

- [54] **PLANAR VOICE COIL LOUDSPEAKER**
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- [58] **Field of Search**..... **179/115.5 PV, 115.5 R, 179/115.5 DV, 181 R, 181 F, 138 VL; 335/231**

[56] **References Cited**

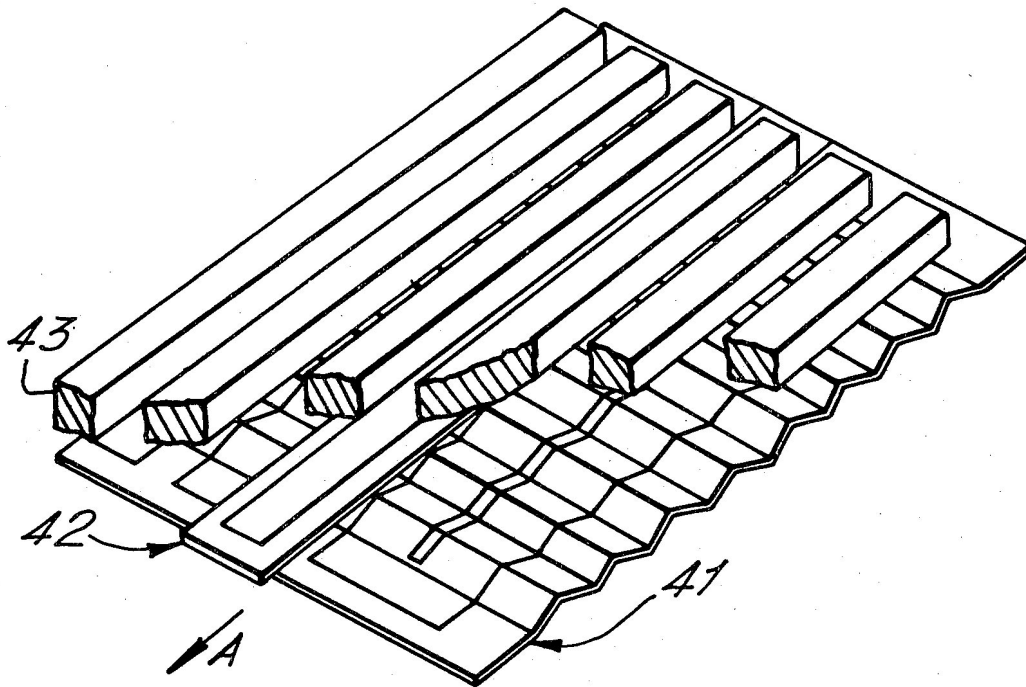
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[57] **ABSTRACT**

An audio-transducer incorporates a diaphragm carrying a current conductor and a plurality of permanent magnets constituting a magnet unit disposed in spaced relationship to the conductor. The magnets are formed of a material consisting of magnetizable particles embedded in a matrix of non-magnetic material. The diaphragm may be curved and/or corrugated.

10 Claims, 6 Drawing Figures



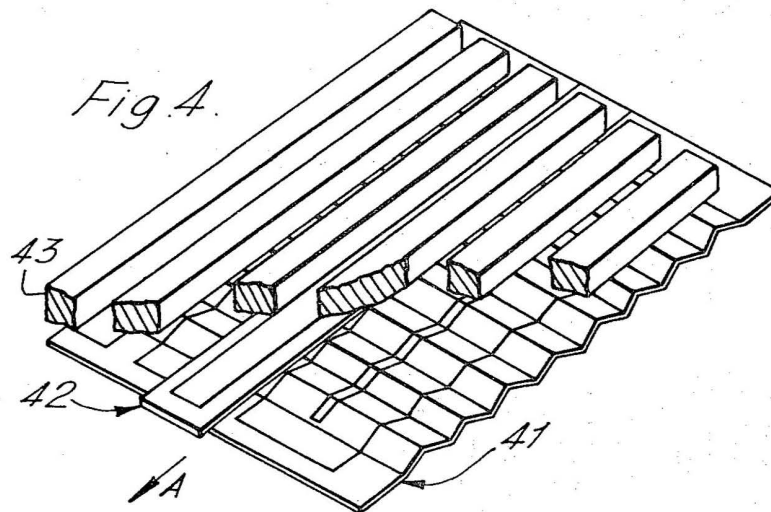
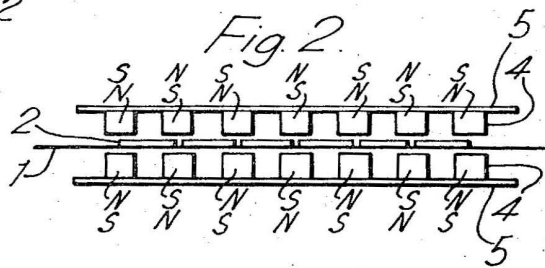
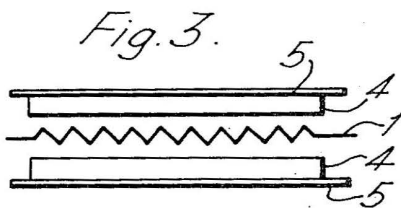
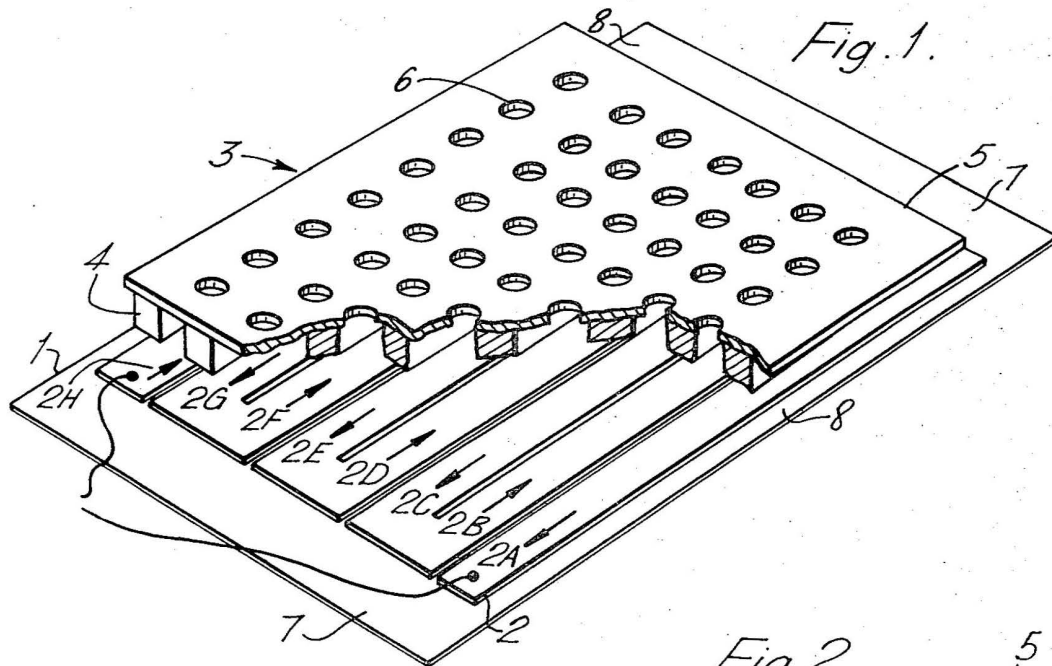


Fig. 5.

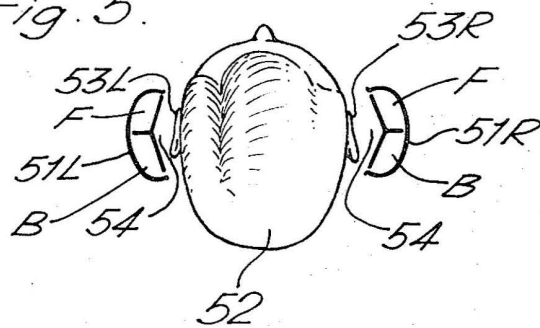
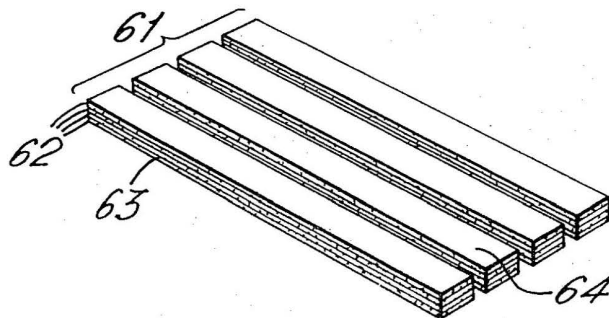


Fig. 6.



PLANAR VOICE COIL LOUDSPEAKER

This invention relates to electromagnetic audio transducer such as loudspeakers, earphones and microphones.

Loudspeakers as originally constructed contained small rigid diaphragms and horns to amplify the sounds produced by the diaphragms when they vibrated under the influence of the applied electrical signals. The introduction of the large conical diaphragm provided an important advance in fidelity of reproduction but still left much to be desired. A difficulty with the conical diaphragm is that because of the differences in the diameters of the periphery and the centre part connected to the armature of the driving unit the diaphragm does not vibrate throughout at the same speed, but has different regions all resorting with a complex pattern of oscillations. Many of these oscillations are of incorrect amplitude and contain parasitic frequencies. A cone also has considerable inertia and momentum so that it has a poor transient response.

The aim is thus to provide a diaphragm every point on which can be directly controlled.

The first transducer constructed with this object in mind was the Plathaller loudspeaker, which incorporated a flexible metallic diaphragm gripped at two opposite edges and held under tension and carrying on one face a strip of copper turned back on itself at regular intervals to provide a set of series-connected spaced parallel conductors, and a set of magnet pole pieces arranged adjacent the side of the diaphragm carrying the copper strip, thereby being a pole piece arranged between each pair of adjacent conductors and adjacent pole pieces being of opposite polarity. In one construction the pole pieces carried field coils wound around them and in another construction field coils encircled the diaphragm, one between every two adjacent pole pieces, the field coils having a common axis parallel to the plane of the diaphragm. Subsequently in an attempt to reduce the size and weight of the device permanent magnets were substituted for the pole pieces and field coils. Other changes made were to substitute a flexible non-metallic plate for the flexible metallic diaphragm and to fit a set of conductors on both faces of the diaphragm.

A later development still employs a light but rigid diaphragm which in one construction is formed from a thick slab of expanded polystyrene with a number of parallel grooves milled into one face to form parallel walls on the tops of which metallic strips connected in series and forming the conductor are fastened.

The loudspeakers just described give very good results and being of flat form are extremely convenient for fitting almost anywhere, not necessarily only in cabinets specially built for them. They do, however, suffer from the disadvantage that their response at the lower audio frequencies is not as good as their response at the higher frequencies. In an endeavour to avoid this disadvantage an audio transducer was devised including a diaphragm carrying on one face at least an electrical current conductor consisting of a number of spaced parallel conductor portions and a fixed magnet unit disposed in spaced relationship to the conductor, the magnet unit consisting of a row of permanent magnets arranged with their poles in a selected pattern of polarity and with a magnet pole opposite and extending along each gap between adjacent parallel conductor portions

and a backing plate of magnetic material to which the magnets are attached, the portions of the backing plate between at least selected pairs of adjacent magnets of the row being perforated.

In an alternative transducer a similar basic principle is employed, but the magnet structure is formed in a relatively thick unitary body of anisotropic sintered oxide permanent magnetic material.

With conventional magnetic materials, such as have been employed hitherto it is not possible to employ a shallow magnet structure as this would be self demagnetising. These materials are also costly to machine and in strip form are extremely fragile. Furthermore, the perforations intended to provide air transmission through the back portion of the unitary magnet structure have most often been found to give rise to undesirable resonances at high frequencies.

The technical advance to be aimed at is therefore to provide an audio-transducer which can be thinner than has been heretofore possible and which gives a good frequency response without undesirable resonances even at high frequencies. It is an object of the present invention to provide such an audiotransducer.

An electromagnetic audio transducer according to the invention incorporates a diaphragm bearing on at least one face an electrical current conductor and a fixed magnet unit disposed in spaced relationship to the conductor, the magnet unit consisting of a plurality of permanent magnets arranged so as to produce a magnetic field in the plane of the diaphragm and orthogonal to the conductor, the magnets being formed of plastic-magnetic material, i.e., a material consisting of magnetizable particles embedded in a matrix of non-magnetic material.

The magnets may be attached to a backing plate of magnetic material, the positions of the backing plate between at least selected magnets being perforated.

The diaphragm may be curved to increase the radiation angle, the magnet unit or units being correspondingly curved.

Each conductor may be formed of a single strip turned back on itself at regular intervals to provide a set of series-connected conductor portions. In this construction adjacent poles of the associated row of magnets may be of opposite polarity. Alternatively, the conductor portions may be connected in parallel or in series-parallel.

The diaphragm may be corrugated, the lines of the corrugations being preferably at right angles to the lines of the parallel conductor portions.

A practical embodiment of the invention is illustrated in the accompanying drawings in which FIG. 1 is a perspective view of an audio transducer showing a portion of one of the magnet units cut away to illustrate the construction, FIG. 2 is a section through a transducer which incorporates a diaphragm provided with one conductor only and magnet units adjacent opposite faces of the diaphragm, FIG. 3 is a section through a transducer incorporating a corrugated diaphragm, the plane of the section of FIG. 3 being at right angles to the plane of the section of FIG. 2, FIG. 4 shows a transducer incorporating a second diaphragm, FIG. 5 shows an arrangement for four channel reproduction and FIG. 6 illustrates diagrammatically the strip magnet construction.

In the drawings 1 denotes a diaphragm carrying a conductor 2 in the form of a flat strip consisting of a set

of series-connected spaced parallel conductor portions 2A-2H, fixed thereto.

A magnet unit 3 consists of a row of magnets 4, a magnet being opposite and extending along each gap between adjacent parallel conductor portions 2A-2H. The magnets 4 are attached to a backing plate 5 of magnetic material such as soft iron sheet. The portions of the backing plate 5 between adjacent magnets 4 are formed with perforations 6. It will be observed from FIG. 2 that in the construction illustrated the adjacent magnets in each row are of opposite polarity. With reference to FIG. 3 the diaphragm 4 is corrugated, the lines of the corrugations being at right angles to the parallel conductor portions.

In practice, an alternating current such as that generated by an audio power amplifier is applied to the conductor 2. The pattern of polarity of the magnets 4 is so arranged that the leakage flux between adjacent pairs of poles is in conformity with the direction of the current flow in the associated conductor portions 2A-2H and orthogonal thereto so that the net effect is for the whole diaphragm 1 to be uniformly attracted and repelled by the magnet unit or units 4. Where the transducer incorporates magnet units adjacent opposite faces of the diaphragm one unit is arranged to attract the conductor 2 and thus the diaphragm 1 at the same time as the other unit repels it.

The perforated backing plates 5 allow free passage of air and a greatly improved response at low frequencies. By suitable shaping and sizing of the perforations, for example, by their omission in certain regions, it is possible to provide a damping effect and thus locally modify the acoustic impedance, thereby controlling unwanted resonances.

The diaphragm is freely supported by gripping the opposite edges 7 but not the edges 8. Low frequency response is improved by corrugating the diaphragm in a direction parallel to the clamps, that is, orthogonal to the direction of the principal conductors and the plastic-magnetic strip magnets. The corrugations in a preferred embodiment are triangular in section and have an included angle of $2/3 \pi$ radians. A section through the corrugated diaphragm is shown in FIG. 3.

It is well known that the higher frequencies from a physically large sound source tend to become 'beamed', so that small diameter 'tweeters' are used to increase the spread. With the present form of construction it is possible to fit a second diaphragm in front of the main diaphragm, near to the front set of magnets for the treble range. As the amplitude of the movement of a diaphragm at high frequencies is much less than it is at low frequencies, this treble diaphragm can be quite close to the magnets and therefore be in a higher magnetic flux, giving it higher efficiency, (to compensate for its smaller size). Preferably it will also be tensioned, as the need for 'floppiness' to improve the bass output will not be necessary for this treble diaphragm. The tension may be used as a mechanical crossover filter so that the two diaphragms can be connected directly to an amplifier without any intermediate electrical crossover unit. A suitable arrangement is shown in FIG. 4 wherein a full range diaphragm 41 is disposed adjacent a treble diaphragm 42 and magnets 43. Tension is applied to the treble diaphragm in a direction indicate by arrow A.

The polar response of the transducer may be modified by curving or bending the magnet structure.

The ability to control the polar response gives rise to a further feature of the invention. With conventional earphones in order to maintain bass response it is necessary to couple the transducer to the ear by means of an acoustic seal between the casing and the head. With transducers constructed in accordance with the present invention it is found that satisfactory bass response is maintained with an air gap between the head and the transducer. Not only does this permit the subject to hear external sounds such as door bells, but is also allows the construction of earphones suitable for quadra-sonic reproduction. In this system four channels are used in place of two in a conventional stereophonic system. A typical arrangement is shown in FIG. 5 in which earphones 51L and 51R are placed on each side of a subject 52. Each earphone consists of a front portion F and a back portion B each of which contains a directional transducer which beams sound towards the adjacent ear 53L, 53R from which it is separated by an air gap 54.

The strip-like construction of the magnets and voice coil conductors permits a number of additional design freedoms. For example, by asymmetric placing of conductors and the corresponding magnets the driving force on the diaphragm may be made inhomogenous. This may be employed to cancel the effect of harmonic distortion by the creation of anti-nodal positions in a manner analogous to bowing a stringed instrument so as to eliminate discordant harmonics. A complementary effect may be achieved by placing shorted loops of conductors at suitable positions on the diaphragm to provide eddy current damping.

It is possible to manufacture the voice coil as a number of elementary coils and connect them in various series-parallel combinations to alter the impedance.

An important feature of the design is the use of plastic-magnetic magnets as already defined, the construction of which is illustrated in FIG. 6. The material is produced by impregnating granules of magnetizable material in a nonmagnetic matrix. A suitable matrix is neoprene rubber. A thick sheet structure is assembled by bonding together a number of thin elementary sheets. The material is made anisotropic by mechanical working which aligns the magnetic material 63 during the mechanical working operation. The cured sheet may be readily cut, for example with a knife, into strips 64, and, although its permittivity is not so great as bulk materials such as ferrites, it is adequate for the production of satisfactory transducers. Furthermore it is extremely rugged, whereas ferrite is brittle, and thin sheets can be magnetized across their thickness whereas conventional materials are self-demagnetizing.

We claim:

1. An audio transducer comprising:

a first diaphragm,

an electrical conductor on at least one face of said first diaphragm, said electrical conductor including spaced parallel conductor portions,

a fixed magnet arrangement disposed substantially parallel to said diaphragm spaced from said at least one face thereof, the magnet arrangement comprising a plurality of substantially parallel permanent magnets so disposed with respect to said diaphragm that a part of the magnetic field created thereby lies in the plane of said diaphragm and orthogonal to said parallel portions of said conductor,

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a second diaphragm of smaller area than said first diaphragm located between said first diaphragm and said fixed magnet arrangement, and

an electrical conductor on said second diaphragm, said electrical conductor having at least one conductor portion substantially parallel to said parallel portions of said first conductor.

2. The audio transducer of claim 1 further comprising means holding said second diaphragm under a tension greater than the tension in said first diaphragm, and means feeding the same electrical signals to both diaphragms, whereby said second diaphragm acts as a treble diaphragm by virtue of the tension applied thereto.

3. The audio transducer of claim 2 wherein said tension is applied to said second diaphragm in a direction substantially parallel to said parallel conductor portions of said first diaphragm.

4. The audio transducer of claim 1 wherein there is a further fixed magnet arrangement disposed in spaced parallel relationship with said first diaphragm on the side thereof remote from said second diaphragm.

5. The audio transducer of claim 4 wherein there is further provided a second conductor on the face of said first diaphragm opposite said at least one face thereof, said second conductor also including a plurality of spaced parallel conductor portions extending substantially parallel to said parallel conductor portions of said conductor on said at least one face of said diaphragm.

6. The audio transducer of claim 1 wherein said magnets are made of a material comprising magnetised particles embedded in a matrix of non-magnetic material.

7. An audio transducer comprising:

a diaphragm corrugated along a first direction, means supporting said diaphragm along the edges thereof parallel to said corrugations,

an electrical conductor on at least one face of said diaphragm, said electrical conductor having parallel conductor portions extending orthogonally of said corrugations,

a fixed magnet arrangement disposed in spaced relationship substantially parallel to the general plane of said diaphragm on at least one side thereof, said magnet arrangement comprising a plurality of substantially parallel permanent magnets so disposed with respect to said diaphragm that a part of the magnetic field created thereby lies in the plane of said diaphragm and orthogonal to said parallel por-

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tions of said conductor, said magnets being formed of a material comprising magnetised particles embedded in a matrix of non-magnetic material, and,

a second diaphragm located in a position between but spaced from said corrugated diaphragm and said fixed permanent magnet arrangement.

8. The audio transducer of claim 7 wherein there is provided a further conductor having parallel conductor portions on the face of said corrugated diaphragm opposite said at least one face thereof, and

a second fixed permanent magnet arrangement in spaced relation substantially parallel to the general plane of said diaphragm and on the side thereof remote from said at least one face.

9. The audio transducer of claim 8 wherein said parallel conductor portions of said further conductor are substantially parallel to said parallel conductor portions of said conductor on said at least one face of said diaphragm.

10. An audio transducer comprising:

a corrugated diaphragm,

a conductor on at least one face of said corrugated diaphragm, said conductor having a plurality of spaced parallel series-connected conductor strips,

a fixed permanent magnet structure spaced from said at least one face of said corrugated diaphragm, the magnetic field from said permanent magnet structure having a part extending orthogonally of said parallel conductor strips and lying substantially in the general plane of said corrugated diaphragm,

a backing plate supporting said fixed permanent magnet structure, said backing plate being perforated at least in the region between adjacent magnets of said structure,

a second diaphragm between said fixed magnet structure and said corrugated diaphragm, and spaced therefrom,

means holding said second diaphragm in tension applied perpendicularly with respect to said corrugations of said corrugated diaphragm, and

a conductor on at least one face of said second diaphragm, said conductor including at least one conductor strip portion extending parallel to the general direction of said parallel conductor strip portion of said conductor on said corrugated diaphragm.

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