is highly unlikely that two contacts on a given normal will occur at the same time. The probability of a firm contact between the metallized foil layer and the back plate, i.e., a contact along a single line normal to the plane of vibration, is thus minimized and, in virtually all instances, the diaphragm vibrates freely at all signal levels.

By means of the auxiliary or intermediate dielectric layers, therefore, the air gap between outer conductive layer and the back plate is replaced by a plurality of intermediate air gaps of highly irregular configurations. Since the auxiliary layers responsible for the several air gaps are virtually noncompressible and yet compliant, large signal fluctuations that ordinarily would be sufficient to cause a direct contact of the outer metallized layer with the back plate cause only a contact between two adjacent layers, but not a firm contact from front to back. For example, along a given line normal to the plane of the diaphragm the outer conductive layer may, in its swing toward the back plate, contact the intermediate dielectric layer adjacent to it. However, at this point of contact all vibration of the outer conductor is not stopped. Since a contact between the intermediate layer and the next layer, either another auxiliary layer or the back plate, dependent on the construction, is highly improbable along the same line because of the gross irregularities of the several air gaps, the intermediate layer yields and moves with the conductive layer at the point of contact. Thus, although the fluctuations of the conductive layer may be somewhat damped, the layer, nevertheless, tends to vibrate in a homogeneous manner over its whole surface. In general, fluctuations of a diaphragm composed of several thin layers separated by nonuniform air gaps are less likely to compress, to the limit of contact, the over-all air gap existent between the outer conductive layer and the back plate at discrete points. Thus, points of high mechanical distortion are practically eliminated so that the mean distortion of the transducer is reduced. Further, points of low vibration amplitude are practically eliminated thus increasing the efficiency of the entire system.

As a further advantage, construction of the transducer is simplified because surface irregularities due to normal machine processes are quite satisfactory, and the critical placement of the outer conductor at a specified small distance from the back plate is accomplished automatically by virtue of the auxiliary film layer(s) placed therebetween.

As compared with condenser transducers of the prior art, the present invention thus furnishes an instrument of simplified construction in which (1) the distance between the two electrodes may be made very small thus to increase substantially the efficiency of the unit; (2) the polarizing bias potential may be made considerably higher without danger of a short-circuit developing through the dielectric; (3) the resonant frequency may be controlled by precision adjustment of the mean volume of the air gap between the diaphragm and the rigid back plate, and (4) the transducer can be constructed cheaply since there are few critical parts and it utilizes inexpensive materials.

The invention will be fully apprehended from the following detailed description of a preferred embodiment thereof taken in connection with the appended drawings, in which:

FIG. 1 is a cross-sectional view of a condenser earphone illustrative of a preferred embodiment of the invention;

FIG. 2 is a cross-sectional view, on a greatly enlarged

scale, of a small portion of the diaphragm layers of a transducer constructed in accordance with the invention;

FIG. 3 is a group of wave form diagrams illustrating a form of distortion common to electrostatic transducers;

FIGS. 4 and 5 represent on the frequency scale sound pressure and distortion, respectively, of an electrostatic transducer in accordance with the invention; and

FIG. 6 illustrates the impulse response of a condenser earphone.

Referring now to the drawings, FIG. 1 shows in section a condenser earphone constructed in accordance with the invention. It comprises a rigid back plate 10 preferably of metal, for example, a disc of brass about thirty-five millimeters in diameter. If desired, several small ridges 11 about 0.025 millimeter high may be provided on the upper surface of the back plate to aid in shaping the air gap behind the diaphragm. A plurality of small diameter holes or wells 12 in the back plate provide, together with the ridges, a sufficient air volume to establish a desirable resonant frequency. Approximately two hundred holes each about one millimeter in diameter and about 3.5 millimeters deep have been found to be a sufficient number. If desired, one of the holes may be extended through the back plate or an additional port may be provided to equalize ambient pressure.

Unlike a condenser loudspeaker in which a high resonant frequency is a disadvantage, a high resonant frequency is desirable in an electrostatic earphone because radiation resistance is constant so long as the earphone radiates into a small closed volume. This is normally the case. Further, in a condenser earphone much less vibration amplitude is required as compared with open air loudspeakers to produce sufficient loudness levels. In practice, the mass of the diaphragm and the compliance of the air layer yield a resonant frequency of approximately fourteen kilocycles. The resonant frequency of an electrostatic transducer employing a multilayered diaphragm in accordance with the present invention may easily be selected to lie in the audio frequency or ultrasonic frequency range. For example, the addition of more layers to the diaphragm, or an increase in the volume between the diaphragm and back plate, as by increasing the number and size of the wells in the back plate, decreases the resonant frequency of the system.

Back plate 10 is supported by an insulating annular frame 13 provided with a raised flange at its periphery. Frame 13 may be made of any rigid insulating material, for example, of the plastic material known commercially as Lucite. Disposed across the face of the back plate 10 and clamped in close proximity to the upper surface thereof is a thin circular diaphragm formed of a number of layers of thin dielectric material. The layer next adjacent to back plate (one such layer 14 is shown by way of illustration but several layers may, in accordance with the invention, be used) is formed from a thin sheet of dielectric material, for example, from a thin (0.25 mil) film of plastic material such as polyethylene terephthalate, known commercially as Mylar. A thinner film may be used, if desired. The outer layer 15 is formed from a thin sheet of Mylar which is metallized on one side, for example, with a thin layer of aluminum. Such metallized foil is commercially available.

The metallized coating of foil 15 constitutes one element of a capacitor and the back plate 10 constitutes the other conductive element.

Insulating frame 13 is supported by an annular metal frame 16 provided with a flange on its outer edge. The several layers of foil are clamped to the frame 16 by means of an annular ring 17 constructed to form a taut fit with the upper portion of the flange of frame 16. In practice, a convex protrusion in ring 17 is formed to fit a corresponding concave groove in frame 16. This arrangement has proved satisfactory for providing sufficiently high mechanical tension for the several layers of the diaphragm. The edge of the diaphragm is thus held

in a taut, smooth condition. More elaborate securing means may, of course, be used if desired. Electrical contact to the outer metallized foil element of the capacitor may be made via frame 16, e.g., through terminal 18.

Because of the multilayer construction of the diaphragm, close spacing between the diaphragm and back plate can ordinarily be achieved merely by the diaphragm clamping operation. However, in accordance with the invention, provision is made to compensate for slight manufacturing irregularities and the like. Accordingly, an additional annular support member 19 of insulating material is provided. It is coaxially mounted within annular frame 16 and spaced to abut insulating frame 13. If desired, member 19 may be formed as a boss on frame 13. A metallic member 20 threaded on its outer surface to engage threads on the inner surface of support member 19 may be advanced to urge, by way of a bearing member 21, back plate 10 toward an intimate contact with the diaphragm. Bearing member 21 preferably is of spherical form so that a single adjustment of threaded member 20 suitably tilts the back plate and effects a proper seating of it. With this arrangement it has been found that minute adjustments may be conveniently made. Electrical contact with the back plate 10, e.g., the second capacitor element, is conveniently made via member 20 and bearing 21, e.g., through terminal 22.

The entire transducer is preferably enclosed in an outer case 23 formed of a suitable plastic material and provided on its inner surface with a flange or the like for supporting frame 16. It may be threaded on its outer surface to receive a front cap 24 of similar plastic material. As is usual, the outer case and front cap provide protection for the internal elements both from mechanical damage and dust.

In accordance with the present invention, front cap 24 is also arranged to form, with ring 17 and the diaphragm, a Helmholtz resonator tuned to about 12,000 cycles per second. The rather high resonant frequency is achieved by providing a large neck cross-section. The resonance of the cavity may be further broadened by filling the cavity with damping material 25. For example, porous paper material may be used. The damping material may touch the metallized foil layer without noticeable effect.

FIG. 2 shows an enlarged small section of back plate 10, nonmetallized foil 14, and metallized foil 15. In the illustration, a single foil layer 14, preferably of 0.15 mil Mylar sheeting, is shown placed between an outer foil 15 preferably of 0.25 mil Mylar coated with a thin layer of aluminum on the outer side, and back plate 10. As discussed above, additional auxiliary layers may be placed between foil 15 and back plate 10 if desired. In practice, the several layers are assembled by forcing them together as tightly as possible to avoid the entrapment of large air bubbles. Under normal manufacturing conditions, and without special effort, minute air bubbles are nevertheless trapped between adjacent foils and between foil and back plate because of the inherent irregularities of the various surfaces. Thus, between layers of foil and between the foil and back plate an irregularly shaped air layer is formed. In effect, the single gap ordinarily formed between the conductive diaphragm layer and the back plate is replaced by a plurality of intermediate air gaps. Yet the over-all separation of the conductive layer from the back plate is only slightly greater than that ordinarily achieved in precision construction. Although the exact air gap distribution varies from transducer to transducer, it has been found in practice that the nominal dimensions in a number of manufactured units vary only slightly one from another.

Without the auxiliary layer of uncoated foil 14, coated foil 15 is, in usual practice, placed in close proximity to the back plate 10. With such an arrangement, a single air gap only is present and, for reasonably high efficiency, is very thin. Hence, large signal excursions of the foil layer 15 cause the foil to contact the back plate repeated-

5

ly, and at many points. The number of points of contact is dependent upon the vibration amplitude and the fluctuation of the thickness of the air layer, i.e., as a result of irregularities in the adjacent surfaces. Contacts of this sort result in mechanical distortion when the applied signal voltage has the same polarity as the direct current biasing potential and in substantially lower transducer efficiency.

FIG. 3 illustrates this condition. An applied sine wave signal *a* of low magnitude produces undistorted vibration on both the forward excursion of the diaphragm and on its return to yield a sound pressure wave that closely resembles the signal counterpart. A somewhat larger applied sine wave signal *b* produces a sound wave that is somewhat flattened on the second half cycle due to a slight contact of the diaphragm with the back plate, while a signal of substantially larger magnitude produces a sound wave, e.g., *c*, that is considerably distorted on its second half cycle due to a firm contact at many points of the diaphragm with the back plate. As will be noted in the figure, predominantly second harmonic distortion is imparted to the emitted sound pressure wave.

By means of the auxiliary layers of nonmetallized film 14, according to the present invention, such distortion arising from physical contact is virtually avoided. The combined thickness $S(r)$ of the two air layers in the diaphragm arrangement of FIG. 2 is

$$S(r) = S_1(r) + S_2(r) \quad (1)$$

where S_1 and S_2 denote the thickness of the gaps between layers 14 and 15, and between back plate 10 and layer 14, respectively, on a line normal to the quiescent plane of the diaphragm. The fluctuation of air gap $S(r)$ is generally much smaller than the equivalent fluctuation experienced by a single air gap between the diaphragm layer and the back plate, i.e., than that ordinarily experienced without the interposition of the auxiliary layers. This results in a more homogeneous vibration amplitude over the whole surface of the outer foil of the transducer diaphragm. Moreover, points of mechanical distortion are practically eliminated thus reducing the means distortion of the entire system. Further, points of low vibration amplitude are practically eliminated thus increasing system efficiency. The probability of even higher efficiency and lower distortion increases with the number of auxiliary layers used providing however, that the thickness of the additional layers is not large enough to decrease the electric attraction between the back plate and the metallized layer.

As compared with a dynamic earphone, the condenser earphone of the present invention exhibits superior frequency response, efficiency and freedom from distortion. Efficiency is a function of the applied biasing potential, tension of the diaphragm, and compliance of the air layer. If the applied signal potential is, for example, a sine wave and is constant over the entire frequency range, the resulting force is also constant. At frequencies lower than the resonant frequency of the system, which as mentioned before is about 14,000 cycles per second, a constant force gives a constant displacement. In a closed coupler whose dimensions are small compared to the wave length, a constant displacement causes constant pressure. Therefore, a flat frequency response for the pressure is experienced. A slight roll-off at low frequencies has been found to be a result of slight air leaks in the case of the transducer.

FIG. 4 shows the frequency response of a condenser earphone constructed in accordance with the present invention as compared with that of a typical dynamic earphone. It is quite evident that the condenser earphone exhibits a considerably flatter response, particularly at higher frequencies.

FIG. 5 illustrates the percent of total harmonic distortion produced by an earphone in accordance with the present invention as a function of frequency, and that produced by a high quality condenser transducer con-

6

structed in accordance with prior art techniques, i.e., without provision of the auxiliary layers of dielectric material. Curve 1 illustrates the total harmonic distortion of such a prior art condenser transducer at a signal level of 80 db sound pressure level (SPL). Curve 2, indicating substantially lower distortion at all frequencies than curve 1, shows the distortion produced by a transducer with two foils, i.e., a coated outer foil and an intermediate foil (as illustrated in FIG. 2) at an identical sound pressure level, i.e., 80 db. Curve 3 shows, for the same multifoil transducer, the distortion produced at a signal level of 100 db SPL. It will be noted that even at this high sound pressure level the total harmonic distortion at all frequencies is considerably below that of a condenser earphone constructed according to the prior art. Although not illustrated, it has been found that the condenser microphone of the invention exhibits lower distortion in the low and middle frequency range than does a high quality dynamic earphone. Tests show, however, that a dynamic earphone is somewhat better at higher frequencies. Nevertheless, distortion of the condenser earphone is still less than one percent over the entire range at sound pressure levels of 100 db or less.

FIG. 6 illustrates the impulse response of a condenser earphone constructed in accordance with the principles of the present invention together with the impulse response of a high quality dynamic earphone. With a square wave input signal, for example, of the sort illustrated in line A, the condenser earphone has an impulse response, shown in line B, which is almost a true image of the applied square wave. The dynamic earphone, on the other hand, "differentiates" the input pulse and produces relatively sharp spikes, multiple resonances, and ringing as shown in line C.

In view of the principle of reciprocity it is obvious that the novel transducer of the present invention may also be employed as a microphone to convert sound pressure variations incident on the diaphragm into voltage variations. The term transducer is for this reason employed to designate the unit structurally, independently of whether it effects a conversion from acoustic energy into electrical energy or vice versa.

It will be obvious to those skilled in the art that numerous modifications may be made in the structure described, and other arrangements devised, without departing from the scope and spirit of the invention. For example, the back plate element of the capacitor may be dispensed with in favor of a second metallized foil layer pressed in contact with an intermediate layer so that, in effect, the diaphragm supports both elements of a capacitor. Further, the diaphragm may be formed with the metallized surface facing inward toward the auxiliary dielectric layers, thus to allow the plastic backing for the conductive surface to act as a protective membrane. Additional auxiliary layers may then be used to achieve the proper resonant frequency and diaphragm compliance.

What is claimed is:

1. A condenser earphone comprising a thin flexible layer of a conductive material, a relatively thick metallic back plate of substantially the same surface dimensions as said flexible layer, said back plate having a plurality of spaced wells therein, means for peripherally securing said layer of conductive material in juxtaposition to said back plate, a plurality of layers of substantially noncompressible thin film dielectric material intimately sandwiched between said layer of conductive material and said back plate to form a compliant vibratile member which includes said thin layers of dielectric material and a highly irregular configuration of minute static air layers trapped between said thin layers of dielectric material, insulating covering means for rigidly supporting said several layers and said back plate, said covering means having an opening in proximate relation to the surface of said flexible layer of conductive material, and means for electrically

7

connecting to said layer of conductive material and to said back plate.

2. A condenser earphone as defined in claim 1 wherein said opening in said covering means has a large neck cross-section to form with said flexible layer of conductive material a resonant chamber tuned to approximately twelve kilocycles per second.

3. An electrostatic transducer comprising a thin flexible layer of conductive material, a rigid conductive back plate having a substantially plane surface, means for peripherally securing said layer of conductive material in juxtaposition to the plane surface of said back plate to leave a relatively uniform air gap between said layer and said back plate, means for dividing said air gap into a plurality of relatively nonuniform intermediate air gaps, the dimensions of said intermediate air gaps being highly irregular from point to point in a plane parallel to the quiescent plane of said flexible layer of conductive material but substantially a constant over the entire surface area of said plane in a direction normal to the quiescent plane of said flexible layer, said means comprising a plurality of layers of substantially noncompressible thin film dielectric material intimately sandwiched together and supported by said peripheral securing means between

8

said layer of conductive material and said back plate, and means for connecting electrically to said layer of conductive material and to said back plate.

4. An electrostatic transducer as defined in claim 3 wherein said flexible layer of conductive material is a metallized layer of aluminum deposited on a thin film of plastic, said thin layers of dielectric material are of plastic sheeting approximately 0.25 mil thick, and said back plate is a perforated disc of a copper-zinc alloy.

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