Dec. 19, 1961 W. T. HARRIS 3,014,198

PASSIVE RESONATOR REFLECTOR

Filed Nov. 4, 1958

Fig. 1.

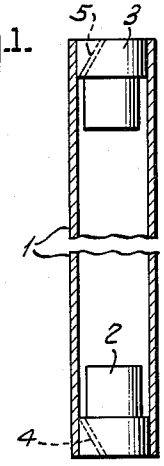


Fig. 3.

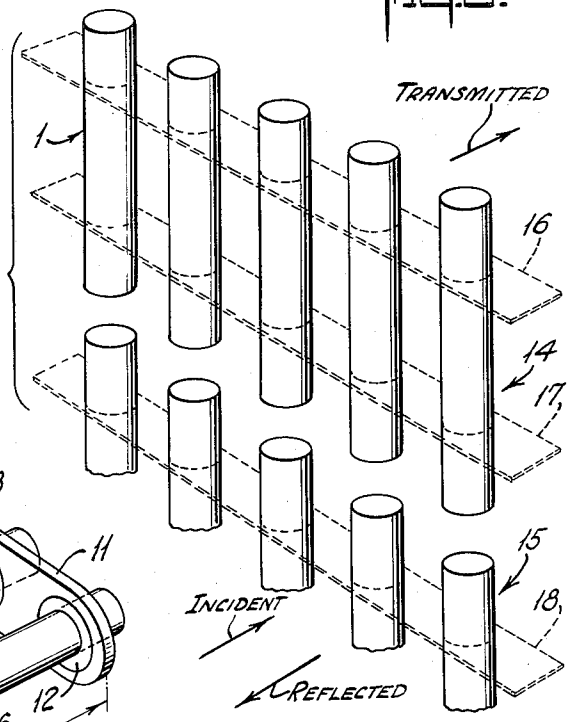
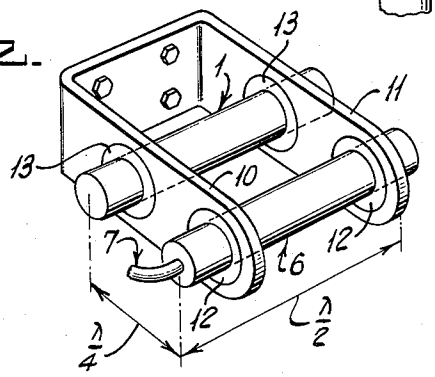


Fig. 2.



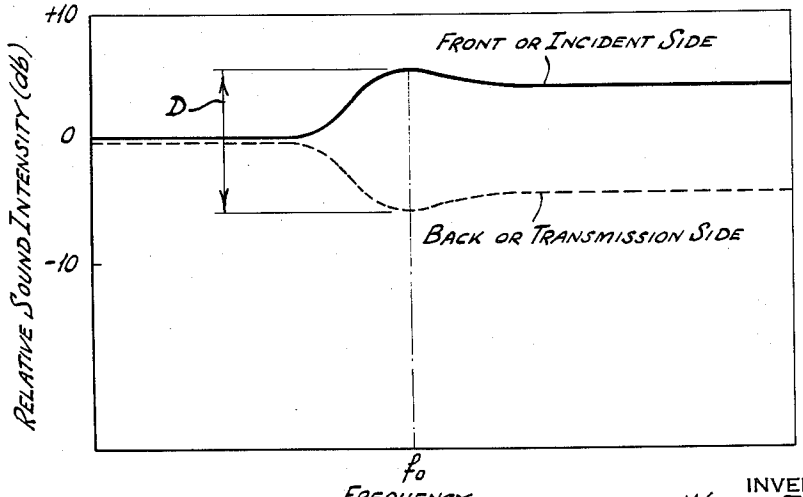


Fig. 4.

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PASSIVE RESONATOR REFLECTOR

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This invention relates to acoustic energy-scattering devices and reflectors, and has particular utility for underwater applications.

Regarding first the acoustic-reflector aspect of the invention, acoustic reflectors are frequently required for use in conjunction with projecting or receiving transducers or transducer arrays to render them unidirectional. For reasons of efficiency, acoustic reflectors should be non-dissipative but substantially opaque to the transmission of sound. Such reflectors, therefore, serve to cause an incident beam and a reflecting beam to be superposed on the incident or front side of the transducer or array, while effectively nullifying or shielding the array acoustically on the rear side.

The reflectors conventionally used for underwater applications are known as boundary-discontinuity reflectors. These reflectors employ a layer of a substance having an acoustic impedance which is substantially different from that of water. The reflecting layer usually comprises materials or structures which are air or gas-filled, such as air-filled cellular rubber, cork, or compliant gas-filled metal or rubber cells. These reflectors, however, have severe limitations caused by properties which are dependent on ambient pressure, as at various depths of immersion. Further, gas-filled structures required hermetic sealing within a skin or sealing material which is impervious to diffusion losses. In the absence of such sealing, the structures tend to lose their gas content and become solid when submerged for long periods of time. These limitations become even more acute when the ambient pressures approach a few thousand pounds per square inch (p.s.i.) because the structures are compressed to such an extent that the impedance discontinuity is no longer adequate and fails to serve its function. Even a thin-walled flat metal enclosure, which is inflated to ambient pressure with hydrogen, becomes a very poor reflector at high pressures, such as 10,000 p.s.i., unless the thickness of the hydrogen slab is made only slightly less than an acoustic wavelength. At low frequencies, such a reflector would have to be very bulky, and the problem of inflating it to maintain its thickness at varying depths of immersion is highly complex.

In another aspect, the invention provides a passive acoustic energy-scattering function, useful, for example, for decoy or masking purposes when released by a submerged submarine.

It is accordingly, an object of the invention to provide improved devices of the character indicated.

It is another object to provide an improved passive, non-dissipative device which is capable of scattering acoustic energy over a predetermined range of frequencies.

It is also an object to provide an improved passive resonant device which lends itself to employment in array configurations.

It is a further object of the invention to provide a passive-resonator structure of the character indicated and which may be either gas-filled or liquid-filled.

It is a specific object to meet the above objects with a passive resonator and resonant arrays which are extremely simple in construction, and which are particularly efficient in underwater applications.

It is a further specific object to provide a passive resonator which can operate underwater and substantially independent of ambient pressure, even at extreme depths of submergence.

In accordance with one aspect of the invention, there is provided a device for scattering acoustic energy, comprising a high-Q tubular resonator having a mode of vibratory motion at its resonant frequency, and adapted for operation when immersed in a medium of acoustic transmission whereby incident acoustic energy at the resonant frequency is scattered by the vibration of the resonator.

In accordance with another aspect of the invention, there is provided an array of tubular resonators having the same resonant frequency and a mode of vibratory motion at the resonant frequency. The tubular members are spaced from each other less than a quarter wavelength in the transmitting medium, whereby at the resonant frequency the acoustic energy is efficiently reflected by the array.

The above-mentioned and other features and objects of this invention and the manner of attaining them will become more apparent and the invention itself will be best understood by reference to the following description of an embodiment of the invention taken in conjunction with the accompanying drawings, wherein:

FIG. 1 is a longitudinal-sectional view of a passive resonator of the invention;

FIG. 2 is a simplified perspective view of the resonator used as a parasitic reflector in combination with an electro-acoustic transducer;

FIG. 3 is a perspective view of an array of such passive resonators; and

FIG. 4 is a plot of relative sound intensity as a function of frequency, illustrating operation of the array as a reflector.

Referring first to FIGURE 1, a passive resonator is shown comprising an elongated metal tube **1** and like end masses or counterweights **2—3** affixed to the opposite ends of the tube. The end weights may be bonded to the tubular member **1** by any suitable resin, such as an epoxy-resin.

The dimensions of the tubular member **1** and the masses of end weights are so chosen that the resonator length is preferably about one-half of an acoustic wavelength in the medium (e.g. water) at the resonant frequency f_0. At this frequency f_0, a wavelength in the metal is much greater than one-half the acoustic wavelength in the medium (e.g. water), and the resonator behaves somewhat as a lumped constant, mass-and-spring, axially resonant vibrator.

The diameter of the resonator may typically be in the order of one-tenth of the wavelength in the medium. The acoustic loading of the resonator in the medium is thus largely sustained by the cylindrical surface or tube and only to a minor extent by the ends **2—3**. Hence, the mechanism by which the resonator is coupled to the medium is that of what I term "Poisson's ratio" radial oscillation, resulting from the axial motion; this mechanism also characterizes transducers described in my copending application, Serial No. 508,074, filed May 13, 1955, now Patent No. 2,880,404. In other words, as the resonator oscillates in an axial mode of vibration, the end masses moving axially in opposed-phase relation, the circumferential surface of the tubular member expands and contracts. During axial elongation of the tubular member, there is a concomitant elastic radial contraction. Thus, efficient interaction with rediation is achieved by the periodic radial contraction and expansion resulting from the axial expansion and contraction, respectively.

The material of the resonator tube **1**, the dimensions of the resonator and the end weights **2** and **3** are selected so that the Q of the resonator in vacuum is very high, in the order of several thousand, and in the order of 10

to 50 in water. The resonators, therefore, may be considered to be substantially non-dissipative. Typically, a resonator according to FIGURE 1 and suitable for underwater use may comprise an aluminum alloy tube 1, 6 inches long, 1⅛ inches in diameter, and 1/16 inch thick, closed by aluminum counterweights 2—3, each approximately 1½ inches long and bonded to tube 1 over continuous cylindrical portions for a bonded axial length of ⅜ inch; when liquid-filled and immersed, such a resonator has a resonant frequency of about 5000 c.p.s.

Although sealed hollow resonators can be constructed to have desired acoustic properties, and still withstand very high pressure, it may be advisable, particularly for use at great depths, to solidly fill the resonators with liquid, so that the resonator structure is not stressed by the ambient pressure. For this purpose, bleeder ports 4 and 5 may be provided in the end weights 2 and 3, respectively. The diameter of the bleeder ports is selected so that the ports are effectively closed to the vibratory motion of the liquid but are just enough open to accommodate the slight flow accompanying changes in ambient pressure at varying depths of immersion. In spite of liquid filling, the liquid-filled device is a high-Q device and may be regarded as non-dissipative, and except for its limitations at great underwater depths, an air or gas-filled device of FIG. 1 is also non-dissipative and is characterized by high Q.

The single resonator has utility as an acoustic scatterer at its resonant or higher frequencies. Such devices, for example, may be released by submarines to serve as noise-scattering decoys or masking devices, and may be designed to be neutrally buoyant, or negatively or positively buoyant, depending on tactical necessity. Other uses for the acoustic-energy scatterer will be apparent to those skilled in the art.

The single-element resonator 1 may also be utilized as a parasitic reflector in combination with an electroacoustic transducer 6, as shown in FIG. 2. The transducer 6 is shown diagrammatically, since the details of the transducer are unnecessary for an understanding of the invention; it may, for example, be of the Poisson-ratio type disclosed in said copending application. The transducer 6 is shown with lead-out wires 7, for suitable circuit connection. The reflector 1 is positioned, preferably, parallel to and one-quarter wavelength behind the transducer 6, so that the reflected energy is superposed on the incident radiation of the transducer, and if like tube and end-mass proportions and materials are employed, both the reflector 1 and the transducer 6 may have the same resonant frequency.

Suitable support for the elements of FIG. 2 may be provided locally or at the longitudinal center of each of the elemental tubes 1 and 6. For the free-flooded or liquid-filled embodiment, spaced bracket members or arms 10—11 carry rubber or plastic bushings 12—13 circumferentially embracing the supported parts of elements 1—6. The material of bushings 12—13 is preferably such as to have substantially the sound-transmitting characteristics of water so as not to impair resonant motion of either element 1 or 6.

A planar array of resonators spaced close together, e.g., less than one-quarter wavelength, comprises a highly effective reflector of plane waves. In FIGURE 3, a planar array is illustrated, with the resonators 1 arranged vertically and parallel in a first row 14, adjacent a similar second row 15. A normally incident sound wave, as suggested by an arrow impinging on one side of the array, is reflected back in the direction of the transducer 6; a relatively small portion of incident energy is transmitted through the array. Support means for the individual elements of the array are not shown but are suggested at 16—17—18 and will be understood to be provided in a manner analogous to that shown and described in connection with FIG. 2.

Although the resonator elements are shown disposed vertically in the array, it is obvious that the elements may be suspended horizontally. Other array configurations will be obvious to those skilled in the art.

A complete mathematical description of the operation of the resonators or resonator array is rather complex. However, the effectiveness of an array can be qualitatively appreciated when it is realized that at frequencies below the resonant frequency of the resonators, the resonators behave as rigid bodies immersed in the medium, and hence the spaced array would be effectively transparent. However, at the resonant frequency of the resonators, the array (as in FIG. 3) tends to become effectively a compliant layer in the medium, and hence presents an impedance discontinuity which is capable of reflecting the incident sound energy. At frequencies above the resonant frequency of the resonators, the resonators still tend to present effectively a layer of compliant material to the incident sound waves as long as they remain closely spaced relative to a wavelength, and, as indicated above, preferably less than a quarter wavelength. Eventually, as progressively higher frequencies are considered, the reflective layer may be expected to lose its ordinarily continuous characteristic and become an array of discrete objects. At sufficiently high frequencies, the purely-radial resonant mode of the cylinders will be approached, causing the reflectors to operate in a different mode of vibration and independent of motion of end masses 2—3.

In FIG. 4 the behavior of an array of reflectors is illustrated by a plot of relative sound intensity in the medium as a function of frequency. It is seen that the array is transparent to sound at frequencies appreciably below the resonant frequency f_0 of the resonators. At frequency f_0, the resonator array becomes a good reflector and remains effective at frequencies above the resonant frequency subject to the limitation noted above for the substantially higher frequencies at which element spacings are greater than one quarter of a wavelength.

It will be apparent to those skilled in the art that passive reflectors may also serve a very valuable purpose as markers on which underwater bearings are to be taken. Such arrays may become, in effect, underwater beacons, responding to directionally responsive echo-ranging sonar equipment, and if different underwater locations are "marked" by such arrays resonant at unique and different frequencies, the detected range, bearing, and frequency of a particular "marker" can provide exact knowledge of one's underwater location.

While the foregoing description sets forth the principles of the invention in connection with specific apparatus, it is to be clearly understood that this description is made only by way of example and not as a limitation of the scope of the invention as set forth in the objects thereof and in the accompanying claims.

I claim:

1. A device adapted to be suspended in a medium of acoustic transmission and adapted to scatter acoustic energy of a predetermined character which impinges thereupon, said device comprising an elongated elastic tubular resonator having a resonant frequency of vibration in a vibratory mode such that the ends of said resonator move in the direction of its axis and its elongated side surfaces contract and expand in a radial direction, said side surfaces being substantially completely acoustically operatively exposed to the medium in which it is suspended and substantially free to vibrate radially.

2. The device of claim 1, in which the length of said device is on the order of one-half the wavelength, in said medium, of vibrations at said resonant frequency.

3. The device of claim 1, in which the length of said device is on the order of one-half the wavelength, in said medium, of vibrations at said resonant frequency and the diameter of said device is on the order of one-fifth its length.

4. The device of claim 1, in which said device has a hollow interior and is provided with an opening communicating between said interior and the exterior thereof,

through which said medium is adapted to pass, said opening being of such dimension as to admit the surrounding medium into the interior of said device but being effectively closed to the vibratory motion of the medium within the device.

5. The device according to claim 1, wherein said resonator comprises a hollow metal cylindrical member, and a pair of end weights affixed to and closing the opposite ends of said cylinder.

6. The device according to claim 5, wherein said resonator has an axial length approximately one-half of the acoustic wavelength, in said medium, of vibrations at said resonant frequency, and its diameter is substantially less than its length.

7. The device according to claim 5, wherein said device is provided with an opening communicating between the hollow interior thereof and the exterior thereof, through which said medium is adapted to pass, said opening being of such dimension as to admit the surrounding medium into the interior of said cylinder but being effectively closed to the vibratory motion of the medium within the cylinder.

8. The device of claim 5, and including a liquid completely filling the interior volume of said device.

9. The device of claim 5, and including a gas completely filling the interior volume of said device.

10. An acoustic-energy reflector, comprising a plurality of elongated elastic tubular resonators, each having a longitudinally resonant mode of vibratory motion at a predetermined resonant frequency, and means mounting said tubular resonators to form an array, in which said resonators are parallel and in which the spacing between adjacent resonators is less than substantially one quarter the acoustic wavelength in the transmitting medium at the highest of said resonant frequencies, whereby at said resonant frequency the acoustic energy is substantially reflected by said array.

11. The reflector according to claim 10, wherein said plurality of resonators resonate at substantially the same frequency.

12. The reflector according to claim 10, wherein each of said resonators comprises a hollow metal cylindrical member and a pair of weights of substantially equal mass affixed to the opposite ends of said cylindrical member.

13. The reflector according to claim 10 wherein the axial length of each of said reflectors is approximately one-half the acoustic wavelength, in the transmitting medium, at its resonant frequency, and in which the diameter of said cylinder is substantially less than the axial length thereof.

14. The reflector according to claim 10, wherein each of said reflectors is filled with liquid.

15. The resonator of claim 10, in which said resonators have side surfaces which vibratorily resonantly contract and expand in a radial direction when said resonators vibrate longitudinally, said resonators being mounted with their side surfaces substantially completely acoustically operatively exposed to the medium which surrounds them and substantially completely free to vibrate radially.

16. The reflector according to claim 15, wherein said plurality of resonators resonate at substantially the same frequency.

17. The reflector according to claim 15, wherein each of said resonators comprises a hollow metal cylindrical member and a pair of weights of substantially equal mass affixed to the opposite ends of said cylindrical member.

18. The reflector according to claim 15, wherein the axial length of each of said reflectors is approximately one-half the acoustic wavelength, in the transmitting medium, at its resonant frequency, and in which the diameter of said cylinder is substantially less than the axial length thereof.

19. The reflector according to claim 15, wherein each of said reflectors is filled with liquid.

20. An acoustic energy reflector, comprising a plurality of tubular resonators, each resonator comprising a hollow metal cylinder and a pair of weights affixed to the opposite ends of said cylinder, the cylinder and end weights of each resonator being selected so as to determine a resonant frequency in an axial mode of vibratory motion for that resonator, the lengths of said resonators respectively being approximately equal to one-half an acoustic wavelength, in the transmitting medium at their respective resonant frequencies, the diameters of said cylinders being substantially less than the axial lengths thereof, and the spacing between adjacent resonators being less than one-quarter of an acoustic wavelength, in the transmitting medium, at the highest of said resonant frequencies, whereby at said resonant frequency the acoustic energy is substantially reflected by said array.

21. The resonator of claim 20, in which said resonators have side surfaces which vibratorily resonantly contract and expand in a radial direction when said resonators vibrate longitudinally, said resonators being mounted with their side surfaces substantially completely acoustically operatively exposed to the medium which surrounds them and substantially completely free to vibrate radially.

22. In combination, an electro-acoustic transducer capable of transmitting or receiving energy in water as the acoustic medium, an elongated essentially cylindrical resonator having a resonant frequency of vibration in a vibratory mode such that the ends of said resonator move in the direction of its axis and the side surfaces of said resonator contract and expand in a radial direction, and means for mounting said transducer and said resonator with said resonator spaced from said transducer by a distance equal to $N\lambda/4$, where N is an odd integer and λ is the wavelength of sound in water at said resonant frequency, the axis of said resonator being perpendicular to a line through the centers of said transducer and resonator.

23. The combination of claim 22, in which said transducer comprises an elongated essentially cylindrical body which vibrates at a frequency and in a mode similar to said resonator, and electro-mechanical means operatively associated with said body for transducing purposes.

24. The resonator of claim 22, in which said resonator has side surfaces which vibratorily resonantly contract and expand in a radial direction when said resonator vibrates longitudinally, said resonator being mounted with its side surfaces substantially completely acoustically operatively exposed to the medium which surrounds it and substantially completely free to vibrate radially.

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