

June 13, 1950

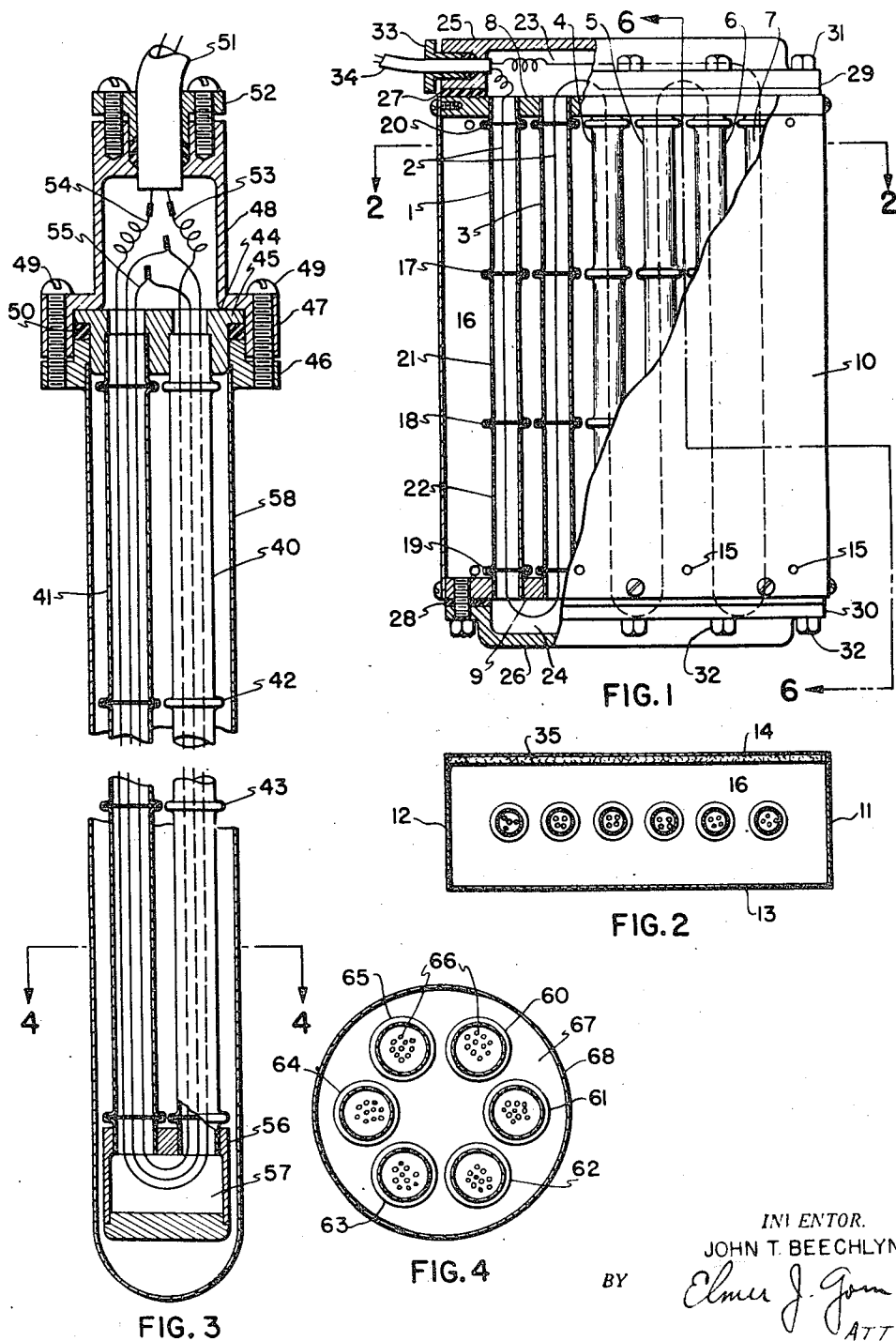
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2,511,689

SUBMARINE SIGNALING APPARATUS

Original Filed Feb. 28, 1944

2 Sheets-Sheet 1



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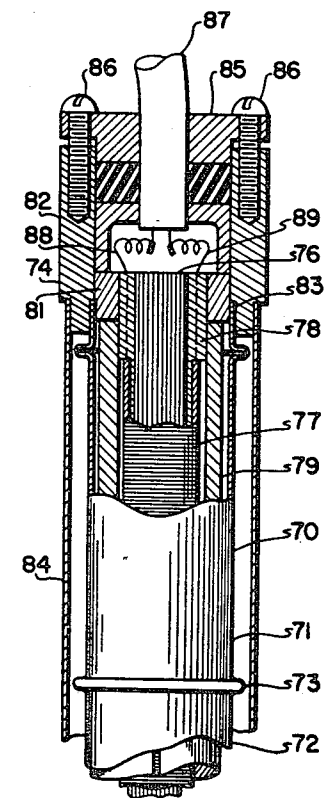


FIG. 5

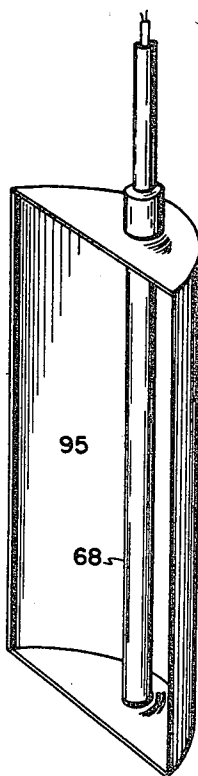


FIG. 8

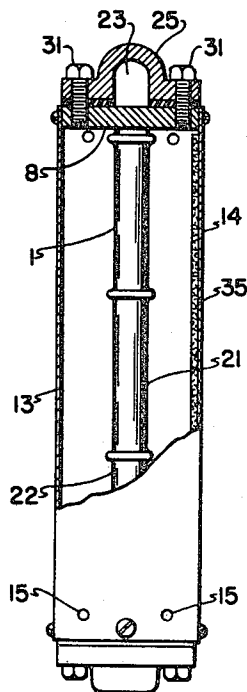


FIG. 6

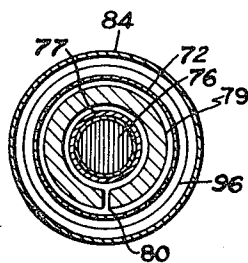


FIG. 7

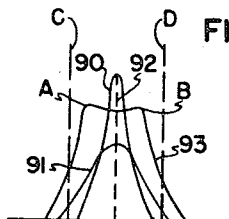


FIG. 9

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UNITED STATES PATENT OFFICE

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SUBMARINE SIGNALING APPARATUS

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Original application February 28, 1944, Serial No.
524,989, now Patent No. 2,443,177, dated June
15, 1948. Divided and this application February
11, 1947, Serial No. 727,922

5 Claims. (Cl. 177—386)

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The present application is a division of my
copending application, Serial No. 524,989, filed
February 28, 1944, now Patent No. 2,443,177
dated June 15, 1948.

The present invention relates to a device for
sending and receiving compressional waves and
more particularly to a magnetostrictive device
adapted to be used in a fluid and liquid medium
for the transmission of compressional waves in
sub-audible, audible or super-audible range. The
invention is particularly applicable to submarine
signaling both for transmission and for reception
and may therefore be called a transducer which
is commonly applied to devices capable of trans-
lating compressional energy to electrical energy
or vice versa. The device may also be used as a
transceiver for transmitting and receiving com-
pressional waves. The design of magnetostrictive
devices for the transmission and reception of
compressional waves has brought into common
use certain types of these devices which operate
successfully for the purposes to which they are
applied. Among the commonly used devices are
so-called magnetostrictive oscillators built up of
laminations forming blocks through which coils
are threaded in a number of ways, most of which
are resonant at a desired frequency. Another
known type of magnetostrictive oscillator or
transceiver is one in which one or more tubes are
surrounded by coils producing longitudinal vary-
ing flux which creates corresponding mechanical
motion. A plate or sound radiator at the end of
the tube provides a coupling with a propagating
medium.

The present invention differs from the art
briefly described above and from other devices in
a number of features which provide definite ad-
vantages under many circumstances where the
present device is to be used. The arrangement
according to the present invention may be built
up into almost any desired form of radiating sur-
face, itself occupying substantially a rectangular
casing with desired elongated dimensions, or a
circular casing with elongated dimensions so that
the device may be placed in a desired position in
the water to produce the most favorable results.
However, it should also be noted that the radiat-
ing surface consists of the tubes directly moved
by the magnetostrictive forces and having the
water medium only on the outer side of the tube.
No diaphragms are used in the present device.
A chief advantage in this connection is that the
apparatus is comparatively light in proportion to
its size, and can easily be used and manipulated
in the water in connection with overboard devices

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and floating devices or devices which may be fixed
with anchorage in definitely chosen spots.

The apparatus is also adaptable for use with
a parabolic or hyperbolic reflector for directive
transmission and reception in a beam or in a
fan-shaped plane and for this purpose the sound
characteristic pattern is made up of arrange-
ments of groups of tubes covering the space over
which radiation is desired to be provided. As
regard the acoustical properties and advantages
of the present construction, it is desirable to point
out that resonance of the structure is produced
for a motion of the structure against which no
direct radiation damping occurs. In this respect
a group of independently vibrating longitudinal
sections is used in which resonance may be estab-
lished for the longitudinal length, whereas the
actual radiation into the medium occurs through
the transverse expansion and contraction of the
tubes.

Further the design of the present invention is
particularly adaptable for providing either a
sharply tuned or broadly tuned system, since the
device has two modes of resonance, the longitudi-
nal and the transverse, which are coupled in-
herently in the tubes of the device. These and
other features will be more fully described in
connection with the specification annexed hereto
describing the invention as illustrated by the
drawings, in which Fig. 1 shows an elevation of
the invention with parts in fragmentary section;
Fig. 2 shows a section taken on the line 2—2 of
Fig. 1; Fig. 3 shows a broken section through a
modification of the invention shown in Fig. 1;
Fig. 4 shows a cross-section through a further
modification of the invention corresponding to a
transverse cut of the section of Fig. 3; Fig. 5
shows a broken section with parts in fragmentary
view of a still further modification of the inven-
tion shown in Fig. 1; Fig. 6 shows a section taken
substantially on the line 6—6 of Fig. 1; Fig. 7
shows a section taken substantially on the line
7—7 of Fig. 5; Fig. 8 shows a device in accord-
ance with Fig. 4 or 5 used with a reflector; and
Fig. 9 shows a set of resonance curves relating to
the operational characteristic of the apparatus.

In the invention shown in Figs. 1, 2, and 6, the
invention comprises mainly a group of tubes 1,
3, 4, 5, 6 and 7 which are made of magnetostric-
tive material through which is threaded one or
more electrical conducting wires 2, longitudinally
the length of the tube as indicated in Fig. 1. This
wire may be threaded down through one tube
and up through the next tube and passing in this
manner through all of the tubes. While a single

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turn is shown in Fig. 1, the conductor 2 as indicated in Fig. 2 may comprise a group of wires and also the manner of threading the wires may be in accordance with any desired arrangement. For instance, the wires may be looped through any pair of tubes, as shown in Fig. 3, or may be looped through some pairs of tubes first before entering the other tubes. The main purpose of the arrangement of the conductors is to establish a magnetic flux in the magnetostrictive tube members 1, 3, 4, 5, 6, 7 which circulates around the circumference or wall of the tube. The tubes are opened at each end, as indicated in Fig. 1, and are set in and sealed at both ends in retaining plates 8 and 9 forming parts of enclosing chambers from which the liquid propagating medium is excluded. The retaining plates 8 and 9 at each end form end supports which are supported by the external casing 10, which is provided with end walls 11 and 12 and side walls 13 and 14. These walls are perforated by holes 15—15, et cetera, to permit the propagating medium or liquid, as for instance water, if the device is used for signalling in water, to enter into the chamber formed within the casing for the purpose of filling the chamber and surrounding the tubes with the propagating or radiating medium but no liquid enters into the tubes. The tubes 1, 3 et cetera may be made of the same or different diameters and may be divided into independent vibrating sections by projecting flanges 17, 18, 19 and 20. These flanges are formed by any suitable means which bend out the walls of the tubes forming a narrow U-shaped section as viewed in Fig. 1. This type of joint between any two sections of the tube, as for instance, sections 21 and 22, permits the sections to vibrate longitudinally unimpeded, without any substantial reaction from one section to the other. By establishing the various sections of the tubes at the same lengths, the tubes will be made substantially resonant at the same frequency in a longitudinal direction. This resonance is substantially independent of the diameter of the tube. In the arrangement indicated in Fig. 1, the magnetic flux circulates through the walls of the tube in directions concentric with the axis of the tube. As is well known, magnetostrictive tubes made of nickel undergo an increase in flux in response to a contractive force, and vice versa an increase in flux produces a contractive action which tends to contract the tube so that when the flux increases, the circumference of the tube decreases. Whether this is a primary or a secondary effect has not been scientifically established but, with the alternate expansion and contraction of the diameter of the tubes due to the alternating flux in the tubes, a corresponding longitudinal vibration takes place in the tube section and if this longitudinal vibration is established for the longitudinal resonance of the tube, then the mechanical forces in the tube act at resonance to enhance the lateral contraction and expansion amplitude of the tube itself. The longitudinal resonance of the tube is unimpeded from the point of view no radiation occurs because of this motion and therefore no water load is impressed upon the tube merely by means of this longitudinal vibration. The lateral expansion and contraction of the tube acts against the propagating medium to impart vibrations to the medium and this furnishes the comparatively large water load with small linear amplitude as compared to the larger longitudinal linear amplitude of the sections of the tubes. The radiation

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of each tube section will be in the same phase when the tubes are made substantially alike, and therefore a substantially plane wave may be produced when the tubes are arranged side by side over a considerable surface.

The tubes are sealed in the end plates 8 and 9 so as to prevent the liquid within the casing 16 from leaking out into the end chambers 23 and 24 into which the conducting wires extend where electrical terminals and joints may be made and assembled. The end chambers 23 and 24 are formed by the plates 8 and 9 over which are placed cover members 25 and 26 which are sealed to the end plates by suitable gaskets or flanges 27 and 28 which are clamped between flanges 29 and 30 of the covers by means of the bolts 31 et cetera for the flange 29 and 32, 32 et cetera for the flange 30. The cover member 25 may have a cable fitting 33 through which the cable 34 is sealed. This construction will prevent the liquid from entering into the inside of the tubes and also acting on the electrical conductors. It is very necessary that the insides of the tubes be kept free from external liquid in order to avoid damping of the tubes if the liquid were within the tubes.

As indicated in Fig. 2, if radiation is desired only through one side of the casing, the other side may be lined with an acoustic reflecting layer 35 which may be cork with a plastic binder, as for instance the material called "Corprene," or any other suitable sound reflector may be used. The spacing of the tubes from the reflecting wall may be such as to provide the proper reflecting phase between the reflected waves and the propagated waves so as to build up the radiation amplitude. If the tubes are spaced substantially a quarter of a wave length from the reflecting wall, then the reflected wave from the wall will be substantially in phase with the wave radiated from the tube in the direction normal to the reflecting wall. In the arrangement just described, the tube lengths 21 and 22 may be given a longitudinal resonance for the wave to be propagated or received while the lateral hoop resonance of the tube is made higher than that at which the device is intended to operate.

In the description of some of the other arrangements it will be pointed out how the longitudinal and lateral or hoop resonance may be established at the same or nearly the same value and how this inter-action of the two resonances may be used to establish and broaden the resonance curve which is particularly useful for the device when it is used as a receiver of noise or broad band signals.

The arrangement shown in Fig. 3 may be used with a single pair of tubes or with groups of tubes forming two lines, one of each line forming a pair. The arrangement shown in Fig. 3 also differs, however, from that of Fig. 1 in its structural effect. In this case the tubes 40 and 41 may be substantially larger than the corresponding ones of Fig. 1 or they may have a large number of longitudinal sections separated by the connecting flanges 42, 43, et cetera. The top end of the tubes may be supported in a frame 44 in which the ends of the tubes are hermetically sealed. The frame 44 may be provided with an outwardly extending flange 45 which is clamped between two collars or rings 46 and 47, the ring or collar 47 being the end element of a cover or casing 48 enclosing the end of the device. The flanges 46 and 47 are held together by means of the screws 49 which thread

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through the flanges 46 and 47 and pull the flange 45 against the face of the flange 46 between which elements a clamping ring 50 is positioned to effect a water-tight seal. A conductor 51 enters through a packing gland 52 at the top of the casing 48 and this conductor 51 carries the conducting wires 53 and 54 which are the terminals of the coil 55 which threads longitudinally down through one tube 41 and up through the other tube 42. The lower ends of the tubes 41 and 42 are sealed in a head 56 which forms one wall of a chamber 57 in which the conducting coils pass going from one tube to the other tube. The current circulating in the wires 53 and 54 provides a circulatory flux concentric with the axis of the tubes 40 and 41 and the magnetostrictive effect of the tubes is the same as that described in connection with Fig. 1, namely the alternating flux expanding and contracting the tubes laterally provides a lateral radiation of the compressional waves. The longitudinal lengths of the section may here also be designed to provide a longitudinal resonance at the frequency at which the devices will operate. The tubes 40 and 41 may be surrounded with a shell 58 which may be welded to the inside of the flange 46. This shell may have perforations so as to permit the entrance of the propagating liquid or fluid medium.

In Fig. 4 a section is shown through a modification in which a number of tubes are arranged uniformly in a circular or polygon shape. Each of these tubes 60, 61, 62, 63, 64 and 65 may be retained and supported in a manner similar to that shown in Figs. 1 and 3, and the coil 66 may be threaded in and out of the tubes in the same manner as that shown in Figs. 1 and 3. The threading of the coil in the tubes may be in series or series parallel or in any desired arrangement. The tubes of Fig. 4, like those of Figs. 1 and 3, are sealed against fluids and liquids, but are immersed in the chamber 67 which may be filled with the propagating medium and which is protected by means of the shell 68. The operation of the device according to Fig. 4 is similar to that described in connection with Figs. 1 and 3.

In the arrangement shown in Figs. 5 and 7 the construction is such as to send the flux lengthwise in the magnetostrictive tube. Here the magnetostrictive tube 70 is of the same type as described in the previous modifications with sections of the tube 71, 72 joined by coupling flanges 73 which permit each tube to vibrate independently both in the longitudinal and transverse direction. These tubes may be of such a diameter that they have a so-called hoop resonance at the same resonant point as the longitudinal resonance of the sections. The tube is supported at its ends in top and bottom heads 74, and 75, respectively. Within the magnetostrictive tube 70 there is positioned an assembly comprising an inner laminated core 76 surrounded by a coil 77 wound on an insulating form 78 which may be of Bakelite or other suitable material. The form fits closely to the core and the coil carries the alternating current for vibrating the tube or acts to pick up the currents received by the system, depending upon what use the device is put to, whether a transmitter or receiver. Surrounding the coil and fitting close to the coil form is a shell 79 which may be concentric with the inner core and the coil and which is a permanent magnet made of such material as Alnico or other highly permanent magnetizable metal. As indicated in Fig. 7, this shell 79 is split as at 80 to prevent the circulation of eddy currents. A collar 81 is placed

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around the top of the form 78 to which it fits snugly and about this collar fits the sleeve 82 which has an internal recess 83 holding the end of the tube 70. The sleeve 82 is recessed on the outside to receive the tube or shell 84, of copper or other conductive material, for purposes of confining the alternating magnetic flux within the shell of the tube. The top of the device is made watertight by means of the packing gland 85 which is clamped by means of the screws 86 to the ends of the sleeve 82. The cable 87 is led through the packing gland and connects by means of the wires 88 and 89 to the coil 77.

In the arrangement as described, the coil 77 carries the alternating flux at the frequency at which the vibrations in the tubes are to be produced. Normally with no current flowing in the coil 77, the return magnetic path for the permanent magnet is divided, part flowing through the magnetostrictive tube and the other part flowing through the laminated central core. When alternating current flows through the coil, the direct current flux through the laminated core is alternately opposed and aided by the alternating current flowing through the coil. This action will unbalance the portion of the constant flux flowing through the magnetostrictive member, and the reaction of this and of the alternating flux through the laminated core will vary the flux through the magnetostrictive member in accordance with the variation of current flow through the coil. The outside tube 84, which provides in effect a short-circuited secondary coil, acts through the eddy currents circulating in it to confine the magnetic flux emanating from the permanent magnet to flow through the magnetostrictive tube rather than to spread out in the space beyond the wall of the tube. The variation in longitudinal flux in the magnetostrictive tube will produce a longitudinal vibration and a corresponding transverse vibration in the form of a lateral expansion and contraction of the tube. The diameter of the magnetostrictive tube may be so chosen that its hoop resonance or the resonance in the motion of the lateral expansion or contraction is of the same frequency as the longitudinal resonance between coupling flange sections of the tube.

In Fig. 9 a set of curves is shown illustrating the combination of resonance of the system due to the longitudinal and transverse resonance peaks. The curve 90 may be the curve corresponding to the longitudinal resonance of the tube sections while the curve 91 may correspond to the hoop or lateral resonance of the tube sections. These resonance peaks may coincide with the axis 92 or, if desired, they may be separated by a small frequency difference. When the two resonance peaks are so separated, the coupling of these two resonance modes of the system produces a broadened resonance curve, as illustrated by 93, in which there are two peaks A and B, one corresponding to longitudinal resonance and the other corresponding to transverse resonance. The tuning in this case has a band width substantially between vertical lines C and D whereas the individual resonance elements have a much narrower band width. For reception purposes, a resonance system is obtainable which has a considerable breadth for tuning over the receiving range. The device of this nature may be designed for reception over a broad supersonic band or over a narrower sonic band, depending upon the dimensions and couplings in the system. In a closely coupled structure where most

of the respective energies in the two resonant modes are interchanged with each other, the peaks A and B are more widely separated than where the coupling is not so close. In systems such as the present case where the masses of the moving parts are quite small, the coupling may be very close and therefore the system may be broadly tuned, that is, tuned over a wide band.

In the arrangement shown in Fig. 8, a device such as disclosed in Fig. 4, or, in fact, some of the other figures, may be used. Here the tube 68 may be set at the focus of a parabola or of the corresponding point of a rectangular hyperbola or any other reflecting body such as the reflector 95. The reflector may, if desired, be turned about the tube 68 as the axis both for directionally sending and for reception.

In the constructions which have been described, it will be noted that the tubes are substantially freely supported inasmuch as the end coupling sections are positioned substantially just beyond the place of support of the tube. This is clearly indicated in Figs. 1, 3 and 5.

In Fig. 5 the lower support end is similar in structure to the top support end. The support for the tube 70 is in the section just beyond the coupling flange section 96 leaving the tube 72 substantially free for longitudinal and transverse vibrations. The external tube 84, as indicated in Fig. 5, fits around a shouldered recess 97 formed in the end cap 98. The inner side of the end cap 98 has also a recessed shoulder 99 in which the end of the tube 70 is supported. The inner portion of the end structure is similar to that at the top of the structure, with the laminated core 76 extending down to the base of the cap 98 and the bottom of the form 78 on which the coil 77 is wound extending also down to the base of the cap 98.

Having now described my invention, I claim:

1. Means for sending or receiving compressional waves comprising a magnetostrictive tube having flexible coupling sections dividing said tube into independently vibratable portions, a permanent magnet formed as a shell positioned concentrically within said magnetostrictive tube, a core positioned within said shell having material permeable to magnetic flux, and means surrounding said core for producing alternating magnetic flux in said core, the ends of said core and said magnet being substantially adjacent to said tube whereby the flux in either one element may circulate through the other element.

2. Means for sending or receiving compressional waves comprising a magnetostrictive tube having flexible coupling sections dividing said tube into independently vibratable portions, a permanent magnet formed as a shell positioned concentrically within said magnetostrictive tube, a core positioned within said shell having material permeable to magnetic flux, and means surrounding said core for producing alternating magnetic flux in said core, the ends of said core and said magnet being substantially adjacent to said tube whereby the flux in either one element may circulate through the other element, said magnet shell being split longitudinally the length thereof.

3. Means for sending or receiving compressional waves comprising a magnetostrictive tube having flexible coupling sections dividing said tube into independently vibratable portions, a permanent magnet formed as a shell positioned concentrically within said magnetostrictive tube, a core positioned within said shell having material permeable to magnetic flux, and coil means surrounding said core for producing alternating magnetic flux in said core, the ends of said core and said magnet being substantially adjacent to said tube whereby the flux in either one element may circulate through the other element, means for supporting the ends of said magnetostrictive tube, said magnet and said core, and electrical conducting means, connected to said coil for energizing the same.

4. Means for sending or receiving compressional waves comprising a magnetostrictive tube having flexible coupling sections dividing said tube into independently vibratable portions, a permanent magnet formed as a shell positioned concentrically within said magnetostrictive tube, a core positioned within said shell having material permeable to magnetic flux and means surrounding said core for producing an alternating magnetic flux in said core, the ends of said core and said magnet being substantially adjacent to said tube whereby the flux in either one element may circulate through the other element and an electrically conducting shield member spaced from and surrounding said magnetostrictive tube.

5. Means for sending or receiving compressional waves comprising a magnetostrictive tube, a permanent magnet formed as a shell positioned concentrically within said magnetostrictive tube, a core positioned within said shell having material permeable to magnetic flux and means surrounding the core for producing an alternating magnetic flux therein, the ends of said core and said permanent magnet being substantially adjacent to said magnetostrictive tube whereby flux in either the permanent magnet or the core may circulate through each other and the magnetostrictive tube for alternating the flux intensity in said magnetostrictive tube to produce longitudinal and transverse vibrations.

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