Dec. 15, 1936. R. L. STEINBERGER 2,063,951

APPARATUS FOR TRANSMISSION AND RECEPTION

Original Filed Dec. 4, 1931 2 Sheets-Sheet 1

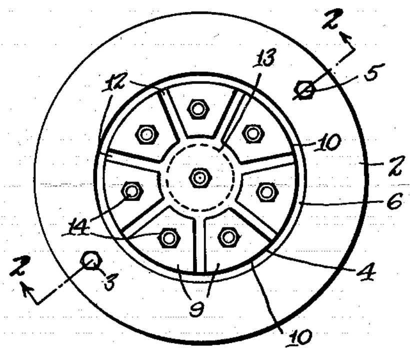

Fig.1.

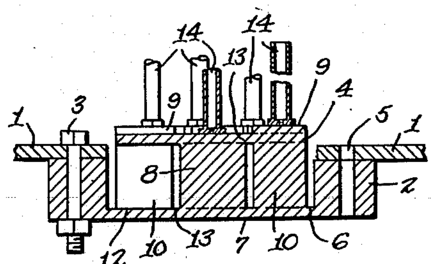

Fig.2.

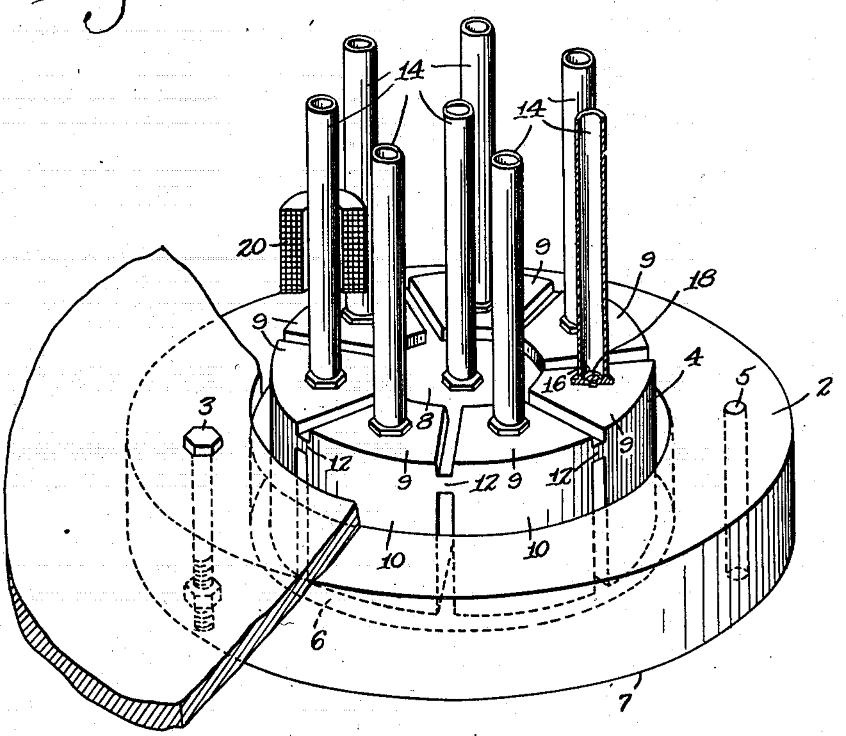

Fig.3

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APPARATUS FOR TRANSMISSION AND RECEPTION

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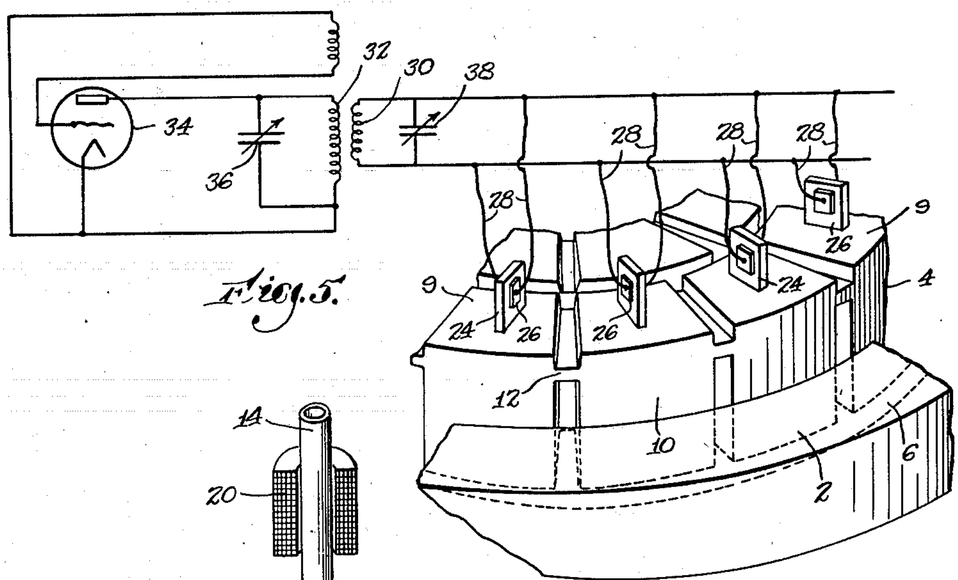

Fig. 5.

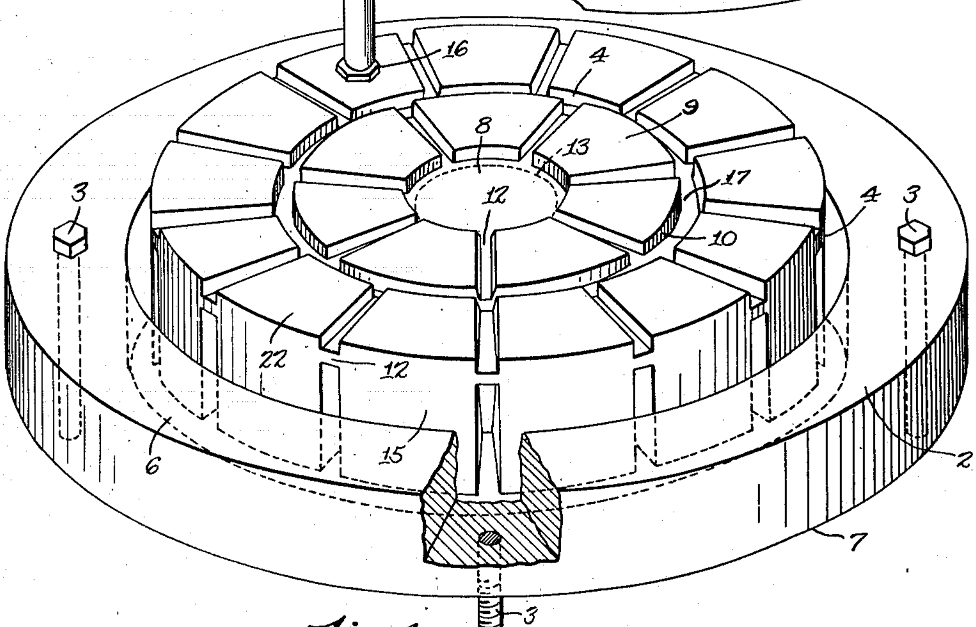

Fig. 4.

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UNITED STATES PATENT OFFICE

2,063,951

APPARATUS FOR TRANSMISSION AND RECEPTION

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Original application December 4, 1931, Serial No. 579,039. Divided and this application July 19, 1935, Serial No. 32,252

11 Claims. (Cl. 177—386)

The present invention, although having fields of more general usefulness, is particularly related to devices for converting or translating acoustic energy into electric energy and vice versa. From a more limited aspect, the invention relates to diaphragms. The present application is a division of application, Serial No. 579,039, filed December 4, 1931.

It has long been recognized, for theoretical reasons which need not be entered into here, that the ideal coupling element for radiating a concentrated beam of acoustic energy into a liquid or gaseous medium, or for the directionally-selective reception of acoustical energy from such a medium in electro-acoustic energy-convertor systems, is a diaphragm whose face dimensions are relatively large compared to the wave length of the acoustic energy in the medium, and in which all points of the radiating face are vibrating in phase and with equal amplitude like a piston.

The ordinary metal membrane diaphragm commonly used at the present time in the communication art, does not satisfy this ideal condition. It cannot move as a piston because it is clamped along its periphery. Such a diaphragm may introduce a dispersion of the radiated energy at its several higher modes of vibration which will cause the various parts of the diaphragm to be out of phase with one another so that the transmitted energy, for example, is not properly focused. It is well known that, in order to be an efficient translating member, such a diaphragm must be tuned to the frequency of the radiated or received acoustic energy. At the very high sound frequencies called into play in supersonic work, say, 30 kilocycles, a resonant disc vibrating in the manner of an ordinary telephone diaphragm is, indeed, wholly impractical. At such frequencies a resonant plate or disc has proportions more nearly comparable to a short cylinder.

In the ordinary diaphragm clamped along its periphery and vibrating in its fundamental mode, all portions of the diaphragm will be moving in the same direction at any given time; that is to say, they will be in phase. In the diaphragm described in the present application, the median plane, parallel to and midway between the faces of the diaphragm, executes no appreciable motion along the axis of the diaphragm; that is, it is a node; while the two faces of the diaphragm move in opposite directions along the axis at all times; that is, the two faces execute vibrations essentially 180° out of phase. This mode of vibration, for a particular frequency, is realized by making the thickness of the diaphragm, that is, the length along the axis, substantially equal to one-half of the wave length of sound in the material comprising the diaphragm. The vibration of the diaphragm in this manner will hereinafter be defined as expansional vibration.

Any longitudinal element of the diaphragm along the axis is, therefore, contracting and expanding along and parallel to the axis. The central, nodal portion of the diaphragm, which has no longitudinal motion, nevertheless, at the same time expands and contracts in the nodal plane perpendicular to the axis. It is to permit this transverse motion in the nodal plane that the diaphragm is subdivided in the manner described below.

An object of the present invention is to provide a very sensitive, energy converter of the above-described character that shall translate acoustic into electric energy or vice versa, with greater efficiency than has been possible heretofore.

A further object is to provide a new and improved acoustic piston. This piston will, hereinafter, in the specification and the claims, for convenience and by analogy, be referred to as a "diaphragm".

A further object is to provide a sectional diaphragm, the sections or blocks of which are properly designed and individually driven in unison so as to cause the diaphragm to move as a unit expansionally.

A further object is to provide a sectional diaphragm, the sections or blocks of which are permitted a transverse dilation and contraction as they execute a longitudinal contraction and expansion along their axes.

A further object is to provide a novel expansional metal diaphragm.

Another object is to provide a novel diaphragm energized by driving members which are operative through internal stresses, such as are brought about by magneto-striction, or piezo-electricity.

Another object is to provide a novel diaphragm particularly adapted for supersonic electro-acoustic energy conversions.

Other objects will be explained hereinafter, and will be more particularly pointed out in the appended claims.

The invention will be explained in connection with the accompanying drawings, in which Fig. 1 is a plan of a preferred embodiment of the piston diaphragm of the present invention; Fig. 2 is a section taken upon the line 2—2 of Fig. 1, looking in the direction of the arrows; Fig. 3 is a perspective upon a larger scale, one of the magnetostrictive-driving elements and an energizing coil being shown in section; Fig. 4 is a similar perspective of a modification; and Fig. 5 is a diagrammatic view of circuits and apparatus illustrating one form of the invention as applied to piezo-electric-crystal drive.

The invention is illustrated in the accompanying drawings as applied to a supersonic transmitter or receiver, but it will be obvious that the invention is not limited thereto, and is applicable to other types of transmitters as well as to receivers. The device, if to be used under water, may be mounted in a rotatable, submerged housing, or it may be secured to any object 1, as the side of a water craft, by means of bolts 3 passing through openings 5 in a relatively fixed or immovable, outer, inertia annular or ring portion 2. The inner, vibratory, diaphragm portion 4, cylindrical or disc-shaped, is integrally connected to the outer annular portion 2 by an intermediately disposed, relatively thin, annular web 6. A uniform, metallic connection is thus obtained between the outer ring 2 and the diaphragm 4. The web 6 is thin enough so as to be relatively yielding, thus permitting the receiving or radiating face 7 of the diaphragm portion 4 to vibrate substantially like a piston, in a direction transversely of itself, substantially all the flexing taking place in the web 6. The large mass of the inertia ring 2 prevents transmission of vibration thereto.

All points on the upper and lower end faces of the single expansional, resonant, cylindrical units of which the diaphragm is built, which individual units should have as large a diameter and as small a length as possible, should vibrate in phase over each face. The limit in choosing a large cross-sectional area compared to axial length, however, is small, because the cylinder has a tendency to vibrate, not only according to its fundamental, but also according to many higher modes of vibration, with resulting nodal lines on its lower, emitting face 7. This phenomenon is enhanced owing to the fact that, if the diameter of the diaphragm is large compared to its axial length, the necessary transverse vibration of the diaphragm material in its median plane is restricted. Parts of this face, therefore, have a tendency to vibrate in a phase opposite to that of other parts. At a distance from the transmitting face 7, therefore, the vibrations set up from the transmitting face 7 in the medium would cancel each other, so that the diaphragm will not efficiently emit a focused beam of sound energy. These considerations are particularly potent at high frequencies.

The diaphragm portion 4 illustrated in Figs. 1, 2, 3 and 4 is therefore divided into sections or blocks. According to the embodiment of the invention there illustrated, these blocks are of two kinds: a central, inner, cylindrical or disc-like block 8 and seven outer blocks 10, each in the form of a sector of an annulus. It will be understood, however, that the circular arrangement is merely the preferred form, and that other shapes could be used. Thus, a rectangular assemblage of square blocks is theoretically operable. Clamping devices for holding a rectangular diaphragm, however, are non-uniform around the periphery and are somewhat unreliable in operation. Hexagonal and other shapes could also be employed.

The sector sections or blocks 10 are integrally connected to one another by relatively thin, radially disposed webs 12, located at or near the axial upper and lower extremities of the blocks, and to the central section or block 8 by similar thin, but annular, webs 13. The blocks are thus mechanically coupled together so that, though it is possible to drive them individually, each of the opposite faces 7 and 9 of diaphragm 4 will vibrate as a piston with the faces 7 and 9 opposed in phase. Diaphragms of this kind may be manufactured conveniently by casting.

The diaphragm 4 is in this manner separated into eight resonant blocks, and the spaces between the webs 12 and 13 permit the median nodal sections of the individual blocks to vibrate transversely independently of each other, without having any block react unfavorably upon any of the others and without, therefore, introducing vibrations of different phase in the various portions of the radiating face 7. These spaces between the webs 12 and those between the webs 13 should not be very wide for this purpose, the desirable minimum transverse width of the spaces being determined rather by considerations of easy casting.

As the diaphragm sections vibrate expansionally, as before described, there is a node of longitudinal motion about half way between their faces 7 and 9 and loops of longitudinal motion at the said faces. It will thus be observed that the diaphragm sections are supported by the annular web 6 near these loops of motion.

According to the preferred embodiment of the invention, the driving of the individual blocks 8 and 10 is effected magnetostrictively. To this end, each of the diaphragm blocks 8 and 10 is provided with a magnetostrictive core 14, so as to cause individual driving of the blocks 8 and 10. The cores 14 may, of course, be replaced by piezo-electric crystals 24, as shown in Fig. 5, or the blocks may be driven in any other desired manner. When operated magnetostrictively or piezo-electrically, the blocks 8 and 10 are driven by means of reversible internal stresses to obtain high frequencies. The cores 14 may be constituted of any desired magnetostrictive material. A thin, nickel tube, resonant with the blocks 8 and 10 to which it is attached, operates very well in practice. To the lower end may be rigidly attached an interiorly threaded cap plate 16 by means of which the core may be threaded upon a screw 18 that is integrally fixed to the diaphragm blocks 8 and 10. The cores 14 may be individually and simultaneously caused to vibrate by means of energizing coils, one of which is shown at 20, and supplied with power from any desired source. These coils may also supply a constant magnetic polarization to the core. The vibrations of the core 14 are of such a nature that it executes longitudinal expansion and contractions, the free and attached ends being in motion while there will be one or more nodes suitably disposed along the core. The vibrations of the lower extremity of the core 14 will be communicated to the block 8 or 10 to which it is attached, and the block in turn will also vibrate expansionally, the degree of vibration depending upon how close it approaches resonance to the driving frequency and to the resonant frequency of the core 14, and upon the magnitude of the internal frictional losses. Theoretically, the core 14 and the block to which it is secured should have substantially the same natural frequency. No mass other than that of the nickel tube itself is necessary for the vibration of the tube to react against. The purpose of the cap plate 16 is to provide a convenient means of rigid assembly of the core 14 to the face 9, thereby providing a tight coupling between the core 14 and the face 9. This cap plate, however, influences the resonant frequency of the driving member in a manner which will be demonstrated.

It can be shown mathematically and tested by experiment that the optimum lengths for the tubes 14 constitute a series of values given by the equation

$$L=\frac{v}{f}\left(\frac{\phi}{2\pi}+\frac{k}{4}\right)$$

where v is the longitudinal velocity of sound in the metal of the tube, f is the resonant driving frequency, k is any odd integer, while ϕ, which is independent of L, is determined by the mass of the threaded cap in a manner shown by the equation

$$\phi=\tan^{-1}\frac{v}{2\pi f}\frac{m_0}{M}$$

m_0 being the mass per unit length of the tube and M the total mass of the cap. From the equation for L, we see that successive optimum values are obtained by starting with the shortest value

$$L=\lambda\left(\frac{\phi}{2\pi}+\frac{1}{4}\right),\ when\ k=1$$

and increasing the length of this value by successive additions of 1/2 λ, λ representing the wave length.

By proper design of the sections 8 and 10, the cores 14 and the coils 20, and by having the current in the coils 20 in phase, the blocks 8 and 10 will be caused to be driven in unison, with the result that the emitting face 7 of the diaphragm 4 will be caused to vibrate as a unit at the resonant frequency, say 30 kilocycles, its motion very closely approximating to a true piston motion. The webs 12 and 13 are made short so that they have no possible mode of vibration as low as 30 kilocycles. In this manner, they will introduce no disturbing modes of vibration into the face 7 of the diaphragm as a whole. The diaphragm 4, therefore, presents to the medium, such as water, a substantially plane face 7, all parts of which are in time phase.

The parts may be varied in design according to the purpose in hand. As shown in Fig. 4, an additional ring of sectors 15 may be interposed between the sectors 10 and the ring 2, separated by a web 17 similar to the web 6. The diaphragm will still consist of a compressional head, operating in the same manner as before described. It is preferred to make the diaphragm of metal having small mechanical viscosity. Aluminum has a low viscosity, its elastic losses and its decrement are low and it yields a very satisfactory diaphragm.

The operation of the diaphragm may be improved by a composition of cast aluminum with about 5 percent silicon. The silicon, though not materially affecting the vibrational qualities, lowers the melting temperature and, therefore, facilitates foundry manipulation.

It is desirable to present as large a vibrating surface to the medium as possible with the least complexity of design. The individual blocks or sections 10 and 8 should, therefore, have as large an emitting surface 7 as possible. The metal of the diaphragm should, therefore, preferably be such that the bulk velocity of sound therein is large. Aluminum, besides having a low mechanical viscosity, has also a large bulk velocity of transmission of sound.

It is possible to compute the most suitable dimensions for the blocks. For a cylindrical block, such as the block 8, the practical minimum limit of length to radius of block cross section is about 3 to 1 for all frequencies. If the ratio is much less than this, the block will not vibrate in a simple manner, as before described, but a series of nodal lines will appear upon the radiating face due to the restriction of the necessary lateral vibration in the median plane. The same ratio applies approximately for rectangular and sector blocks, replacing the radius by half the side of the square section or half the mean arc width of the sector. The length is determined by the frequency desired and the bulk velocity of sound in the material of the block. For aluminum blocks, the following dimensions are found convenient at 30 kilocycles:

a=1 inch, approximately,
L=3 inches, approximately,

where a is the redius of the black 8 or half the mean arc width of the cross-sectional area of the block 10; and L is the height of the blocks. The ratio of the length to the width is thus not substantially less than 3/2.

The resonant frequencies of two short cylinders equal in length whose section areas are equal, one of which is circular and the other square, are nearly, but not quite, equal. If the number of sector blocks 10 is properly chosen, their areas will not differ greatly from the area of the central block 8. By proper design, the areas of the blocks 8 and 10 may be made exactly equal, with the ratio of mean arc width to radial thickness nearly equal to unity for each of the sector blocks. This approximation to unity ratio depends upon the number of blocks per annulus, and becomes the better the larger the mean radius of the annulus. In designing the diaphragm, the number of whole blocks in the given annulus is computed. The departure from the unity ratio of width to thickness necessary in making the cross-section areas equal introduces a negligible error in the frequency computation.

It is found, however, because of the difference in shape between the block 8 and the block 10 and because of the loading effect of the webs 6, 12 and 13, that the height of the block 8 may, under certain conditions, be slightly different from that of the blocks 10, else the frequency of the central block 8 will be slightly different than that of the other blocks 10. The exact design cannot readily be worked out mathematically, but may best be checked experimentally. In Fig. 3, the central block 8 is shown slightly shorter in length than the annular blocks 10 and the upper faces of the webs 12 and 13 are disposed in the same plane with the upper face of the central sector 8. These webs must not, of course, be positioned lower down, at a point of nodal expansion and contraction, but could be positioned elsewhere.

The frequency of a longitudinally-vibrating bar can be computed even when the ratio of radius of the cross-section to the length becomes large by making a suitable correction for radial inertia. If the length is not large compared with the diameter of the bar, the expression for the frequency of longitudinal resonance of a short thick bar of elliptical or rectangular cross-section as given by Chree, Quart. Math. Journal, vol. 23, p. 317, 1889, becomes

$$f=\frac{k}{2L}\sqrt{\frac{E}{d}}\left[1-\left(\frac{\pi kP}{L}\right)^2\frac{K^2}{2.}\right]$$

where f is the frequency in cycles per second, k is any integer, odd or even, L is the total length of the bar, E is the modulus of elasticity, d is the density, P is Poisson's ratio normally taken as 1/3, and K is the radius of gyration of the section about the cylindrical axis.

The above equation is also valid for the case where K/L is small. Then it reduces to

$$f=\frac{k}{2L}\sqrt{\frac{E}{d}}$$

which is the familiar formula for the frequency of longitudinal vibrations in a slender bar.

The difference between this latter formula and the more accurate formula given by Chree for the general case is a small correction term about 3 percent for bars in which the ratio of radius of cross-section or half side of rectangular section to the length is about 1:3.

The ratio

$$\frac{E}{d}$$

which is the square of the bulk velocity may be computed after experiments performed upon the specific material used and the result employed in connection with the computation of new vibrators of that material.

Using these formulas for the block frequencies, it will be found that if

$$a=1 \text{ inch, as above,}$$

the corresponding length of the aluminum central block 8, as determined for a 30-kilocycle frequency is

$$L=3.2 \text{ inches.}$$

This is a very fair approximation of the 3 to 1 ratio before mentioned. In practice, however, good results may be obtained if the ratio is as great as, or even greater than, 20 to 1. The thickness of the diaphragm is equal to a half-wave length of sound in the material thereof, or to integral multiples of the half-wave length.

These dimensions are suitable for a 30-kilocycle frequency. To increase the area of the sound-emitting plane surface 7 at this frequency, it is preferable to add additional annuli 22 of sector blocks between the annulus blocks 10 and the fixed annular portion 2, as shown in Fig. 4.

According to the modification illustrated in Fig. 5, each of the blocks is driven by a piezo-electric crystal 24 rigidly fastened at one end by means of suitable cement to the upper face 9 of the block. The crystal electrodes may consist of tin-foil layers 26 deposited upon opposite faces of the crystal, but any other electrodes of suitable type may be employed.

The tin-foil layers or other electrodes may be connected by conductors 28 in parallel to a coil 30 coupled to a coil 32 in the output circuit of a vacuum-tube oscillator 34 or of any other source of alternating-current frequency. The frequency of the output of this oscillator may be adjusted by means of a tuning condenser 36. A further condenser 38 in parallel with the crystal vibrators 24 may be employed to adjust the voltage on the crystals.

It will be understood that the invention is not restricted to the illustrated embodiments thereof, but is susceptible to further modifications and change within the skill of the artisan, and all such modifications and changes are considered to fall within the spirit and scope of the invention as defined in the appended claims.

What is claimed is:

1. A diaphragm comprising a plurality of diaphragm sections each provided with a radiating or receiving face and a face opposite thereto, the sections being adapted to vibrate so as to produce a loop of motion at the radiating or receiving faces and a node of motion between the faces of each section, and a web or webs connecting the sections near the said opposite face in a region substantially removed from the said nodes and at a substantial distance from the radiating or receiving face.

2. A diaphragm comprising a plurality of diaphragm sections each provided with a radiating or receiving face and a face opposite thereto, the sections being adapted to vibrate so as to produce a loop of motion at the radiating or receiving faces and a node of motion between the faces of each section, and a web or webs connecting the sections near the radiating or receiving face in a region substantially removed from the said nodes and at a substantial distance from the said opposite face.

3. A device of the class described having a diaphragm comprising a plurality of diaphragm sections, each section having two oppositely disposed faces and being adapted to vibrate expansionally by contracting and expanding to and from a nodal plane disposed intermediately between the faces to produce loops of expansional vibration at the said faces, and webs coonnecting the sections for cophasing their vibrations.

4. A device of the class described having a diaphragm comprising a plurality of diaphragm sections disposed along an annulus, and means connecting the sections together, each section having two oppositely disposed faces and being adapted to vibrate expansionally by contracting and expanding to and from a nodal plane disposed intermediately between the faces to produce loops of expansional vibration at the said faces, the sections being dimensioned so as to have substantially the same natural frequencies.

5. A diaphragm comprising a central diaphragm section and a plurality of diaphragm sections disposed about the central section, the last-named sections having substantially equal heights and areas, the central section being of different cross-sectional shape from the shape of the other sections and having a compensatingly different height from the height of the other sections such that it has substantially the same frequency as the frequency of the other sections.

6. A diaphragm comprising a central diaphragm section and a plurality of diaphragm sections disposed about the central section, the last-named sections having substantially equal shapes, heights and areas, the central section being of different shape and area from the shape and area of the other sections, the difference in shape and area being compensated by a height slightly different from the height of the other sections, the sections being connected together by webs the upper faces of which are substantially in the same plane with the upper face of the central section.

7. Means for supporting and cophasing the vibrations of a plurality of expansionally vibratory diaphragm sections each having two oppositely disposed faces reciprocally vibratory toward and from each other, comprising a relatively fixed member and a system of thin, narrow webs interconnecting the diaphragm sections and the fixed member, the web system being essentially coplanar with one set of said faces.

8. A diaphragm comprising a plurality of dia-

phragm sections each having two oppositely disposed faces and each having length and width, the ratio of the length to the width being substantially equal to or greater than 3/2, the sections being connected together by webs, and means for actuating the diaphragm sections at a common resonant frequency of expansional vibration, the relative dimensions and the materials of the diaphragm sections and of the actuating means being such as to render their combination resonant at the said common resonant frequency.

9. A vibrator for interchanging electrical and mechanical energy with a sound-conveying medium comprising a plurality of diaphragm sections having substantially the same natural frequency and adapted to be positioned in sonorous relation to the sound-conveying medium, the diaphragm sections each having two oppositely disposed faces and each being expansionally vibratory so as to contract and expand lengthwise to and from nodal planes disposed intermediate to said faces, the sections being spaced from one another transversely at the nodal planes so as to be free to expand and contract transversely at the nodal planes and being connected together into a unitary vibrator by webs having a face coplanar with one set of said faces for supporting the sections and cophasing their vibrations, and means individually connected with each section for driving the corresponding section at a common resonant frequency of expansional vibration, the relative dimensions of the sections and of the individual driving means being such as to render their combination resonant at the said common resonant frequency, whereby the sections and the webs will be driven in synchronism as a unitary vibrator with the sections all in substantially the same phase.

10. A device of the class described having a vibratory diaphragm portion and a relatively fixed portion, an intermediately disposed web connecting the portions, the relatively fixed portion constituting a support for the vibratory portion, the vibratory portion comprising a plurality of diaphragm sections, each section having two oppositely disposed faces and being adapted to vibrate expansionally by contracting and expanding toward and from an intermediately disposed nodal plane, whereby one face of each section is adapted to vibrate between limiting positions on both sides of the position of rest occupied by the said one face when the sections are at rest, one set of said section faces being disposed in a single plane, and a plurality of webs for connecting the sections and cophasing their vibrations affixed to the individual sections near the said positions of rest of the said faces in a region substantially removed from the said nodal plane and aside from the path of vibration in the section, means connected with each section for vibrating the corresponding section expansionally, and means for actuating the vibrating means in unison.

11. A diaphragm comprising a plurality of diaphragm sections each having two oppositely disposed faces and each having length and width, the ratio of the length to the width being substantially equal to or greater than 3/2, and individual means for actuating the diaphragm sections at a common resonant frequency of expansional vibration, the relative dimensions of the diaphragm sections and of the individual actuating means being such as to render their combination resonant at the said common resonant frequency, and the plurality of sections being joined to form a unitary vibrator by a system of webs coplanar with one set of said faces.

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