Dec. 19, 1961 **R. R. GAMZON ET AL** 3,013,905

ELECTROACOUSTIC TRANSDUCERS

Filed Nov. 20, 1958 4 Sheets-Sheet 1

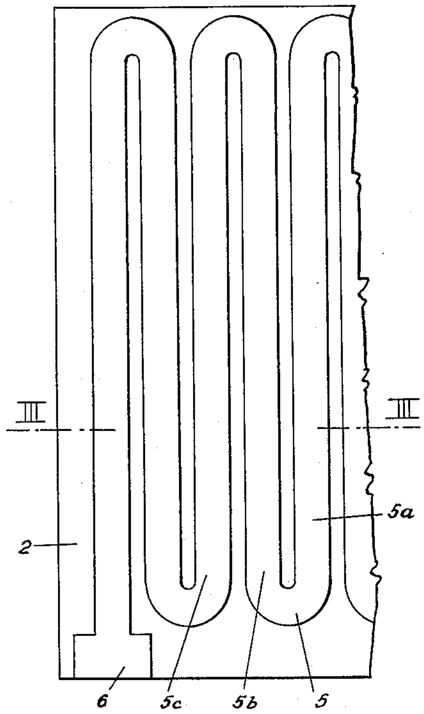

FIG. 1.

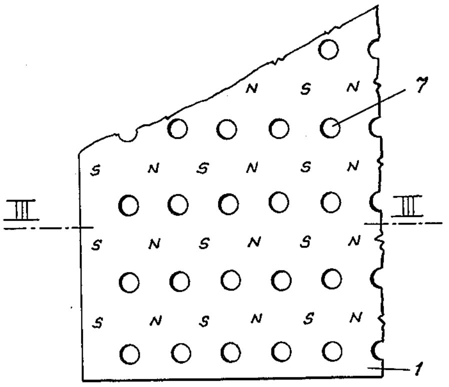

FIG. 2.

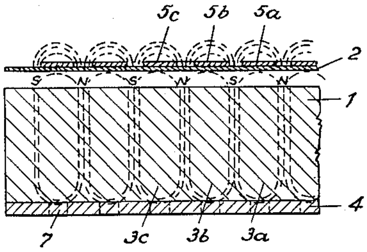

FIG. 3.

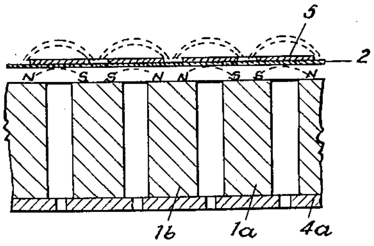

FIG. 4.

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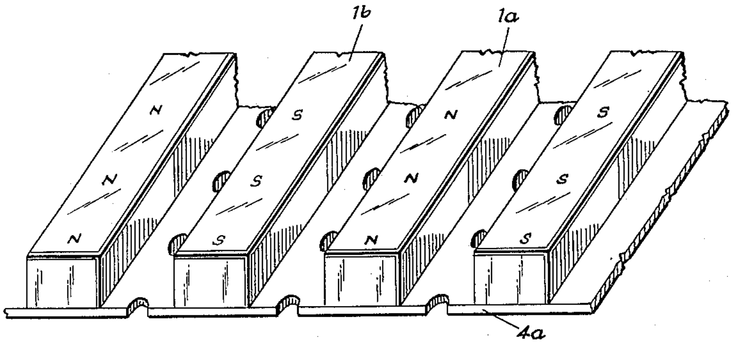

FIG. 5.

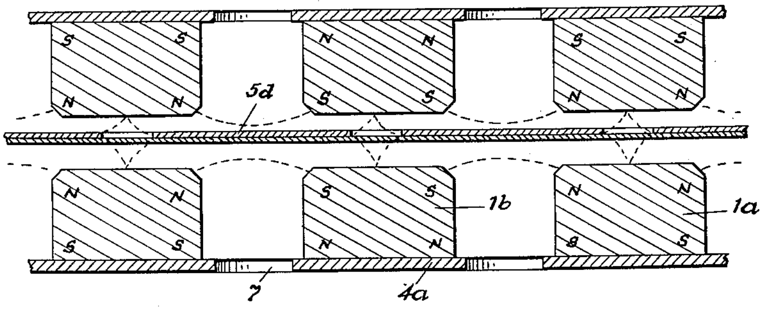

FIG. 6.

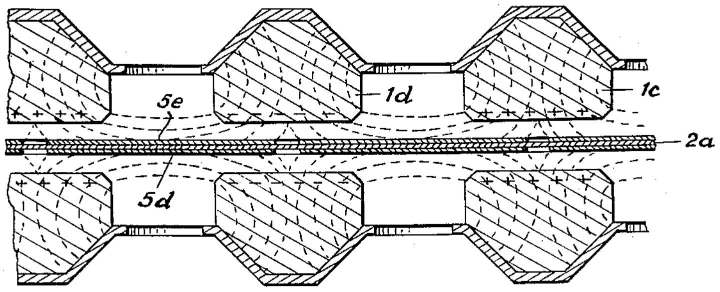

FIG. 7.

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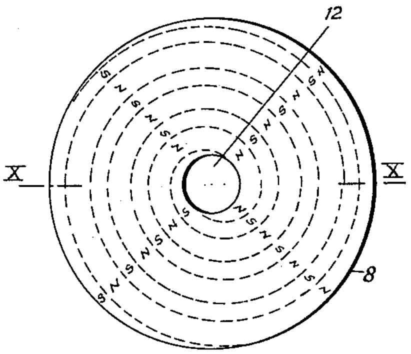

Fig. 8.

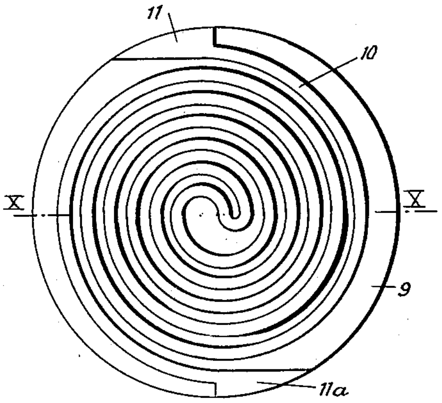

Fig. 9.

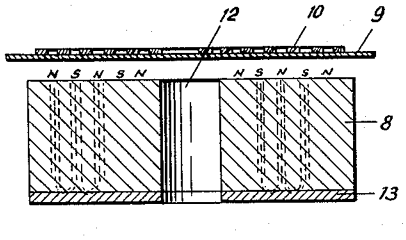

Fig. 10.

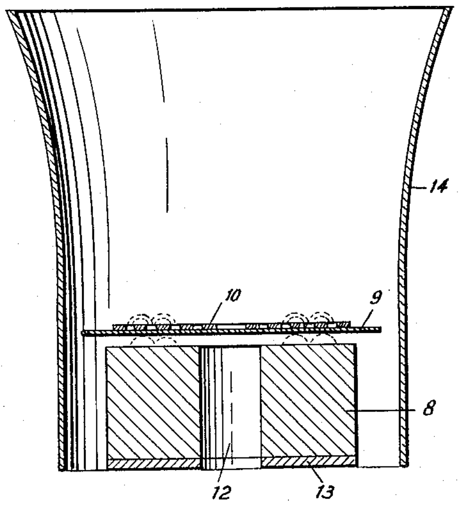

Fig. 11.

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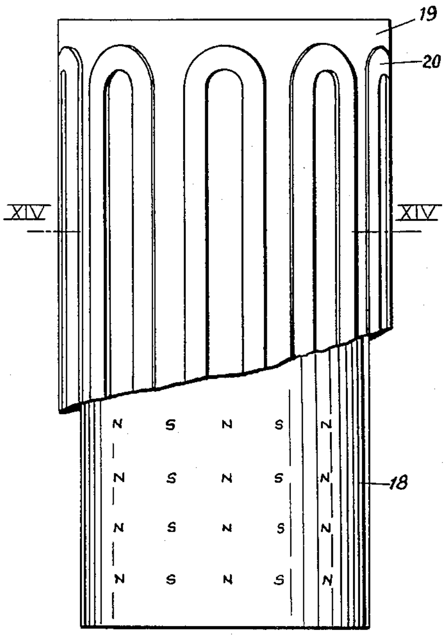

Fig. 13.

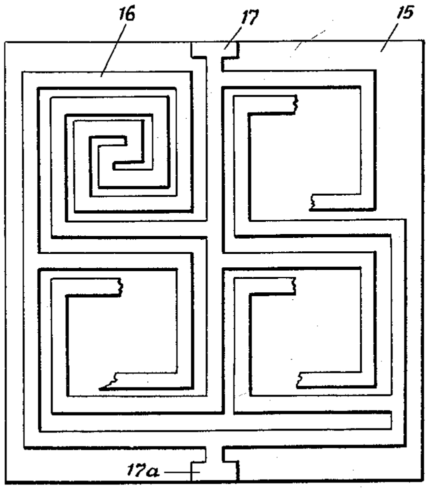

Fig. 12.

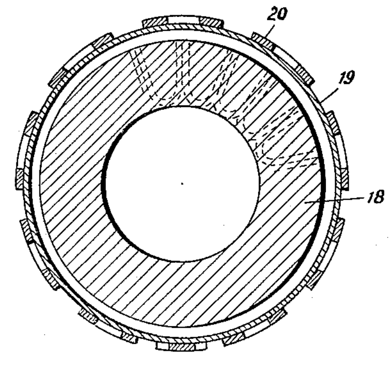

Fig. 14.

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ELECTROACOUSTIC TRANSDUCERS

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13 Claims. (Cl. 179—115.5)

This invention relates to electroacoustic transducers of the electrodynamic type for the conversion of electric oscillations of audio frequencies or higher frequencies near the audio range into sound or ultrasonic oscillations, or conversely, of sound or ultrasonic oscillations into electric oscillations, that is, loudspeakers, headphones or microphones.

Some conventional electrodynamic loudspeakers comprise a cone-shaped membrane or diaphragm driven by a coil, the so-called voice coil, in a constant magnetic field. The coil carries current of audio or ultrasonic frequencies and its oscillations in the magnetic field are transmitted to the membrane. Their main disadvantage is the linear distortion which is due to the fact that the cone-shaped membrane does not always oscillate uniformly in phase over its entire surface and its bad high frequency response. An analogous disadvantage is inherent in electrodynamic microphones which are in principle an inversion of the electrodynamic loudspeaker.

In another known kind of electrodynamic loudspeaker a diaphragm, which is clamped at its edges, has secured to it a conductor constituted by a rigid rib or by a flexible wire, which conductor is disposed within the air gaps between the poles of a plurality of magnets arranged in a flat or curved plane parallel to the magnet. The conductor is crossed by the lines of force of the magnetic fields between the poles, and through it flows the electric current of audio frequency which, in the case of a loudspeaker, generates the oscillations of the diaphragm or, in the case of a microphone, is generated by the oscillations of the diaphragm. Known transducers of this kind are cumbersome because of the necessity to place the ribs or wires within the narrow gap between the poles and had, moreover, to have a comparatively thick diaphragm, since the interaction between the magnetic field and conductor took place within the air gaps only, that is, in relatively limited zones. In spite of their comparatively strong magnetic field the acoustic efficiency of such transducers was not satisfactory, particularly so in the higher frequencies, mainly because of their high mechanical impedance, and the use of such loudspeakers was in practice abandoned in favour of cone loudspeaker.

The invention provides an electrodynamic diaphragm transducer which avoids the drawbacks of known electrodynamic transducers of both the diaphragm and cone type.

The transducer according to the invention comprises a magnet unit consisting of oriented ferrite or other oriented-magnetic material having a coercive force not below 750 oersteds, in which a plurality of poles alternate along at least one straight line, and substantially parallel to the magnet unit at a small distance therefrom an oscillatable membrane or diaphragm of non-magnetic material carrying at least one flat, ribbon-like, pliable conductor which is located outside any spaces which may exist between said poles of the magnetic unit, said poles resulting from orienting and magnetizing the magnetic material in such a manner that horseshoe-like magnetic field lines result which extend in the immediate vicinity of the surface substantially normal thereto, said conductor being connectable to an outer circuit and arranged in the same pattern as are said magnet poles and so disposed relative to the latter that the vector product of the current with the magnetic field has the same sign in all parts of the conductor.

The magnet unit may be a continuous plate magnetized with a plurality of poles, or it may be constituted by several discrete magnet elements mounted on a soft iron plate, with the magnet consisting of high coercive material whose grains or crystallites are oriented mainly perpendicular to the face of the magnet unit, so as to create a high field strength in the space where the membrane oscillates. For the sake of simplicity both arrangements will be referred to herein as "magnet plate" or "magnet system." The magnet plate may either be plane or curved, e.g. in cylindrical shape, in which latter case the "straight" line along which the poles alternate, will be a geodesic line.

Owing to the location of the conductor carried by the membrane outside spaces between magnet poles, where such spaces exist at all, the membrane can be impulsed along contiguous strips or bands, that is virtually over its entire surface in a uniform manner, in contrast to the known electrodynamic diaphragm loudspeakers aforesaid in which the diaphragm is impulsed along those zones only which register with the air gaps between the magnet poles engaged by the conductor or conductors. As these known diaphragms are thus subjected to pressure along relatively narrow bands only they must be made comparatively thick so that the deformations may not become too great. The thickness of these known diaphragms is of the order of millimeters, while the membranes of transducers according to the invention may be made thinner. Experimental transducers with membranes as thin as 7 microns have successfully been built. This thinness of the membrane makes for a much better acoustic reproduction. It is also for acoustic reasons that the magnet plate is perforated, e.g. with conical holes, whereby the magnitudes of the alternating states of elevated and reduced air pressure set up between the magnet and oscillating membrane are diminished.

The thickness of the conductor band is preferably very small compared to its width, and the width of the band is preferably large in proportion to the distance between consecutive rows of magnet poles. If P is the distance between the center lines of consecutive rows of magnet poles and E is the width of the conductor band, the proportion

$$\frac{E}{P}$$

may be as large as up to 0.9. This means that the major part of the membrane is submitted to the impulses which are converted into air pressure nearly uniformly distributed over the entire surface of the membrane.

With a view to making the magnetic field particularly strong and homogeneous, the invention also provides an arrangement wherein a single membrane is disposed between two similar magnetic plates arranged symmetrically in such a manner that poles of the plates having the same sign face each other. In this case, at least one of the plates will be perforated.

In several embodiments of the invention the conductor is situated on one side of the membrane. It is, however, also possible to have two conductors, one on each face of the membrane, and both conductors suitably connected in series or in parallel. In this case of two conductors it is possible, if desired, to use one of the conductors, for constituting a negative feed back "coil."

Feed back coils are known and used in high fidelity loudspeaker systems. However, the feed back coils used in high fidelity speakers are not very efficient because in a cone speaker it is practically impossible to avoid phase differences between the velocity of the cone and that of the coil.

In contrast thereto the negative feed back "coil" according to the above embodiment of the invention is completely in phase with all that part of the membrane surface covered by the conductor which, as stated before, amounts to 90% of the surface. In this manner very effective feed back and consequently very high fidelity is ensured.

If a conductor is used for feed back its thickness may be a fraction of a micron so that its weight becomes quite negligible. Conductors of such reduced thickness are easily obtainable by vacuum evpaoration processes as known per se.

The reproduction quality of loudspeakers according to the invention is especially good in regions of higher acoustic frequencies. Good reproduction can be extended also into the region of lower frequencies by making the membrane and magnets large, or combining several plates in a larger surface. Owing to the fact that the membrane swings in phase over its entire surface there is practically no limit to the dimensions of the membrane, and it is even possible to constitute an entire wall of a room as a membrane plate of a transducer according to the invention, which can be of advantage in large halls.

Particularly suitable magnetic materials for the purposes of this invention are those ferrites which contain barium oxide in combination with various proportions of iron oxides.

The non-magnetic membrane may consist, for example, of a synthetic plastic material such as polyethylene, glycol terephthalate, or another polyester.

The invention is illustrated, by way of example only, in the accompanying drawings in which:

FIG. 1 is a fragmentary plan view of the membrane of a transducer according to the invention;

FIG. 2 is a fragmentary plan view of the magnet plate of the same transducer;

FIG. 3 is a cross-section of the transducer on lines III—III of FIGS. 1 and 2;

FIG. 4 is a fragmentary cross-section of a transducer according to a second embodiment of the invention;

FIG. 5 is a fragmentary perspective view of the magnet plate of the transducer of FIG. 4;

FIGS. 6 and 7 are fragmentary cross-sections of two further transducers according to the invention;

FIGS. 8 and 9 are plan views of the magnet plate and membrane of a further transducer according to the invention;

FIG. 10 is a cross-section on lines X—X of FIGS. 8 and 9;

FIG. 11 is an axial section of a loudspeaker (tweeter) embodying a transducer according to FIGS. 8 to 10;

FIG. 12 is a fragmentary plan view of the membrane of yet another transducer according to the invention;

FIG. 13 is a fragmentary elevation of a transducer according to a further embodiment of the invention;

FIG. 14 is a cross-section on line XIV—XIV of FIG. 13.

The transducer according to FIGS. 1 to 3 comprises a magnet plate **1** and a membrane **2**. The plate is made from highly coercive oriented ferrite material, e.g. the barium ferrite commercially known as "Indox V" (trademark) of a high coercive force, being of the order of 2000 oersteds. It is magnetized in such a manner that alternating north poles and south poles extend in parallel over the entire length of the plate. Between each two vicinal poles the flux runs through the depth of the plate. FIG. 3 shows diagrammatically the form of these flux lines and the preferred grain orientation in the material. The flux can be conceived as a horseshoe magnet **3***a*, **3***b*, **3***c* etc., and the magnets, as it were, are contiguous and share pairwise their poles of equal sign, e.g. the magnets **3***a* and **3***b* share a south pole, the magnets **3***b* and **3***c* a north pole, and so forth. These poles lie in the top face of the plate while the bottom of the face is constituted by a soft-iron armature plate **4**.

The membrane **2** is a pliable sheet of non-magnetic material, e.g. a polyester plastic material, of a thickness of about 0.01 mm. On it, a conductor **5**, e.g. of aluminium, is printed in the form of a very thin, flat band which is pliable and has a very low mechanical impedance. The membrane is substantially coextensive with the plate **1**, tautly stretched above the plate at a distance of about 1 mm. or less, and secured at its edges in any suitable conventional manner. The conductor is continuous and runs in parallel stretches from end to end of the membrane, returning at the ends in short arcs. The stretches are in registry with the magnetic gaps (which expression does not, in this case, imply a conventional air gap as the plate has a continuous plane surface) between consecutive opposite poles of the plate **1**, i.e. stretch **5***a*. With the gap between the poles of magnet **3***a*, stretch **5***b* with the gap between the poles of magnet **3***b*, and so forth. At its ends the conductor **5** has two or more terminals **6**, of which one has been shown in FIG. 1, for connection to the input or output circuit, as the case may be. The magnet plate has a plurality of holes **7**, for the equalisation of the air pressure in the gap between the magnet plate and membrane.

When an electric current flows in the conductor, its direction is reversed from stretch to stretch of the conductor, and each change of direction corresponds to a change of direction of the magnetic field or, in other words, the vector product of the current with the magnetic field has the same sign in all parts of the conductor. The membrane thus oscillates in phase over its entire surface with the frequency of the alternating current passing through the conductor.

In the transducer according to FIGS. 4 and 5 the magnet plate is built up from discrete bars **1***a*, **1***b* mounted in parallel on a soft-iron, perforated armature plate **4***a* with equal gaps between them. Their top faces form alternately north and south poles. The design of the membrane **2** and conductor **5** are similar as in the embodiment of the invention according to FIGS. 1 to 3. The advantage of this design, as compared with the continuous magnet plate according to FIGS. 1 to 3, is in the easier magnetization and the stronger magnetic fields attainable.

FIG. 6 shows a transducer comprising a single membrane **2***a* with broad conductor stretches **5***d* suspended between two equal and symmetrically disposed magnet plates designed in accordance with FIG. 5. Magnet poles of like sign face each other across the membrane **2***a*, i.e. bars **1***a* with their north poles turned towards the membrane, and bars **1***b* with their south poles. The acoustic efficiency of a transducer of this kind is even greater than that of the single-magnet-plate transducers according to FIGS. 1 to 3 or FIGS. 4 and 5.

FIG. 7 shows a transducer similar to that of FIG. 6, except that the magnet bars **1***c*, **1***d* are bevelled at their faces turned away from the membrane with a view to saving material and making the transducer lighter, and diminishing the mechano-acoustical impedance of the slots. In this embodiment the membrane **2***a* supports two conductors **5***d*, **5***e*, each on one face, of which one may serve as feed back conductor.

In the transducer according to FIGS. 8 to 10 the magnet plate **8** and membrane **9** have circular outline. The plate is magnetized, instead of in parallel lines as in the embodiment according to FIGS. 1 to 3, in the form of two intertwined spirals obtained by starting a spiral from the edge towards the center and returning from there to the edge. The two spirals are thus generally parallel to one another.

The conductor **10** of the membrane is disposed in the same manner so that it registers throughout with the space between the magnet poles. At the edges of the membrane it ends in terminals **11**, **11***a*. North and south poles alternate along radial lines drawn across the magnet plate. The plate has a central aperture **12** and a bottom armature plate **13**.

A circular transducer of this kind is particularly suitable for horn loudspeakers or tweeters for high acoustic frequencies. FIG. 11 illustrates such a loudspeaker. It has a horn **14** associated with a transducer according to FIGS. 8 to 10.

FIG. 12 shows the membrane **15** of yet another transducer. Its conductor **16** is disposed in four square fields. In each of these it has the form of two intertwined labyrinths, analogous to the intertwined spirals of FIG. 9. The conductors of the four fields are connected in parallel between terminals **17**, **17***a*. The magnet plate is magnetized according to the same pattern so that the conductor is in registry with the gaps between alternating magnet poles as in the transducers described hereinbefore. The transducer may have fewer or more than four such fields.

FIGS. 13 and 14 show a cylindrical type of transducer according to the invention. A hollow cylinder **18** of ferrite material is surrounded by a cylindrical membrane **19** on which the conductor **20** is imprinted. The conductor extends in parallel stretches along generatrices of the cylinder while the poles are disposed in alternation along circles round the plate **18**. The advantage of this arrangement is that the membrane radiates symmetrically in all radial directions. This design makes for a very simple construction of the transducer.

We claim:

1. An electro-acoustic transducer comprising an oscillatable membrane of non-magnetic material; a permanent magnet system having a series of elemental magnet portions, each portion having first and second poles on a line extending perpendicular to said membrane, said magnet portions being of a material having crystallite grains oriented along said line and having a coercive force of at least 750 oersteds, said first poles being arranged in a plurality of elongated unipolar zones extending parallel to one another and parallel to said membrane, said first poles alternating in polarity from one of said zones to the next, said unipolar zones being separated by elongated transition zones across which there exists a magnetic field bridging said first poles; and continuous flexible conductive strip means disposed flat on and carried by said membrane and covering a major fraction of the surface area of said membrane, said strip means being coextensive with a meandering path interconnecting all of said transition zones with such directional changes that, upon said strip means being traversed by an electric current, the vector product of said current and of said magnetic field is of the same sign throughout the length of said strip.

2. A transducer according to claim 1 wherein said system has a thickness which is small compared with its lateral dimensions, said elemental magnet portions being contiguous portions of said system.

3. A transducer according to claim 1 wherein said system has a thickness which is small compared to its lateral dimensions, said elemental magnet portions being contiguous portions of each of a plurality of separate permanent magnets.

4. A transducer according to claim 1 wherein said system is provided with a soft-iron plate in contact with said magnet portions on the side remote from said membrane.

5. An electro-acoustic transducer comprising an oscillatable membrane of non-magnetic material; a permanent magnet system composed of a series of elemental magnet portions each extending perpendicular to said membrane and having one pole located in a surface of said system closely spaced from and parallel to said membrane, said magnet portions being of a material having coercive force of at least 750 oersteds, said poles forming a plurality of elongated unipolar zones extending parallel to one another across said surface and alternating in polarity from one of said zones to the next, said system being provided with elongated transition zones which separate said unipolar zones and across which there exists a magnetic field bridging said poles; and continuous flexible conductive strip means disposed flat on and carried by said membrane and covering a major fraction of the surface area of said membrane, said strip means being coextensive with a meandering path interconnecting all of said transition zones with such directional changes that, upon said strip means being traversed by an electric current, the vector product of said current and of said magnetic field is of the same sign throughout the length of said strip means.

6. An electro-acoustic transducer comprising an oscillatable membrane of non-magnetic material; a generally rectangular permanent magnet system composed of a series of elemental magnet portions each extending perpendicular to said membrane and having one pole located in a surface of said plate closely spaced from and parallel to said membrane, said magnet portions being of a material having crystallite grains oriented substantially perpendicular to said membrane and having a coercive force of at least 750 oersteds, said poles forming a plurality of elongated unipolar zones extending parallel to one another across said surface along straight lines parallel to two sides of said plate and alternating in polarity from one of said zones to the next, said system having elongated transition zones which separate said unipolar zones and across which there exists a magnetic field bridging said poles; and continuous flexible conductive strip means disposed flat on and carried by said membrane and covering a major fraction of the surface area of said membrane, said strip means being coextensive with a meandering path interconnecting all of said transition zones with such directional changes that, upon said strip means being traversed by an electric current, the vector product of said current and of said magnetic field is of the same sign throughout the length of said strip means.

7. An electro-acoustic transducer comprising an oscillatable membrane of non-magnetic material; a permanent magnet system comprising a plurality of elemental magnet portions, each having a pair of poles with an axis extending away from said membrane and being formed of a material having crystallite grains oriented along said axis and having a coercive force of at least 750 oersteds, each magnet portion also having one pole thereof closely spaced from said membrane and the other pole more remote from said membrane, said closely spaced poles being substantially equidistant from said membrane so as to lie in a geometric surface closely spaced from and substantially parallel to said membrane, said poles being arranged along said surface in a pair of unipolar zones of opposite polarity with a transition zone between said pair of zones, whereby across said transition zone there exists a magnetic field bridging said poles; and continuous flexible conductive strip means disposed flat on and carried by said membrane and covering a major fraction of the surface area of said membrane, said strip means being in registry with said transition zone.

8. An electro-acoustic transducer comprising an oscillatable membrane of non-magnetic material; a permanent magnet system comprising a plurality of elemental magnet portions, each having a pair of poles and an axis extending away from said membrane and being formed of a material having crystallite grains oriented along said axis and having a coercive force of at least 750 oersteds, each magnet portion also having one pole thereof closely spaced from said membrane and the other pole more remote from said membrane, said closely spaced poles being substantially equidistant from said membrane so as to lie in a geometric surface closely spaced from and substantially parallel to said membrane, said poles being arranged along said surface in a plurality of unipolar zones alternating in polarity from each zone to the next and with a transition zone between each pair of adjacent unipolar zones, whereby across each transition zone there exists a magnetic field bridging said poles; and continuous flexible conductive strip means disposed flat on and carried by said membrane and covering a major frac-

tion of the surface area of said membrane, said strip means being in registry with each transition zone, the vector product of said magnetic field with a current traversing said strip means being of the same sign throughout the length of said strip means.

9. An electro-acoustic transducer comprising an oscillatable membrane of non-magnetic material; a permanent magnet system comprising a plurality of elemental magnet portions, each having a pair of poles and an axis extending away from said membrane and being formed of a material having crystallite grains oriented along said axis and having a coercive force of at least 750 oersteds, each magnet portion also having one pole thereof closely spaced from said membrane and the other pole more remote from said membrane, said closely spaced poles being substantially equidistant from said membrane so as to lie in a geometric surface closely spaced from and substantially parallel to said membrane, said poles being arranged along said surface in a plurality of elongated unipolar zones alternating in polarity from each zone to the next and with a plurality of elongated transition zones each respectively located between each pair of adjacent zones, whereby across each transition zone there exists a magnetic field bridging said poles; and continuous flexible conductive strip means disposed flat on and carried by said membrane and covering a major fraction of the surface area of said membrane, said strip means being coextensive with a meandering path interconnecting all of said transition zones with such directional changes that, upon said strip means being traversed by an electric current, the vector product of said current and of said magnetic field is of the same sign throughout the length of said strip means.

10. An electro-acoustic transducer comprising a planar permanent magnetic system comprising a plurality of elongated permanent magnet portions arranged in parallel rows, each magnet portion being of an oriented material having a coercive force of at least 750 oersteds and having an axis of magnetization and a crystallite grain orientation perpendicular both to its length and to the plane of said magnet system, said magnet portions having alternating polarity from one magnet portion to the next, an oscillatable membrane of non-magnetic material parallel to and spaced closely to said plane, and continuous flexible conductive strip means disposed flat on and carried by said membrane, and covering a major fraction of the surface area of said membrane, the major portion of said conductive strip means extending parallel to said elongated magnet portions.

11. An electro-acoustic transducer comprising a planar permanent magnetic system comprising a plurality of elongated permanent magnet portions arranged in parallel rows, each magnet portion being of an oriented material having a coercive force of at least 750 oersteds and having an axis of magnetization and a crystallite grain orientation perpendicular both to its length and to the plane of said magnet system, said magnet portions having alternating polarity from one magnet portion to the next, an oscillatable membrane of non-magnetic material parallel to and spaced closely to said plane, and continuous

flexible conductive strip means disposed flat on and carried by said membrane and covering a large fraction of the surface of said membrane, the major portion of said conductive strip means extending parallel to said elongated magnet portions.

12. An electro-acoustic transducer comprising a first planar system of elongated permanent magnets arranged in parallel rows, each magnet being formed of an oriented material and having an axis of magnetization and a crystallite grain orientation perpendicular both to its length and to the plane of said system of magnets, each magnet having a polarity opposite to that of its neighboring magnet, a second planar system of elongated permanent magnets of said material, each magnet of said second system being parallel to and opposite a respective magnet of said first system to form a pair therewith, the magnets of each such pair having the same polarity facing each other, an oscillatable membrane disposed normally equidistant between the magnets of said pairs and parallel to the planes of said magnet systems, and continuous flexible conductive means disposed flat on and carried by said membrane and having portions extending parallel to said magnets, said conductive means covering a major fraction of the surface area of said membrane.

13. An electro-acoustic transducer comprising a first planar system of elongated permanent magnets arranged in parallel rows, each magnet being formed of an oriented magnetic material having a coercive force of at least 750 oersteds and having an axis of magnetization and a crystallite grain orientation perpendicular both to its length and to the plane of said system of magnets, each magnet having a polarity opposite to that of its neighboring magnet, a second planar system of elongated permanent magnets of said material, each magnet of said second system being parallel to and opposite a respective magnet of said first system to form a pair therewith, the magnets of each such pair having the same polarity facing each other, an oscillatable membrane disposed normally equidistant between the magnets of said pairs and parallel to the planes of said magnet systems, and continuous flexible conductive means disposed flat on and carried by said membrane and having portions extending parallel to said magnets, said conductive means covering a major fraction of the surface of said membrane.

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