

[54] **ELECTRO-ACOUSTIC TRANSDUCER**

[76] Inventor: **Oskar Heil**, 1775 Panott Dr., San Mateo, Calif. 94402

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[51] Int. Cl. **H04r 9/06**

[58] Field of Search 179/115.5 R, 115.5 DV, 179/115.5 PV, 115.5 VC, 181 R, 181 F, 138 R, 138 VL, 119 R, 115 R; 181/32 R, 31 R

[56] **References Cited**
UNITED STATES PATENTS

3,497,642 2/1970 Pintell 179/181 R

FOREIGN PATENTS OR APPLICATIONS

423,353 7/1947 Italy 179/138 VL

Primary Examiner—Kathleen H. Claffy
Assistant Examiner—Thomas L. Kundert
Attorney, Agent, or Firm—Robert R. Tipton

[57] **ABSTRACT**

An electro-acoustic transducer comprising permanent magnet means producing a magnetic field and defining a space communicating with the outer atmosphere, and diaphragm means located in said space and comprising a corrugated sheet of flexible material and a metal foil applied in a meander pattern to at least one face of the plastic sheet.

11 Claims, 9 Drawing Figures

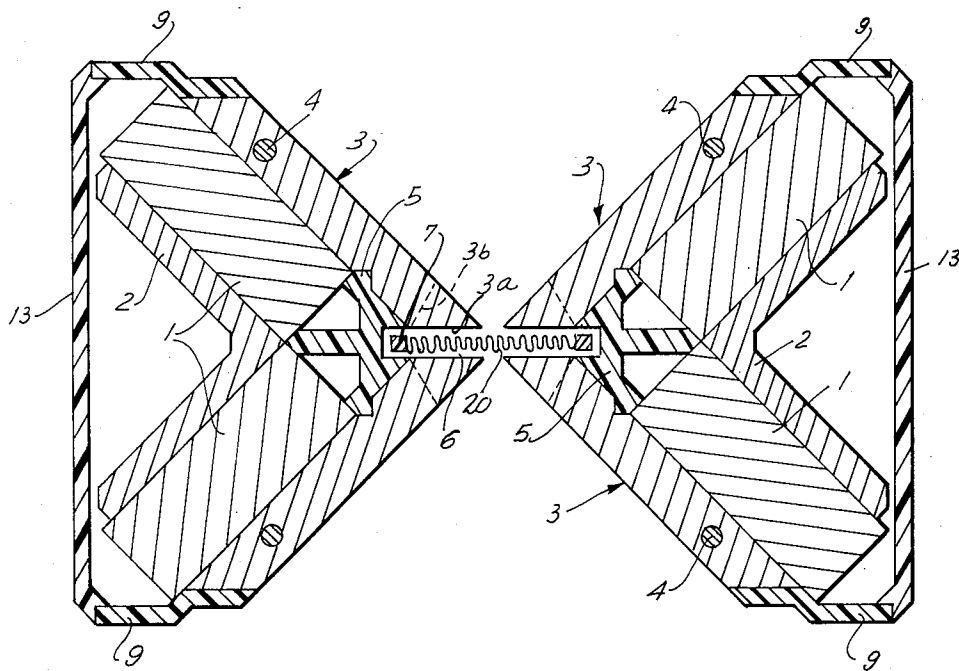


FIG. 1a

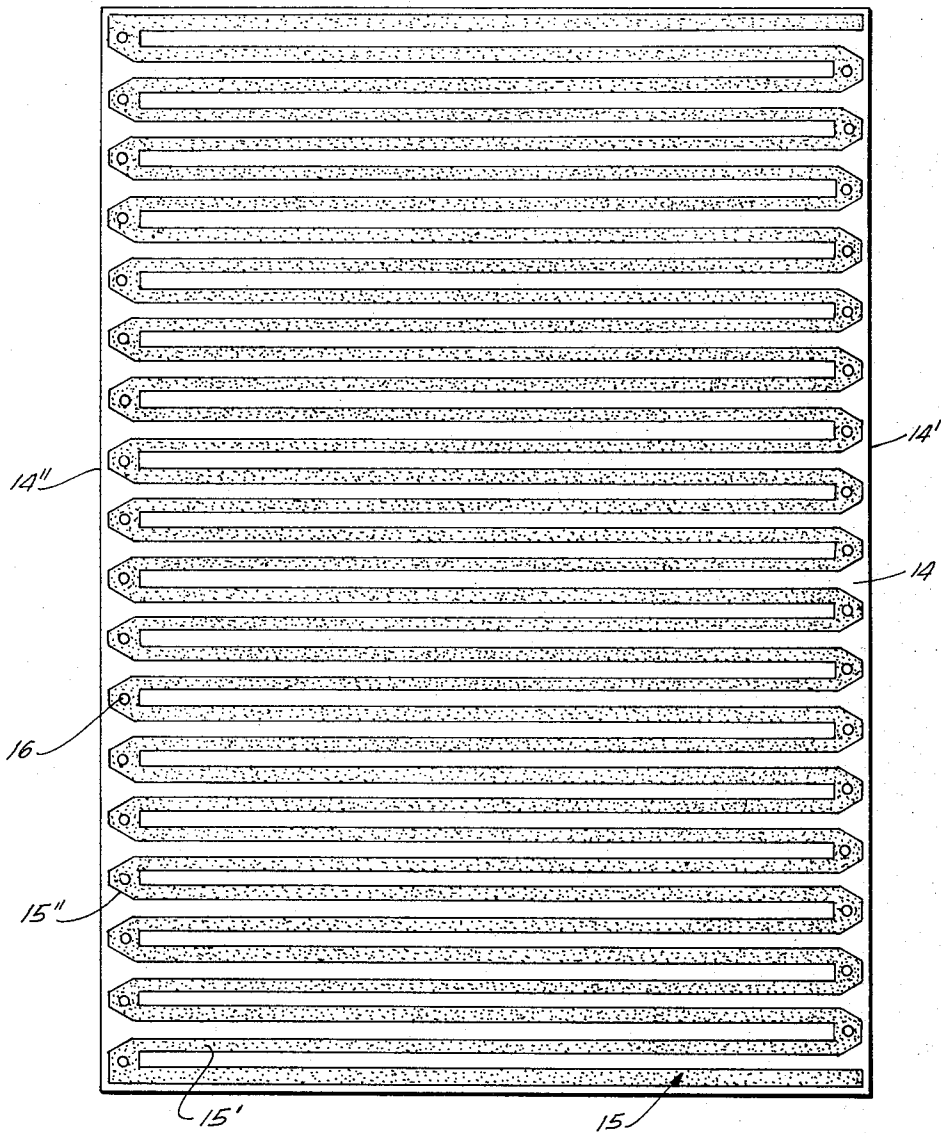


FIG. 1b

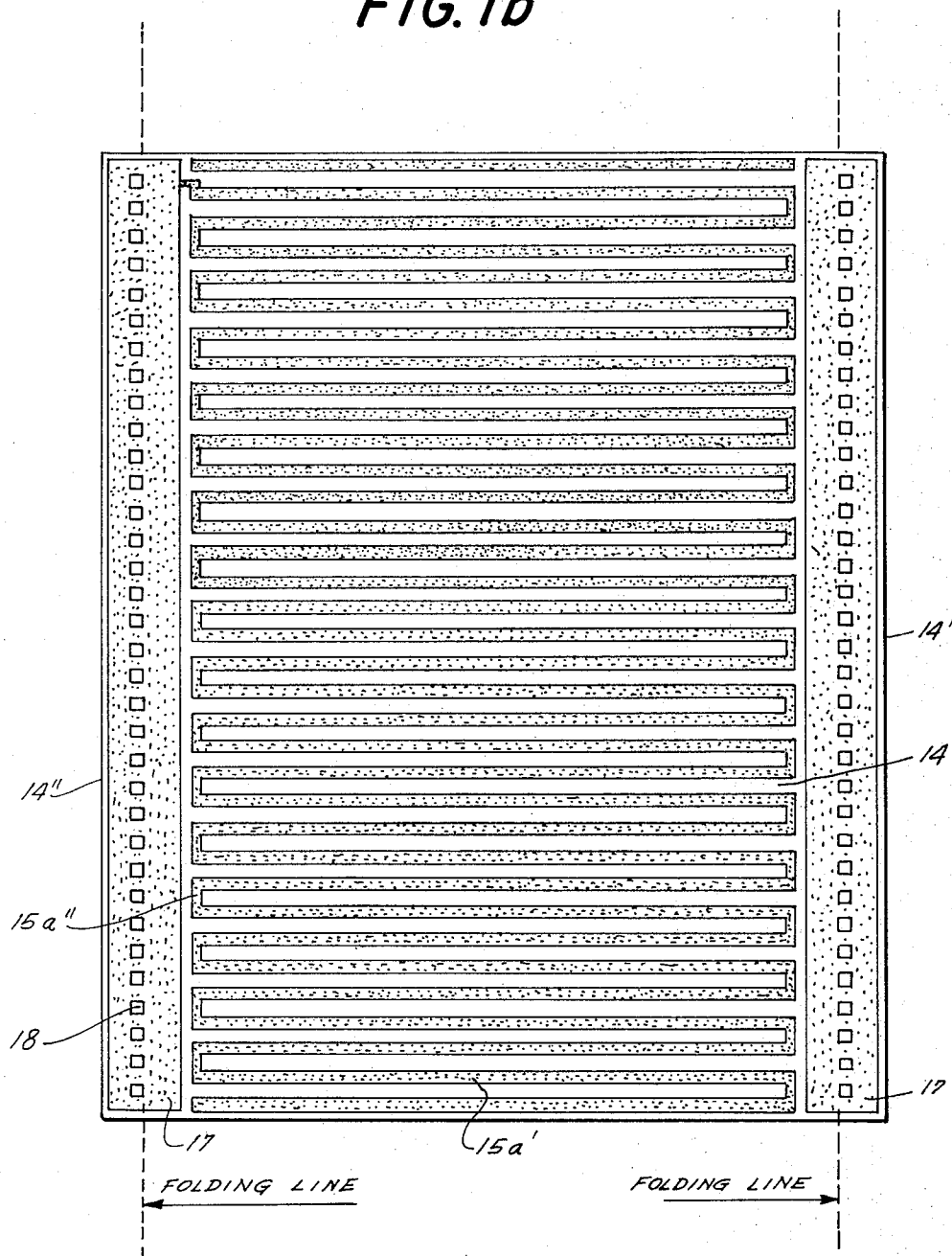


FIG. 2

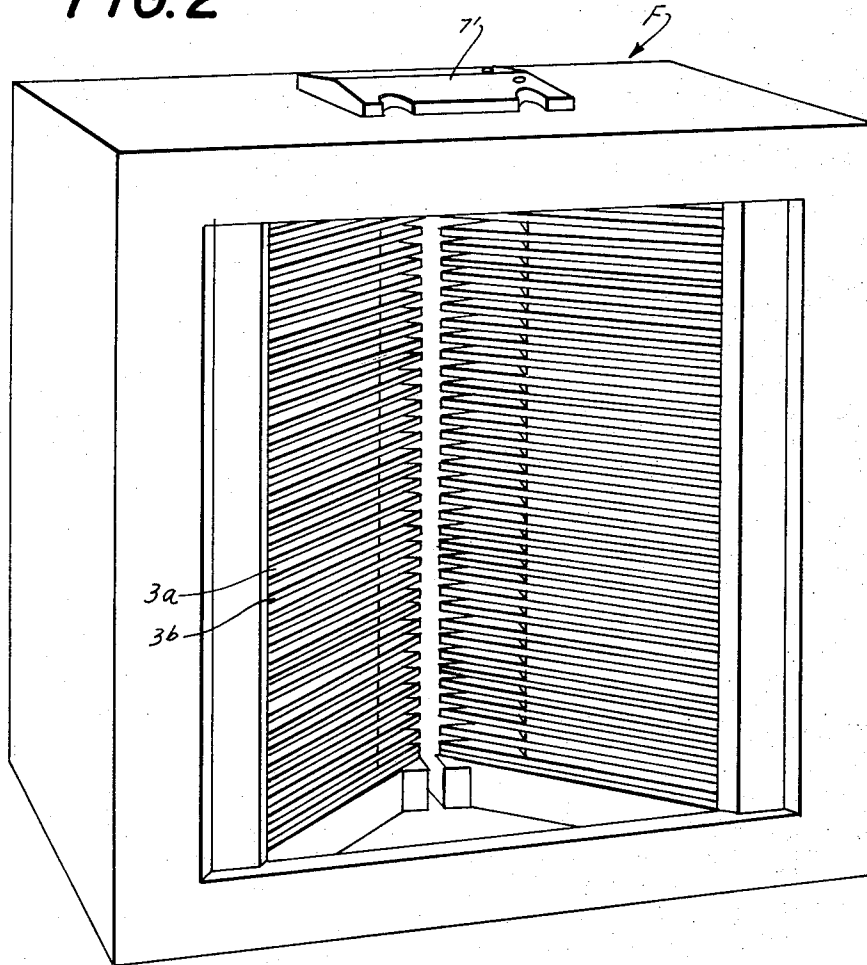


FIG. 4a

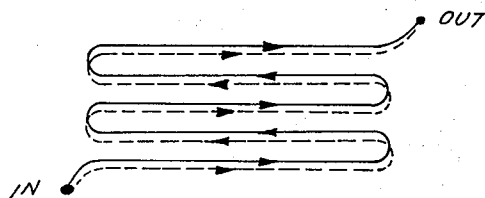


FIG. 4b

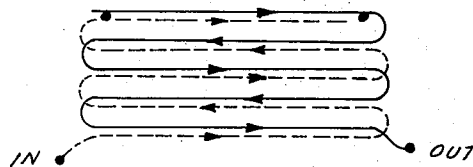


FIG. 2a

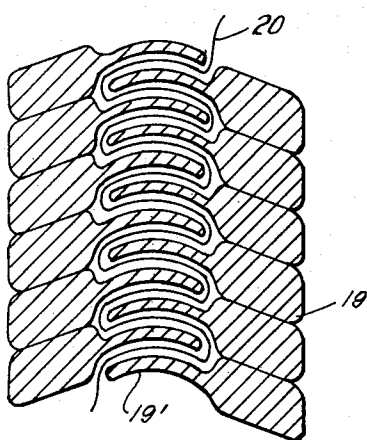
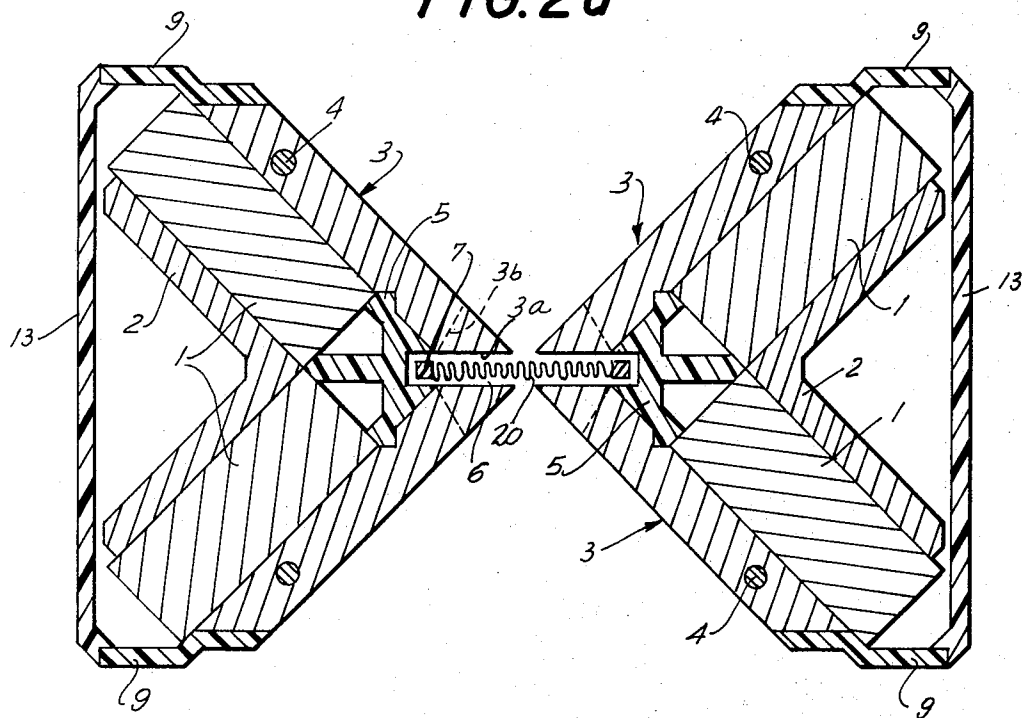


FIG. 5

FIG. 3

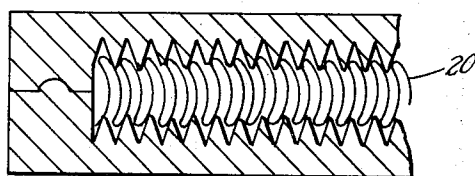
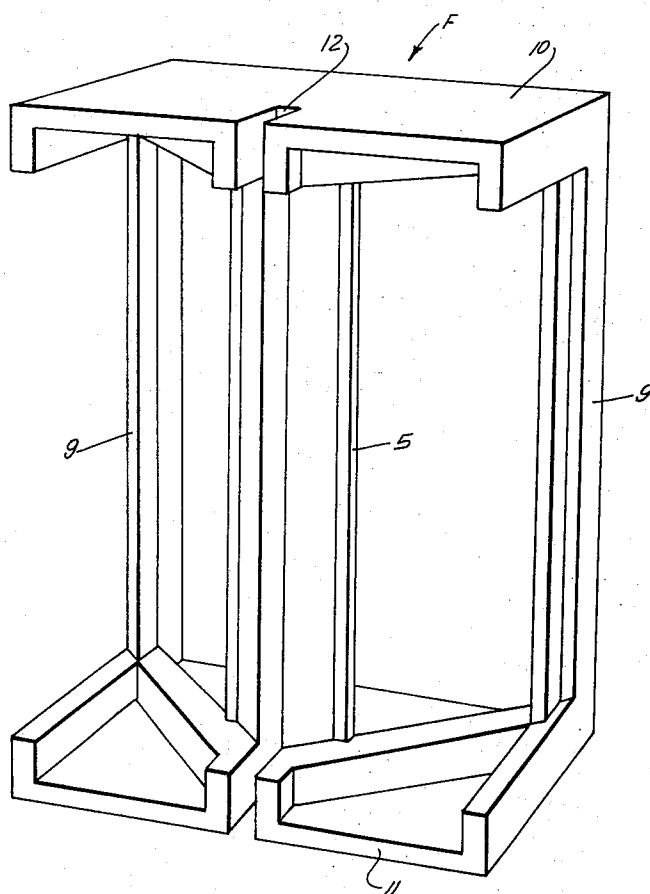


FIG. 6

ELECTRO-ACOUSTIC TRANSDUCER

BACKGROUND OF THE INVENTION

The present invention relates to an acoustic transducer and more specifically to an acoustic transducer as used in loudspeakers.

Such electro-acoustical transducers will comprise permanent magnet means for producing magnetic fields and defining a space communicating with the outer atmosphere and diaphragm means located in this space and comprising a thin corrugated sheet of non-conductive material defining a plurality of adjacent air spaces which alternately open to opposite sides, and conductor means connected to the sheet and subjected to the influence of the magnetic field to cause during passage of an audio current through the conductor means oscillation of the vibratable portions of the sheet to produce sound waves to be emitted through the open sides of the air spaces. Such electro-acoustic transducers are known in the art and for instance disclosed in my U.S. Pat. No. 3,636,278.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide for an electro-acoustic transducer which is improved as compared with the electro-acoustic transducer disclosed in the aforementioned patent.

It is a further object of the present invention to provide an electro-acoustic transducer in which especially the diaphragm construction is improved over the diaphragm construction as shown in this patent.

It is a further object of the present invention to provide for an electro-acoustic transducer of the aforementioned kind in which especially the magnet construction of the transducer is improved over the corresponding construction shown in the aforementioned patent.

With these and other objects in view, the electro-magnetic transducer mainly comprises permanent magnet means for producing a magnetic field and defining a space communicating with the outer atmosphere, and diaphragm means comprising a corrugated sheet of thin, flexible, non-conductive material having a pair of opposite edges and a plurality of adjacent substantially parallel portions extending between said edges and curved connecting portions alternately connecting said adjacent portions to each other so that the sheet defines a plurality of narrow air spaces having open sides alternately facing in opposite directions, and a metal foil applied to at least one face of the aforementioned sheet and comprising a plurality of elongated strip portions respectively extending along the substantially parallel portions of the sheet substantially normal to the edges thereof and each having a pair of ends adjacent to these edges and short connecting strip portions for connecting one end of one elongated strip portion to the adjacent end of the adjacent elongated strip portion and the other end of the adjacent elongated strip portion to the adjacent end of the next elongated strip portion in meander-shaped pattern, whereby during passing of audio current through the metal foil the diaphragm means will be vibrated to emit sound waves through the open side of the air spaces.

The permanent magnet means may comprise at least one permanent magnet portion and pole shoe portions held by magnetic attraction onto said permanent mag-

net portion and comprising a stack of alternately arranged longer and shorter iron laminates and defining a space in which the aforementioned diaphragm means is located, the longer and shorter laminates defining between themselves a plurality of air gaps through which the space communicates with the outer atmosphere.

The novel features which are considered as characteristic for the invention are set forth in particular in the appended claims. The invention itself, however, both as to its construction and its method of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific embodiments when read in connection with the accompanying drawing.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1a is a plan view of the diaphragm means before the plastic sheet to which the metal foil is attached is corrugated;

FIG. 1b is a plan view similar to that shown in FIG. 1a and showing a modification of such diaphragm means before corrugation;

FIG. 2 is a perspective view of the electro-acoustic transducer;

FIG. 2a is a cross-section taken along the line 2a—2a of FIG. 2;

FIG. 3 is a perspective view of a frame of preferably plastic material for supporting the permanent magnet means;

FIG. 4a illustrates schematically an arrangement in which metal foils are arranged to opposite sides of the plastic corrugated sheet of the diaphragm means, and in which the metal foils on opposite sides of the sheet are connected in parallel to each other;

FIG. 4b is a schematic view similar to that shown in FIG. 4a in which the metal foils to opposite sides of the sheet are in series connected; and

FIGS. 5 and 6 schematically illustrate jigs used during folding the diaphragm.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring now to the drawing, and more specifically to FIGS. 2 and 2a of the same, it will be seen that the electro-acoustic transducer according to the present invention comprises permanent magnet means for producing a magnetic field and defining a space communicating with the outer atmosphere in which the diaphragm means are located and subjected to the influence of the magnetic field. The permanent magnet means preferably comprise four elongated substantially prism-shaped magnet blocks 1 arranged in pairs spaced and opposite each other and extending in each pair substantially normal to each other. An angle 2 is applied to the outer faces of each pair of magnet blocks 1 and magnetically and/or mechanically connected thereto in any suitable manner, whereas a stack of laminates 3 is applied to the inner faces of each pair of magnet blocks 1. The stack of iron laminates forming the pole shoes of the permanent magnet means alternately comprise longer parallelogram-shaped members and shorter trapeze-shaped or rectangular members 3b having end edges 3b', as shown in FIG. 2a so as to define a plurality of air gaps between the members 3a and 3b inwardly of the end edges 3b'. Each of the laminates is formed with a circular hole therethrough through which aligning rods 4 respectively extend through the

stack of laminates to keep the latter aligned with each other.

The longer laminates 3a have end edges 3a' facing and spaced from each other to define between themselves a space 6 which communicates with the outer atmosphere through the aforementioned air gaps, as well as through air gaps formed between the facing ends of the two pairs of laminates.

The aforementioned elements of the magnet means are arranged within a frame F shown in longitudinal cross-section in FIG. 3 and in a horizontal cross-section in FIG. 2a and comprising a pair of inner uprights 5 and four outer uprights 9 which are preferably connected at their outer ends thereof in pairs by cover members 13. The frame F has a top wall 10 and a bottom wall 11 and these walls are formed with a slot 12 therethrough which forms a continuation of the aforementioned space 6. The frame F is formed of non-magnetic material, for instance plastic, or die-casting metal as for instance zinc alloy, aluminum or magnesium. The frame F may be formed out of two integral members as shown in FIG. 3 which are joined later together after the various elements of the magnet means are respectively inserted therein. The inner members 5 of the frame preferably have a pair of projecting edge portions 8, best seen in FIG. 2a, engaging in corresponding notches of the laminates 3a and 3b to help proper alignment of the latter.

The electro-acoustic transducer includes further diaphragm means made from metal foil plastic film laminates. The diaphragm means 20 are corrugated as shown in cross-section in FIG. 2a, whereas FIGS. 1a and 1b show the diaphragm in a plane before folding. The diaphragm as shown in non-folded or non-corrugated plane condition in FIG. 1a comprises a thin plastic sheet or film 14 to one or both faces of which a metal foil in a meander-shape pattern is applied. The metal foil 15 comprises thin elongated strip portions 15' extending substantially normal to opposite end edges 14' and 14'' of the plastic sheet 14 and the elongated strip portions 15' are respectively connected in pairs and alternately at opposite ends by connecting portions 15'' so that the metal foil forms a meander-shape strip as shown in FIG. 1a. The metal foil is preferably formed from aluminum, but copper may also be used, but aluminum has a higher conductivity per unit of weight and it is therefore preferred. The diaphragm may be made by etching from a metal foil plastic film laminate, or the metal foil may be applied to the plastic film by silk screening, vapor deposition or in any other way well known in the art of printed circuits.

Diaphragm 20 is folded as shown in FIGS. 5 and 6 with elongated metal strip foils 15' (FIG. 1a) and 15a' (FIG. 1b) disposed between the sharply curved edges or connecting portions of folded diaphragm 20.

FIG. 1b shows another embodiment of a diaphragm in plane condition before folding, and this embodiment differs from that shown in FIG. 1a in that the elongated strip portions 15a' end short of the end edges 14' and 14'' of the plastic sheet 14 and are connected by short connecting strip portions 15a'' into a meander-shaped pattern, which connecting strip portions are parallel and spaced from the aforementioned end edges 14' and 14'' of the plastic sheet. Two elongated metal strip foils 17 are respectively arranged between the end edges 14' and 14'' and the strip connecting portions 15a'' adjacent thereto. The metal foil strips 17 are each folded

along a fold line 17' against themselves so as to provide a greater rigidity than the remainder of the diaphragm to form after folding or corrugating of the whole diaphragm two stable end pieces which hold the flexible folds of the diaphragm at equal spacings. FIG. 1b shows also rows of square holes in the strips 17, that is in the outer portions of these reinforcing strips which get bent over. The location of these holes are in line with the diaphragm folds and the holes weaken the strips 17 in the areas where they become bent and act as aids for folding up the diaphragm. These holes are not essential but present a manufacturing advantage.

If metal meanders are applied to both sides of the plastic sheet, they must be connected either in series or in parallel in such a manner that the current flows in the same direction on both sides of the sheet. Proper series connection is conventionally made by directly joining the meanders on one side and by making one meander the mirror image of the other. Series connection of the two meanders is preferred because the impedance of the speaker assumes ohm values conventional for speakers and amplifiers, eliminating the use of matching transformers.

FIG. 4a schematically illustrates a parallel connection of the two meander-shaped metal foils respectively applied to opposite faces of the plastic sheet or film. The solid line in FIG. 4a indicates the meander-shaped metal foil on one face of the plastic sheet and the dotted line the meander-shaped metal foil on the other face.

Similar to FIG. 4a, FIG. 4b schematically illustrates the series connection of the meander-shaped metal foils on opposite sides or faces of the plastic sheet. As will be seen from these two Figures the two metal foils are connected in such a manner to each other that current will flow in the same direction through both metal foils.

The plastic film or sheet 14 should have a low modulus of elasticity and high internal friction to be acoustically dead. Very suitable materials are polyethylene, ionomers, ethylene-vinyl-acetate-copolymers, and others. If harder plastics such as nylon or polyesters are used, a coating of the folds with latex or similar high viscosity materials is preferred to prevent harmonic generation in the folds.

The plastic sheet 14 with the metal foil applied to one or both faces thereof is then folded or corrugated along fold lines respectively passing through the openings 16 or 18 in the connecting portions 15'' in the embodiment of FIG. 1a or in the strips 17 in the embodiment illustrated in FIG. 1b. This fold line will run parallel to elongated strip portion 15a' in FIG. 1b (15' in FIG. 1a) and, when diaphragm 20 is folded or corrugated, will define a curved connecting portion of diaphragm 20 between parallel portions. Such folding is preferably carried out in a jig as schematically illustrated in FIG. 5 which comprise a plurality of spacers having narrowed curved end portions 19', as shown in FIG. 5 and engaging the diaphragm from opposite sides so as to fold the same in the manner as schematically illustrated in FIG. 5 by the curved end portion 19'. As shown in this Figure the elongated metal strip portions 15' of FIG. 1a or 15a' of FIG. 1b will likewise be curved in accordance with the configuration of the portions 19'. The diaphragm folded in the jig illustrated in FIG. 5 is heat-treated and tempered to stay permanently in this folded form. The crosswise curving of the elongated

metal foil portions gives the same greater rigidity and form stability, and in order not to reduce the possible vibrational amplitudes of the diaphragm portions, the curvature on all elongated strip portions must be in the same direction.

To further improve the stability of the folded or corrugated diaphragm, the folds in the end metal strips 17 shown in FIG. 1b may be filled with a first liquid and then hardening substance such as an epoxy or a rubber compound. The surface tension holds the liquid in the folds and no casting form is required. During application of the liquid to the folds and during hardening of the liquid, the meander diaphragm structure is held in a jig as schematically illustrated in FIG. 6 in its proper position with equal distances for all folds. The jig is then removed after hardening of the liquid. To prevent oozing of the liquid in between the fold portions located between the elongated strip portions of the meander-shaped metal foils, the diaphragm is held in the jig substantially in vertical position and the liquid is applied first to one edge portion of the diaphragm and then the diaphragm is turned around and the liquid is applied to the other edge portion of the diaphragm after the liquid has hardened in the first edge portion.

After the diaphragm is thus formed to its finished corrugated shape, the diaphragm is connected at the edges thereof normal to the edges 14' and 14'' by cementing or otherwise to a plastic frame 7, as shown in FIG. 2a, and the frame with the diaphragm 10 connected thereto is then inserted through the slots 12 formed in the top wall 10 of the outer frame F into the space 6 defined by the slots 12 and the end edges 3a' of the pole shoe laminates, as shown in FIG. 2a. As shown in FIG. 2, the frame top 7' may be connected by screws or the like to the top wall of the outer frame F. The frame 7 with the diaphragm 10 connected thereto may thus be simply inserted and removed from the magnet structure which makes the diaphragm replacement an easy operation.

As clearly shown in FIG. 2a the longer trapezoidal shaped laminates 3a of the pole shoe pieces taper toward the middle of the space 6 in which the diaphragm 20 is located, as these pole shoe laminates have to carry gradually less magnetic flux. The above-mentioned tapering of the pole pieces has also a beneficial effect on the air loading of the diaphragm. The air moves periodically forward and backward in acoustical vibrations in the wedge-shaped narrow air gaps between the iron laminations and also in the free air space between the inner faces of the pole pieces, when an audio current is passed through the metal foil or foils of the diaphragm. For the same air volume displacement, the air in the air gaps between the laminations must move faster than the free air outside the laminations by the factor $a + b/b$, wherein a is the thickness of the longer parallelogram-shaped pole piece laminations and b is the thickness of the shorter, trapezoidal or rectangular formed laminations and therefore also the thickness of the air gaps between the laminations, for the same reason as a river moves faster where its banks are narrow and slower where its banks are wide. The momentum or mechanical impulse, which is mass times velocity ($m \times v$) remains however constant in the narrow air gaps and in the wide air space. The kinetic energy, however, which is $m \times v^2/2$ is increased in the narrow air gaps by the factor $a + b/b$. The mass per unit

length is reduced by the factor $b/a + b$ (cross-sectional reduction) and the square of velocity brings an increase by the factor $(a + b/b)^2$, resulting in the kinetic energy increase by the factor $a + b/b$. For acoustical vibrations the air seems to be heavier in the narrowed sections by the factor $a + b/b$, which is 2 for $a = b$ and greater than 2 for $a > b$.

The folded diaphragm has a very low effective mass, which equals about the weight of an air sheet of the thickness of 1 to 2 cm. The above-mentioned air-mass increase toward the edge of the diaphragm where the narrow air gaps are long is about the same value as the effective diaphragm mass for equal pole piece and spacer thickness a and b . If b is chosen smaller than a this mass loading becomes even heavier. This loading effect tapers down to zero in the middle of the diaphragm, where the narrow air gap length, as measured in the direction normal to the end edge 3a' goes likewise to zero.

For the reproduction of low and medium frequencies these mass loadings have no effect, because the total air mass moved, which is about a quarter wave length air, is big compared with the loading effect. But at frequencies from about 8,000 Hz upwards, where the quarter wave length becomes comparable to the above-mentioned air equivalents the mass loading reduces the diaphragm amplitudes on the edge of the diaphragm and forces the diaphragm activity more and more to the center as the frequency goes up. The sound emitted does not become directional, but spreads even at the highest audible frequencies very well over the front and back side of the speaker.

Another effect of the tapered pole pieces needs mentioning. The air moves not perpendicular to the diaphragm but it tends to cross the air gaps between the tapered pole pieces in the shortest possible distance. This is a straight path inclined towards the center of the diaphragm by half of the angle of each pole piece. This is in the illustrated speaker half of 45° , that is $22\frac{1}{2}^\circ$. That focusing effect further reduces the width of the sound source for the high audio frequencies and moves the sound focus out in front of the pole pieces.

Thus, the speaker has a frequency independant radiation pattern and cannot be acoustically localized very readily, even though it is practically a point source. The reason for this fact is that direct and ambient sound in the listening room will have the same frequency composition and therefore cannot be distinguished. The sound source appears wide like the original sound. Conventional speakers, on the other hand, have their characteristic directional and frequency pattern, which makes them recognizable. Great efforts are being made to hide this character of known speakers. In one system eight out of nine speakers must face the back wall of the room in order to hide their character, and only one is allowed to face the audience. The speaker of the present invention, however, can face the audience directly because it is practically without character and reproduces sound very truthfully.

It will be understood that each of the elements described above, or two or more together, may also find a useful application in other types of electro-acoustic transducers differing from the types described above.

While the invention has been illustrated and described as embodied in an electro-acoustic transducer, it is not intended to be limited to the details shown,

since various modifications and structural changes may be made without departing in any way from the spirit of the present invention.

Without further analysis, the foregoing will so fully reveal the gist of the present invention that others can by applying current knowledge readily adapt it for various applications without omitting features that, from the standpoint of prior art, fairly constitute essential characteristics of the generic or specific aspects of this invention and, therefore, such adaptations should and are intended to be comprehended within the meaning and range of equivalence of the following claims.

What is claimed as new and desired to be protected by Letters Patent is set forth in the appended

1. An electro-acoustic transducer comprising means for producing a magnetic field, a diaphragm disposed in said magnetic field with the plane of the diaphragm generally perpendicular to the lines of force of said magnetic field, said diaphragm comprising a sheet of thin, flexible, non-conductive material having a pair of opposite end edges and having corrugations formed in said sheet defining a plurality of adjacent substantially parallel portions extending between said end edges with curved connecting portions alternately connecting said parallel portions to each other to define a plurality of narrow air spaces having open sides alternately facing in opposite directions; and means for conducting an electric current attached to said sheet and comprising a plurality of elongated electrically conductive portions extending along said parallel portions of said sheet substantially normal to said end edges and parallel to said open sides, and connecting portions serially connecting said elongated portions to each other, whereby during passage of an audio-frequency current through said conducting means, said diaphragm will be vibrated to emit sound through said open sides of said air spaces.

2. An electro-acoustic transducer as defined in claim 1, wherein said parallel portions of said corrugated sheets are curved, the axes of curvature of said curved parallel portions being parallel to those of said curved connecting portions.

3. An electro-acoustic transducer as defined in claim 1, wherein said sheet of thin, flexible, non-conductive material is a plastic having a low modulus of elasticity and a high internal friction.

4. An electro-acoustic transducer as defined in claim 1, wherein said sheet of thin, flexible, non-conductive

material comprises a hard material having a viscous coating.

5. An electro-acoustic transducer as defined in claim 1, wherein said means for conducting an electric current is a metal foil attached to at least one face of said sheet.

6. An electro-acoustic transducer as defined in claim 1, and including a pair of electrical conductors attached to said sheet extending respectively along said end edges, the electrical conductor at one of said end edges being connected to one end of said serially connected conducting elongated portions and the other conductor at said other end edge being connected to the other end of said serially connected conducting elongated portions.

7. An electro-acoustic transducer as defined in claim 1, and including an electrical conductor attached to and extending along each of said end edges of said sheet, said electrical conductor being folded lengthwise onto itself for mechanical reinforcement.

8. An electro-acoustic transducer as defined in claim 1, and including an electrical conductor attached to and extending along each of said end edges of said sheet, said electrical conductor having a row of equally spaced holes the spacing of width equals the width of the diaphragm folds.

9. An electro-acoustic transducer as defined in claim 1, wherein said means for producing a magnetic field comprises a permanent magnet portion having at least two magnetic poles, a pole shoe portion for each of said magnetic poles with oppositely polarized pole shoe portions spaced apart to define openings in said pole shoe portions generally parallel to the lines of force crossing said magnetic field gap through which said magnetic field gap communicates with the space outside of said pole shoe portions.

10. An electro-acoustic transducer as defined in claim 7, wherein said pole shoe portions comprise a stack of alternately arranged longer and shorter magnetically permeable laminates, said longer and shorter laminates defining between themselves, proximate said magnetic field gap, a plurality of openings through which said magnetic field gap communicates with the space outside said pole shoe portion.

11. An electro-acoustic transducer as defined in claim 7, wherein the plane of said pole shoe portions is disposed at an angle to the plane of said diaphragm.

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