Aug. 6, 1946.

W. N. TUTTLE

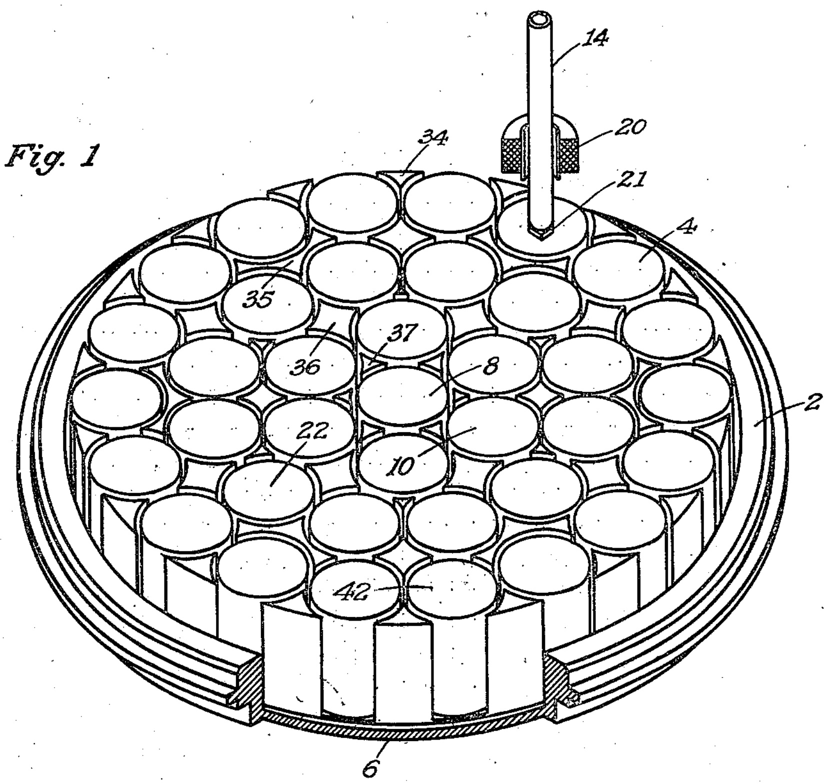
2,405,472

DIAPHRAGM

Original Filed June 12, 1934

2 Sheets-Sheet 1

Fig. 1



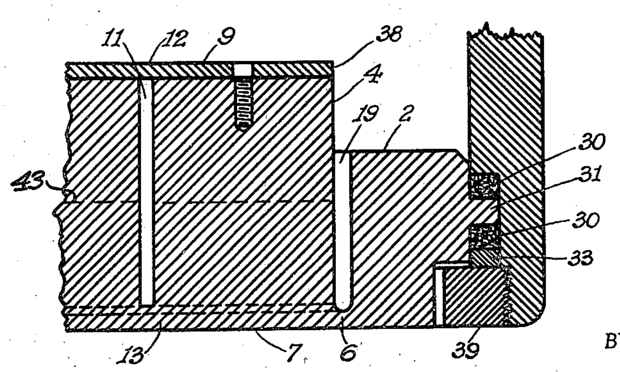


Fig. 2

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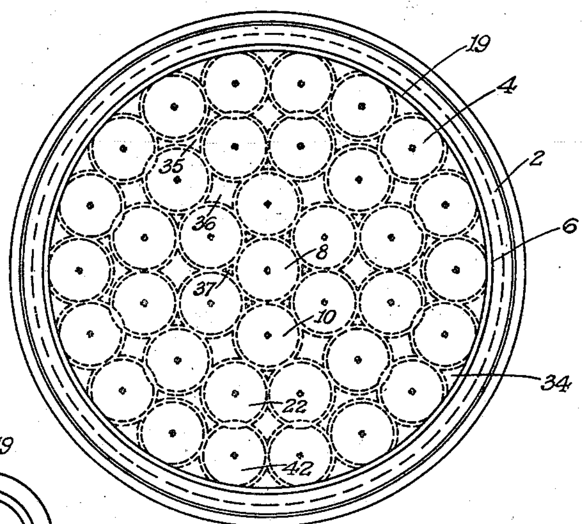
Fig. 3



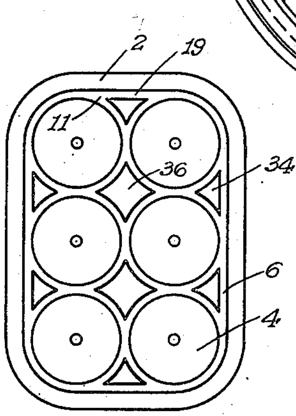


Fig. 4

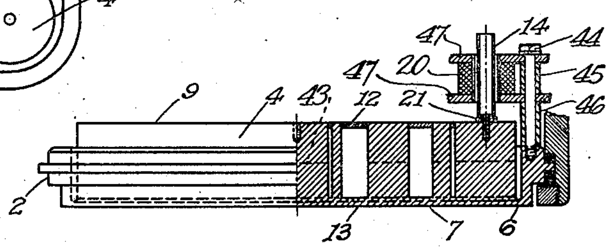


Fig. 5

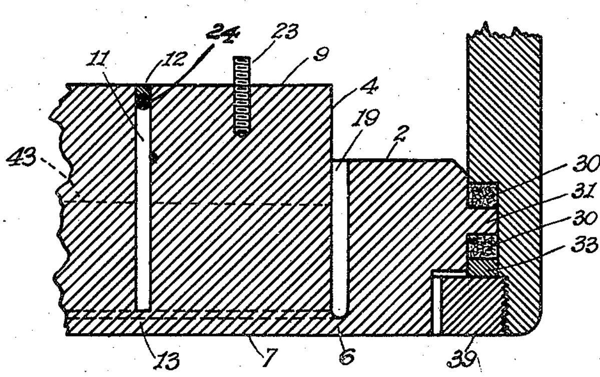


Fig. 6

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UNITED STATES PATENT OFFICE

2,405,472

DIAPHRAGM

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Application June 12, 1934, Serial No. 730,245
Renewed October 22, 1937

18 Claims. (Cl. 177—386)

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The present invention relates to vibratory devices for converting or translating acoustic energy into electric energy and vice versa. From a more limited aspect, the invention relates to diaphragms, more particularly directive-acoustic radiators and receivers adapted for use, for example, in underwater sound signaling, for interchanging electrical and mechanical energy with the water or other sound-conveying medium.

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 acoustic medium, or for the directionally-selective reception of acoustical energy from such a medium is a member having a plane or face of dimensions relatively large compared with the wave length of the sound energy in the medium, and in which all points of the radiating face are vibrating uniformly and in phase and with equal amplitude, like a piston. Sound energy will then be radiated into or received from the medium in a direction perpendicular to the plane area. There will be very little radiation or reception in other directions. If, on the other hand, the vibrating area is small in comparison with the wave length, sound will be radiated or received in all directions. The term "sound" energy or its equivalent will be employed hereinafter, in the specification and the claims, to include the supersonic, as well as the audible part of the sound spectrum. The invention, indeed, finds particular application to supersonic communication.

From a practical standpoint this ideal coupling element is very difficult to obtain. Many arrangements have been proposed, both for audio loud-speakers operating in air and for supersonic radiators operating under water, in which a thin diaphragm is acted on by a driving force acting uniformly over substantially the entire area. Particularly for underwater use it is difficult to make such arrangements sufficiently rigid to withstand the variations of pressure which are encountered under practical operating conditions.

To obtain greater rigidity and to enable the face to be driven in a simpler fashion, various types of thick radiators have been proposed. For convenience these members will also be referred to as diaphragms. The present invention, in this sense, relates to thick acoustic diaphragms.

In Letters Patent 407,704 of Great Britain, a thick diaphragm is described in which the median plane parallel to and midway between the faces

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of the diaphragm executes no appreciable motion along its axis; 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. The resonant frequency of the diaphragm, as modified slightly by the loading of the driving elements, is made equal to the operating frequency. This mode of vibration, for a particular frequency, is realized by making the thickness of the diaphragm, that is, the length along the axis of vibration, 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 is defined in the said Letters Patent as expansional vibration.

In the usual case of a thick resonant plate, the material near the central plane tends to expand outward under compression. This lateral motion disturbs the vibration in the direction of the axis and, at the faces of the plate, it changes the amplitude of the outside relative to the center, and may even cause the outside to vibrate in opposite phase from the center. To permit this transverse or lateral motion to take place freely without disturbing the vibration perpendicular to the faces, the diaphargm described in the said application is subdivided into sections by means of channels. The sections are individually driven in unison, and are so coupled together, mechanically and acoustically, that they are constranted to vibrate in phase, with the result that directive operation is obtained. The said diaphragm is preferably energized by driving members which are operative through internal stresses, such as are brought about by magnetostriction or piezo-electricity.

The diaphragm of the said Letters Patent may be regarded as a vibrating plate containing a network of internal channels such that vibrations depending on lateral motion are suppressed but vibrations due to wave motion normal to the surfaces are unhindered. It may also be regarded as an array of blocks or sections, resonant in the direction of their thickness, coupled to one another at their ends, so that they are constrained to vibrate in phase when the same driving force is applied to each.

The primary object of the present invention is to provide an improved energy converter of the above-described character.

A further object is to provide an improved expansional, sharply directive, acoustic radiator and receiver, particularly adapted for supersonic electro-acoustic energy conversations.

Another object is to provide an improved under-water acoustic radiator and receiver having great mechanical strength and resistance to shock.

Still another object is to provide a composite or sectional diaphragm all the units of which are closely identical, so that they may more readily be constrained to vibrate in phase.

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 perspective of a preferred embodiment of the expansional diaphragm of the present invention in circular form, one of the magneto-strictive-driving elements and an energizing coil being shown in section; Fig. 4 is a plan view of a rectangular modification; Figs. 3, 5, and 6 are plan, section, and detail views, respectively, of a modification of the circular form; and Fig. 2 is similar to Fig. 6 illustrating a modified detail of construction.

For clearness of exposition the first general description of the invention will be confined to the preferred circular form, and the modifications of construction which are necessary for a rectangular diaphragm will be mentioned later. It will be obvious that most of the modifications to be mentioned in connection with the circular form are equally applicable to the other.

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 by means of rubber packing rings 30 on both sides of the flange 31 on a relatively immovable, outer, inertia, annular or ring portion 2; and steel compression and clamping rings 33 and 39, respectively, may be employed to keep the rubber packing under pressure. The device may, however, be attached directly to the side of a ship, or mounted in many other ways well known to the art.

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 parts are formed preferably of a disc-shaped slab or casting, as hereinafter stated, in order that the machine work may be done in a single, metal member. The web 6 is thin enough so as to be relatively yielding at the high frequencies of operation, while being comparatively rigid for slowly varying pressures, thus permitting the active, vibrating area or radiating face 7 of the diaphragm portion 4, which radiating face is disposed in sonorous relation to the sound-conveying medium, to vibrate freely and uniformly, substantially all the flexing taking place in the web 6. The mass of the inertia ring 2, since it is thus loosely coupled to the vibrating area, and since it is non-resonant, prevents transmission of vibration thereto.

The annular supporting web 6 flexes readily by shearing strains in such a direction that the vibrating face is permitted to move freely in the direction of its normal. The web is very much less yielding to stresses perpendicular to the normal, or parallel to the face. The annular web can yield to such stresses only by increasing in diameter. For this reason the web should be attached to the diaphragm near one of the end surfaces where the lateral motion is least, in spite of the fact that the longitudinal motion is often greatest in these regions. In the preferred arrangement shown the web is attached to the front face, which is in contact with the sound-conveying medium, but could also be attached to the back face or, in more complex diaphragms, at any other plane substantially at a node of lateral motion. With the diaphragms illustrated the planes of maximum longitudinal motion are at the nodes of lateral motion. In such cases, therefore, this type of yielding support can be described also as a relatively thin web located at a loop of longitudinal motion. In Figs. 2, 5 and 6, the node of longitudinal motion is indicated by the dashed line 43.

It is highly desirable that the web 6 separating the active and inactive portions of the diaphragm be circular, as shown. A sharp dividing line is thereby obtained, the inactive portion 2 causing very little disturbance of the vibration of the active portion 4.

According to the illustrated invention, the diaphragm is divided into cylindrical or disc-like blocks, preferably alike in shape and dimensions, so as to have substantially the same natural frequency. There is shown a central block 8, six outer blocks 10, circularly or circumferentially arranged about the block 8, twelve blocks 22 disposed circumferentially about the blocks 10, and eighteen blocks 42 disposed circumferentially about the blocks 22, making a total of thirty-seven blocks. A still further ring of blocks may, if desired, be disposed circumferentially about the blocks 42, so as to make sixty-one in all; and so on.

When cylindrical blocks are placed in a circular array, as shown, they are separated from one other by irregular areas. In the preferred form of the invention illustrated these areas are filled by the material of the diaphragm except for a ring-shaped channel surrounding each cylindrical block. Thus in addition to the thirty-seven cylindrical blocks, there are generally as many or more irregular blocks 34, 35, 36, and 37 of smaller cross-section between them. This arrangement not only provides better acoustical behaviour than if the irregular blocks were omitted but also makes possible the simple method of construction which is described later.

The circular sections or blocks 8, 10, 22, 34, 35, 36, 37, 42, etc., are shown in Fig. 2 integrally connected to one another by relatively thin webs 12 and 13, located respectively at or near the axial upper and lower extremities of the blocks. The blocks are thus mechanically coupled together so that they will be constrained to vibrate together, each of the opposite faces 7 and 9 of diaphragm 4 vibrating as a piston, with the faces 7 and 9 opposed in phase. In the diaphragm of Fig. 1, however, the webs 12 are omitted, the webs 13 sufficing.

The spaces between the webs 12 and 13 permit the middle regions of the individual blocks to yield laterally or transversely under the compressional force due to the longitudinal vibration, 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 13 should not be very wide for this purpose, the desirable minimum transverse width of the spaces being determined rather by considerations of ease of manufacture.

Diaphragms of this kind may be manufactured conveniently, preferably by cutting into the face of the beforementioned slap or casting with rotating, hollow, cylindrical, milling cutters (not shown) of thickness equal to the width of the cylindrical or ring-shaped channels 11 surrounding the respective blocks, and continuing the milling out, in a direction perpendicular to the plane parallel faces 7 and 9, to near the opposite face 7. The channel 19 separating the vibrating area 4 from the non-vibrating clamp ring 2 is preferably cut in the slab or casting in order to obtain uniformity of the web 6, but it may also be cast to reduce the necessary machine work. It may be desirable to make the ring-shaped channels 11 less deep than the outside channel 19, as shown, to reduce any slight tendency for the dividing line between the active and inactive portions of the diaphragm to come at any place other than in the web 6.

The webs 12 may be formed at the free ends of the channels 11 by welding, brazing or the like. To aid in this work, the upper ends of the channels 11 may be closed by a ring, bar or other obstruction 24 prior to the welding, though this is not always essential. In place of filling in a small portion of the free end of each channel, a plate 38 of suitable thickness may be attached to the entire face of the diaphragm over the free ends of the channels 11 as shown in Fig. 2. The plate may be attached by soldering, cementing, or brazing; or a particularly strong and uniform bond may be made by copper brazing in a furnace in a hydrogen atmosphere. It should be pointed out that the faces of the diaphragm are essentially at loops of motion, and the internal stresses are consequently very much less than near the median plane of the diaphragm. An extremely strong bond, therefore, is not ordinarily required.

If the cylindrical sections of the diaphragm are of relatively small diameter, the bonds 12 are not always necessary. The larger the diameter relative to the length, the greater is the tendency for the center of each unit to vibrate longitudinally more than the edges, and consequently, the more important are the back webs 12 in maintaining uniformity of vibration of the entire composite diaphragm. With a single block having a thickness of one-half wavelength, it has been found that if the diameter is approximately the same as, or greater than, the length of the cylinder, there is a very noticeable inequality in the vibration of the end surfaces.

In the composite diaphragm of the present invention, it is found, in practice, that when a 15-inch-diameter, cast-iron disc or plate is provided with thirty-seven half-wavelength, cylindrical sectional units, each two inches in diameter and two and one-half inches long the diameter of each unit is so much larger, in comparison with its length, for the same size disc or plate, than when sixty-one units are employed, that satisfactory vibration is not obtained, unless the back webs 12 or back plate 38 is used. When a diaphragm of the same size is divided into sixty-one units, however, the diameter of each unit, about 1.6 inches, is small enough to provide satisfactory operation without the back webs or back plate. In either case, it will be noted that the diameter of the individual cylindrical units is less than one-half of the wavelength. It will be noted, further, that none of the other irregular pieces has a transverse dimension greater than one-half wavelength. This is an important general condition for the satisfactory transmission of vibrations through a plate in the direction of the thickness.

As the blank on which the machining is done is a simple disc, it is possible to use either a casting or a piece of forged or rolled stock. In the case of a casting, this simplicity of shape makes it more easy to obtain uniformity and freedom from flaws than if an array of channels were cast in the plate. The use of forged or rolled stock makes possible even greater strength and uniformity.

In addition to making possible the use of a piece of metal of great strength and uniformity, the particular arrangement of elements employed also results in ease and rapidity in the accomplishment of the machining, and greater mechanical strength and improved acoustical behaviour in the completed diaphragm.

It will be noted also that there are not circular cuts about the center except that the small cut outlining the member 8. This very greatly reduces the possibility of the vibration breaking up into annular areas of different phase.

It will be seen further that the arrangement of channels shown in which there are no diametral cuts is such as to provide great mechanical strength, even when the nonbonded or open-back type of construction is employed.

It should be noted also that the circular arrangement of the outside units permits a circular vibrating area and an annular supporting web without the use of unequal outside pieces. Driven areas on each circle of units are equally loaded.

The rectangular diaphragm of Fig. 4 is similar in most respects to the circular form just described but is preferable where unequal sharpness of beam is desired in two directions, such as in depth-finding equipment for navigation, where the roll of the ship makes it advantageous to obtain a fairly wide lateral distribution of energy.

The essentials of construction are the same as for the circular diaphragm. A pattern of interconnecting cylindrical channels is cut in a metal slab, as before described, but the channels are arranged in rows instead of in circles. It is, of course, not possible to give the channel 19 which separates the active portion 4 from the inactive supporting frame 2 the ideal annular shape obtained with the circular daiphragm, but the corners may be rounded by employing the cuts 11 defining the corner elements to form part of the channel, as shown. The remainder of the channel consists of four straight cuts, made with a flat circular milling cutter, or with an end mill, joining together the four corner circles. The greater the rounding of the corners the more uniform is the loading of the active portion 4 of the diaphragm by the web 6, and the easier it becomes to obtain uniform and piston-like vibration of the radiating or receiving surface. Except for these characteristics resulting from non-uniformity of the supporting web, the operation of the rectangular diaphragm is similar to that of the circular unit, and any of the corresponding types of back construction which have been described may be employed.

In the preferred embodiment of the invention illustrated, the thickness of the diaphragm is substantially one-half the wave length, in the material of the diaphragm, of the sound energy employed. The diaphragm operates by virtue of compressional waves traveling in the material of the diaphragm normally to the radiating or receiving surface. When an internal wavelet strikes one of the surfaces a large fraction of its energy is reflected and remains within the material of the diaphragm. The wavelet is next reflected from the opposite surface, and the thickness of the plate is related to the operating frequency in such a way that the twice-reflected wave is in phase with and added to the new wavelet from the driving mechanism or from the impinging sound wave, according to whether the device is used for sending or receiving, respectively. The internal wave thus builds up to such an amplitude that the energy received per cycle through one end surface is equal to the energy transmitted through the other surface, plus the loss during the cycle due to internal dissipation. Thus, if the internal dissipation is negligible, such a resonant member will perfectly transfer sound energy from the acoustic medium on one side to the mechanism attached on the other side, or vice versa. Resonance thus overcomes difficulties due to the acoustical properties of the diaphragm not being equal to those of the transmitting medium. In effect, resonance adapts the acoustic impedance of the diaphragm to the medium in which it is operated.

The natural frequency of the diaphragm is affected both by the driving mechanism on one face and by the reaction of the medium on the other face. It is due to the fact that both these effects are small in the modifications illustrated, that the thickness of the diaphragm for resonant operation has been specified as approximately one-half wave length or any odd multiple thereof. In practice the two end effects may be regarded as equivalent to a certain positive or negative addition to the thickness of the diaphragm and the design modified accordingly so that the total equivalent thickness is exactly an odd number of half wave lengths of the sound energy in the material of the diaphragm.

The novel diaphragm of the present invention, however, is directly applicable in cases where the driving means makes a large contribution to the resonant frequency. For example, the well-known quartz-sandwich transmitter or receiver is constructed of two electrode plates each approximately one-quarter wave length thick with a layer of quartz crystals between them. In this device the total equivalent thickness of the two plates and the quartz is exactly one-half wave length; and the composite plate vibrates in the same manner as the single plate first described. The operation of this device is much improved if the electrode plates are constructed in accordance with the present invention. More generally speaking, the present invention is applicable wherever a plate having a thickness of an appreciable fraction of a wave length is employed to transmit vibrations in the direction of its thickness.

In most applications of the invention, as in the cases described, the diaphragm and the driving means combine to form a mechanical system resonant to the desired frequency of operation, and thus cooperate effectively in the interchange of energy with the medium. For efficient operation it is necessary that the internal decrement of the mechanical system shall be small compared with the decrement resulting from coupling to the acoustic medium. In other words, it is necessary that the energy dissipated per cycle within the mechanical system shall be small in comparison with the energy per cycle exchanged with the acoustic medium. The requirements on the decrement therefore depend on the medium. When a metal block is vibrating in air, for example, the radiated energy for a given amplitude of vibration is much less than when the block is vibrating in water. In other words, the decrement due to the air is very much less than that due to water. Consequently the material of the block must have extremely small internal viscosity if it is to be efficient in interchanging sound energy with the air, while almost any material is satisfactory for radiating into water. As an illustration, aluminum has been found to be very much better than cast iron for operation in air, but the results with the two metals in water differ only slightly. Cast iron or steel is therefore preferred for undewater use both on account of greater strength and on account of decreased electrolytic action when used on a steel vessel.

According to the preferred embodiment of the invention, the driving of the individual blocks is effected magnetostrictively. To this end, each of the diaphragm blocks is provided with a magnetostrictive core **14**, so as to cause individual driving of the blocks **8**, **10**, **22** and **42**. When operated magnetostrictively or piezo-electrically, the blocks 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-walled nickel tube operates very well, in practice. The coils are assembled in a rigid array between plates **47** which are held at a suitable distance in back of the face **9** by means of stud bolts **44** and spacers **45** and **46**, the stud bolts being threaded into the immovable outer ring **2**. 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 expansions 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 to which it is attached, and if the combined mechanical system is resonant to the driving frequency the block, in turn, will also vibrate expansionally.

It should be noted that it is not necessary for the magnetostrictive cores to be supported at the back end in any way. Since the length of the cores is an appreciable fraction of a wave length, the inertia of the free end provides sufficient backing so that the blocks can be driven effectively.

It is important that the length of core be properly chosen in order to cooperate most effectively with the diaphragm. Although any length of core acting in conjunction with the diaphragm will have one or more resonant frequencies, all such combinations do not result in equally efficient transfer of energy between the tube and the diaphragm, even when driven at resonance. It is not difficult in practise, however, to determine a satisfactory length of core to drive a block of given dimensions.

If the magnetostrictive cores are tubular, as shown, they may be soldered to nuts **21** which in turn are screwed to studs **23** threaded into the blocks as shown in Figs. 5 and 6. A small amount of cement may be placed under each nut before tightening to insure that it will not become loose in operation.

The dimensions and mass of the nut are also important in governing the transfer of energy from the tubes to the blocks. With the 37-unit diaphragm of dimensions above given, a nickel tube two and one-eighth inches long, one-half inch in diameter and ten mils in wall thickness is used with a brass nut three-sixteenths of an inch thick.

In the arrangements illustrated only the equal cylindrical blocks **4** are attached to the magnetostrictive driving tubes **14**. The irregular pieces between the cylinders, since they have the same length and consequently nearly the same resonant frequency, are readily constrained by the webs **12** and **13** to vibrate cophasally with the cylinders.

It is desired that each driving element shall cooperate with its respective block to give as nearly as possible the same combined resonant frequency, so that the webs **12** and **13** will be enabled to draw all the blocks into cophasal vibration with one another to obtain uniform and piston-like vibration of the radiating surface **7**. With the construction illustrated it has been found practicable to obtain this result using cores of equal dimensions and diaphragm sections of equal thickness but this is not a necessary condition for operation. In some cases the dimensions of the cores may be individually adjusted to the vibrational constants of the corresponding blocks in order to achieve the same result.

At the frequency of operation the electrical impedance at the terminals of the driving coils when in operative relation to the magnetostrictive cores and diaphragm is about $600+j\ 1200$ ohms for the thirty-seven-element radiator described. This value is with 138 turns on each coil and the coils connected in series.

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. Apparatus for the transmission or reception of acoustic energy comprising a diaphragm having two oppositely disposed faces and adapted to vibrate in a direction substantially normal to the oppositely disposed faces so as to produce a loop of expansional vibration at one of the faces and a node of expansional vibrations between the faces, whereby the said one face may vibrate between limiting positions on both sides of a position of rest occupied by the said one face when the diaphragm is at rest, the diaphragm being subdivided into sections by interconnecting cylindrical ring-shaped channels extending from near one of the faces to a point substantially beyond the said node of expansional vibration, forming means positioned near the said position of rest of the said one face at a point substantially removed from the said node and aside from the path of vibration of the said one face for supporting the diaphragm.

2. Apparatus for the transmission or reception of acoustic energy comprising a diaphragm having two oppositely disposed faces and adapted to vibrate in a direction substantially normal to the oppositely disposed faces, the diaphragm comprising a plurality of cylindrical diaphragm sections having substantially the same thickness in the direction of wave transmission and mechanically held together in slightly spaced relation with the ends of the sections substantially coincident with the said faces to constitute a unitary vibratory diaphragm.

3. A diaphragm having a fixed outer portion, a vibratory inner diaphragm portion, an intermediately disposed web connecting the portions, the diaphragm portion comprising a plurality of cylindrical diaphragm sections connected together by webs of substantially the same thickness, 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 transverse dimension of the sections being not substantially greater than one-quarter wavelength of the acoustic energy in the material of the diaphragm, and means for cophasing the vibrations of the sections.

4. Apparatus for the transmission or reception of acoustic energy comprising a diaphragm having two oppositely disposed faces and adapted to vibrate in a direction substantially normal to the oppositely disposed faces so as to produce a loop of expansional vibration at one of the faces and a node of expansional vibration between the faces and being subdivided into sections by interconnecting cylindrical ring-shaped channels extending from near one of the faces to a point substantially beyond the said node of expansional vibration, the transverse dimension of the sections between the channels being not substantially greater than one-quarter wavelength of the acoustic energy in the material of the diaphragm.

5. Apparatus for the transmission or reception of acoustic energy comprising a diaphragm in the form of a plate of substantially uniform thickness in the direction of acoustic transmission or reception and adapted to vibrate in a direction normal to the oppositely disposed faces of the plate so as to produce a loop of expansional vibration at one of the faces of the plate and a node of expansional vibration between the faces of the plate and being subdivided into sections by interconnecting cylindrical ring-shaped channels substantially perpendicular to the said faces and extending from near one of the said faces to a point substantially beyond the said node of expansional vibration, and the transverse dimension of the sections between the channels being not substantially greater than one-quarter wavelength of the acoustic energy in the material of the plate.

6. Apparatus for the transmission or reception of acoustic energy comprising a diaphragm in the form of a plate of substantially uniform thickness in the direction of acoustic transmission or reception and adapted to vibrate in a direction normal to the oppositely disposed faces of the plate so as to produce a loop of expansional vibration at one of the faces of the plate and a node of expansional vibration between the faces of the plate and being subdivided into sections by interconnecting cylindrical ring-shaped channels substantially perpendicular to the said faces and extending from near one of the said faces to a point substantially beyond the said node of expansional vibration, and the transverse dimension of the sections between the channels being not substantially greater than one-quarter wave-

length of the acoustic energy in the material of the plate and the said thickness of the plate being substantially greater than that fraction of the wavelength of the acoustic energy in the material of the plate at which substantial motion of the material of the plate perpendicular to the said direction of acoustic transmission and reception takes place due to the said expansional vibration of the plate.

7. Apparatus for the transmission or reception of acoustic energy comprising a diaphragm in the form of a plate of substantially uniform thickness in the direction of acoustic transmission or reception and adapted to vibrate in a direction normal to the oppositely disposed faces of the plate so as to produce a loop of expansional vibration at one of the faces of the plate and a node of expansional vibration between the faces of the plate and being subdivided into sections by interconnecting cylindrical ring-shaped channels substantially perpendicular to the said faces and extending from near one of the said faces to a point substantially beyond the said node of expansional vibration, the transverse dimension of the sections between the channels being not substantially greater than one-quarter wavelength of the acoustic energy in the material of the plate and the said thickness of the plate being substantially greater than that fraction of the wavelength of the acoustic energy in the material of the plate at which substantial motion of the material of the plate perpendicular to the said direction of acoustic transmission and reception takes place due to the said expansional vibration of the plate, means for individually driving the sections and forming with the said plate a composite system having a total equivalent thickness of an odd number of wavelengths so as to be resonant to the acoustic energy in the said direction of the thickness of the plate, and means for operating the individual driving means substantially in phase at substantially the same frequency and with substantially the same amplitude of vibration.

8. Apparatus for the transmission or reception of acoustic energy comprising a diaphragm having two oppositely disposed faces and adapted to vibrate in a direction substantially normal to the oppositely disposed faces so as to produce a loop of expansional vibration at one of the faces and a node of expansional vibration between the faces and being subdivided into a central section and a plurality of sections disposed about the central section by interconnecting cylindrical ring-shaped channels extending from near one of the faces to a point substantially beyond the said node of expansional vibration, the transverse dimension of the sections between the channels being not substantially greater than one-quarter wavelength of the acoustic energy in the material of the diaphragm.

9. Apparatus for the transmission or reception of acoustic energy comprising a diaphragm having two oppositely disposed faces one of which is adapted to be disposed in a medium for the transmission or reception of the acoustic energy, the diaphragm comprising a plate of substantially uniform thickness in the direction of the acoustic transmission or reception and adapted to vibrate in a direction normal to the oppositely disposed faces of the plate so as to produce a loop of expansional vibration at one of the faces of the plate and a node of expansional vibration between the faces of the plate, the plate being subdivided into sections by interconnecting cylindrical ring-shaped channels substantially perpendicular to the said faces and extending from near one of the said faces to a point substantially beyond the said node of expansional vibration, and the transverse dimension of the sections between the channels being not substantially greater than one-quarter wavelength of the acoustic energy in the material of the plate.

10. Apparatus for the transmission or reception of acoustic energy comprising a diaphragm having two oppositely disposed faces and adapted to vibrate in a direction substantially normal to the oppositely disposed faces so as to produce a loop of expansional vibration at one of the faces and a node of expansional vibration between the faces and being subdivided into sections by interconnecting cylindrical ring-shaped channels extending from near one of the faces to a point substantially beyond the said node of expansional vibration, the transverse dimension of the sections between the channels being not substantially greater than one-quarter wavelength of the acoustic energy in the material of the diaphragm, the sections being connected together at the said one face.

11. Apparatus for the transmission or reception of acoustic energy comprising a diaphragm having two oppositely disposed faces and adapted to vibrate in a direction substantially normal to the oppositely disposed faces so as to produce a loop of expansional vibration at one of the faces and a node of expansional vibration between the faces and being subdivided into sections by interconnecting cylindrical ring-shaped channels extending from near one of the faces to a point substantially beyond the said node of expansional vibration, the transverse dimension of the sections between the channels being not substantially greater than one-quarter wavelength of the acoustic energy in the material of the diaphragm, the sections being rigidly secured together at the said one face.

12. Apparatus for the transmission or reception of acoustic energy comprising a diaphragm having two oppositely disposed faces and adapted to vibrate in a direction substantially normal to the oppositely disposed faces so as to produce a loop of expansional vibration at one of the faces and a node of expansional vibration between the faces and being subdivided into sections by interconnecting cylindrical ring-shaped channels extending from near one of the faces to a point substantially beyond the said node of expansional vibration, the transverse dimension of the sections between the channels being not substantially greater than one-quarter wavelength of the acoustic energy in the material of the diaphragm, and a plate connecting the sections together at the said one face.

13. Apparatus for the transmission or reception of acoustic energy comprising a diaphragm having two oppositely disposed substantially parallel faces and adapted to vibrate in a direction substantially normal to the oppositely disposed faces so as to produce a loop of expansional vibration at one of the faces and a node of expansional vibration between the faces, the diaphragm comprising a plurality of cylindrical diaphragm sections held together by webs in slightly spaced relation with the ends of the sections substantially coincident with the said faces, the transverse dimension of the sections being not substantially greater than one-quarter wavelength of the acoustic energy in the material of the diaphragm, a separate vibrator affixed to each sec-

tion for vibrating the sections expansionally at a common frequency, the relative dimensions and the materials of the sections and the vibrators rendering their combination resonant to the said common frequency, and means for operating the separate vibrators substantially in phase at substantially the same frequency and with substantially the same amplitude of vibration.

14. In an acoustical apparatus, a diaphragm having a face and adapted to vibrate in a direction substantially normal thereto so as to produce a loop of expansional vibration at the said face and a node of expansional vibration spaced therefrom, said diaphragm being subdivided into sections by interconnecting annular channels that extend a sufficient distance each side of the said node of expansional vibration to insure substantial in-phase vibration of the aforesaid face.

15. In an acoustical apparatus, a diaphragm having a face and adapted to vibrate in a direction substantially normal thereto so as to produce a loop of expansional vibration at the said face and a node of expansional vibration spaced therefrom, said diaphragm being sub-divided into sections by interconnecting annular channels that extend a sufficient distance each side of the said node of expansional vibration to insure substantial in-phase vibration of the aforesaid face, the transverse dimensions of the sections between the channels being not substantially greater than one quarter wave length of the acoustic energy in the material of the diaphragm.

16. In an acoustical apparatus, a diaphragm having a face and adapted to vibrate in a direction substantially normal thereto so as to produce a loop of expansional vibration at the said face and a node of expansional vibration spaced therefrom, said diaphragm being sub-divided into

sections by interconnecting annular channels that extend a sufficient distance each side of the said node of expansional vibration to insure substantial in-phase vibration of the aforesaid face, the sections being connected together at the said face.

17. Apparatus for interchanging electrical and mechanical energy with a sound-conveying medium comprising a plurality of cylindrical diaphragm sections substantially alike in shape and dimensions, the diaphragm sections being spaced from one another and connected together by webs of substantially the same thickness into a unitary vibratory diaphragm, the unitary vibratory diaphragm being adapted to vibrate expansionally so as to produce a loop of expansional vibration at one of the faces of the unitary vibratory diaphragm and a node of expansion vibration between the said faces.

18. Apparatus for interchanging electrical and mechanical energy with a sound conveying medium comprising a plurality of concentrically arranged cylindrical diaphragm sections substantially alike in shape and dimensions, the diaphragm sections being spaced from one another and connected together by webs of substantially the same thickness into a unitary vibrator, a separate vibrator affixed to each section, each vibrator and the corresponding section providing a combination that is adapted to operate in the same phase and at the substantially same frequency as each other vibrator and its corresponding section, and means causing the vibrators to cooperate elastically with their corresponding sections at substantially the same said phase and frequency to effect an interchange of energy with the sound-conveying medium.

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