March 28, 1961 W. T. HARRIS 2,977,569

DETECTOR WITH MODULATION BY MAGNETOSTRICTIVE-CORE ACOUSTIC TRANSDUCER

Filed April 4, 1951

FIG. 1.

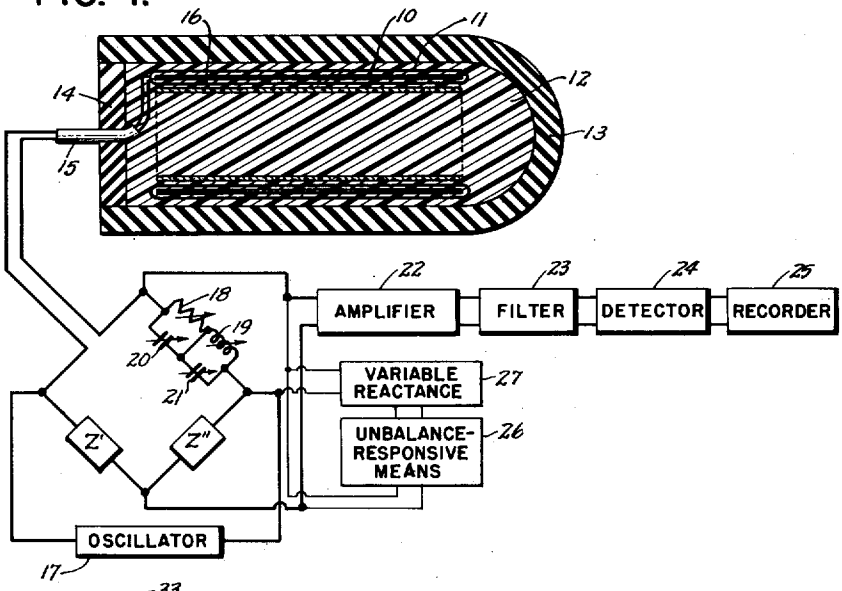


FIG. 2.

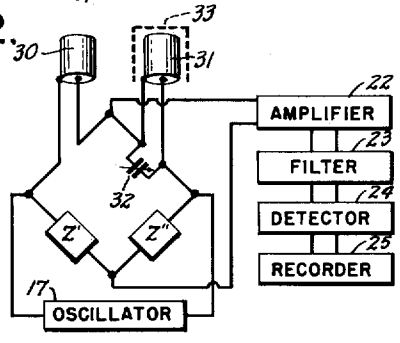
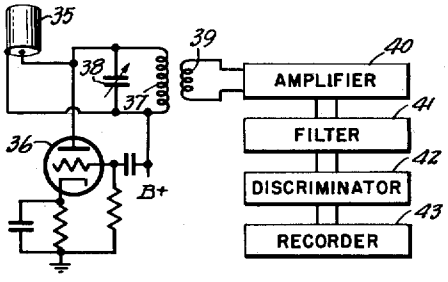


FIG. 3.



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United States Patent Office 2,977,569
Patented Mar. 28, 1961

2,977,569

DETECTOR WITH MODULATION BY MAGNETOSTRICTIVE-CORE ACOUSTIC TRANSDUCER

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Filed Apr. 4, 1951, Ser. No. 219,194

4 Claims. (Cl. 340—5)

My invention relates to improved transducer means, and in particular to transducer means electrically responsive to low-frequency pressure variations.

Magnetostrictive underwater microphones or hydrophones are illustrative of current low-frequency transducer practice. These devices may consist essentially of a hollow cylinder (or an array of cylinders) of magnetostrictive material, the cylinder being toroidally wound with wire. The metal of the cylinder is magnetically polarized at remanance, or is polarized by passing direct current through the winding, or by the use of permanent-magnet material introduced into the magnetic circuit formed by the cylinder wall. In use, an applied sound pressure causes circumferential strains in the cylinder, and because of the magnetostrictive property, these strains cause the magnetic flux in the wall to change, thus inducing a voltage in the winding. The winding is usually connected through a transformer to an amplifier, thence to a reproducer or recorder.

In such magnetostrictive devices, the output voltage (V) increases in proportion to the frequency of the impinging sound wave, and the electrical impedance (Z) of the device increases in the same manner; therefore, the power output (V^2/Z) increases as the frequency, as does the efficiency of the device. With crystal or electrostrictive transducers, the efficiency is also proportional to the frequency, but the output voltage is constant while the electrical impedance decreases with increasing frequency; therefore, the power output of the crystal or electrostrictive transducer also increases with increasing frequency.

The maximum efficiency of a magnetostrictive hydrophone designed for use in the audio-frequency range usually occurs in the region 10–20 kc./s. The efficiency is usually of marginal usefulness at frequencies of 50 cycles and lower, because of the low output voltage and of the low impedance; this impedance is not properly matched by the input transformer, which must function throughout the frequency band of interest.

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

It is another object to provide a low-frequency transducer having an extended broad band of uniform low-frequency response.

Another object is to provide a device of the character indicated in which matching problems characteristic of conventional practice may be substantially avoided.

It is a specific object to provide a transducer of the character indicated with means for automatically maintaining maximum sensitivity of the device.

Other objects and various further features of novelty and invention will be pointed out or will become apparent to those skilled in the art from a reading of the following specification in conjunction with the accompanying drawings. In said drawings, which show, for illustrative purposes only, preferred forms of the invention:

Fig. 1 is a view schematically showing a transducer and circuit incorporating features of the invention, the transducer element being shown enlarged and in longitudinal section;

Fig. 2 is a simplified circuit diagram of a modification; and

Fig. 3 is a simplified circuit diagram of a modification.

Briefly stated, my invention contemplates detection of pressure variations, including low-frequency variations, with uniformly high sensitivity throughout a broad band of response. Such detection is achieved by treating the transducer as a variable reactance and by utilizing low-frequency reactance fluctuations to modulate a high-frequency carrier. The low-frequency signal may finally be resolved by means of a detector and of such filtering and amplifier means as are necessary. In one general form to be described, the reactance changes in the transducer produce amplitude modulations on the carrier, and in another form frequency modulations are produced; but in each case the detector means may readily develop the low-frequency signal.

In Fig. 1 of the drawings, I show a first embodiment of the invention in which the variable inductance thereof is utilized in the detection of low-frequency energy. The transducer may be of generally conventional configuration, comprising an elongated cylindrical member **10** of preferably laminated magnetostrictive material. A toroidal winding **11** may encase the cylinder **10**. As shown, the transducer is particularly adapted to underwater applications and is, therefore, filled with rubber or with a rubber-like plastic **12**, having preferably substantially the sound-transmitting characteristics of water. As shown, the entire unit is encased in a boot **13** of U-shaped section, and closed at the open end with a plug **14**. The boot **13** and plug **14** may be of rubber, and lead cable **15** to the winding **11** may be brought out of the transducer centrally of the plug **14**, as shown. If desired, the response of cylinder **11** to pressures causing radial deformation may be enhanced by placing a thin air-filled or other low-density cylinder **16** within the wound magnetostrictive cylinder **10**; as shown, cylinder **16** is of cork.

In accordance with a feature of the invention, I energize the described transducer with a high-frequency signal which may be derived from an oscillator **17**. This high frequency is to carry low-frequency modulations and is therefore in excess of the maximum frequency to be expected in the low-frequency response band of the transducer; for example, if the response band is to extend from 0 to 10 kilocycles per second, then the frequency of oscillator **17** may suitably be 20 kc./s. In the form shown, oscillator **17** is connected to the transducer through an A.-C. bridge circuit having four interconnected arms. Fixed impedances Z′ and Z″ may characterize two of the conjugate arms; the hydrophone may comprise the third arm, and variable ballast-impedance means may comprise the fourth arm. In the form shown, a variable resistance **18**, a variable inductance **19**, and variable capacitances **20**—**21** bridging resistor **18** and inductance **19** may provide for adjustment of the bridge for complete balance, taking into account the resistance of the winding **11** and leads, eddy-current resistance, distributed winding capacitance, and the inductance of the hydrophone. Bridge output may be taken from the unfed corners of the bridge; I have schematically shown amplifier means **22** to amplify the output signal, filter means **23** to exclude all signals except the carrier and modulation products (i.e. sidebands), detector means **24** to detect the envelope of the modulated carrier frequency, and recorder means **25** to display the detected envelope. It will be understood that the described elements **22** to **25** are merely illustrative and that various forms of detector means and display means may be provided as dictated by particular requirements.

When the bridge has been balanced by appropriate

adjustment of impedances **18** to **21**, the described device will have maximum sensitivity to transient changes in the inductance of the transducer. Such changes develop whenever incident pressure variations change the state of strain in the material of the cylinder walls. Strain changes are accompanied by changes in magnetic permeability of the cylinder **10** so as to alter the inductance of the transducer, as seen through the electric leads thereto.

In certain instances, as where changing ambient conditions cause corresponding unbalances in the bridge, sensitivity may be maintained automatically at substantially the optimum value. In the arrangement shown, unbalance-responsive means **26**, having preferably a longer time constant than the amplifier-detector means **22—24**, is connected across the bridge output in order to generate signals for the control of variable-reactance means **27**. Variable-reactance means **27** may be connected across the ballast arm **18—19—20—21** so as to institute appropriate balancing correction, as will be understood.

It will be noted that, although useful in some applications, magnetic polarization of the transducer is not necessary. This is in contrast to the conventional (generating) type of transducer in which the transducer must generate a voltage. Polarization, if used, may serve the purpose of adjusting the device to maximum sensitivity, as where the property of a particular magnetostrictive material indicates such adjustment. However, with materials such as nickel and nickel-iron alloys there would appear to be insignificant improvement in sensitivity due to polarization.

Advantageous results may be achieved by the strict avoidance of polarization, as by utilizing the unpolarized transducer's property to double the frequency of the applied excitation, insofar as sound transmitted into the medium is concerned. With the described connections, the transducer is a poor sound projector, but in certain underwater applications, as where security is important, it may be desired and it may be preferred to operate in the complete absence of remanant polarization, so that for the case of a 20-kc. bridge such little sound as is propagated from the hydrophone will be at 40 kc., which is beyond the conventional region of operation of sonar gear.

In Fig. 2, I show a slight modification of the arrangement of Fig. 1, and because of circuit similarities corresponding parts are shown with the same reference characters. The circuit of Fig. 2 illustrates the employment of two transducers, each of which may resemble the hydrophone described in detail in connection with Fig. 1. The hydrophones **30—31** are shown connected in conjugate arms of the high-frequency bridge, and a trimming impedance **32** may be connected across one hydrophone **(31)** in order to achieve a desired balance of the bridge. The two hydrophones **30—31** may be utilized in an array in order to achieve a directional response, or series or parallel arrays may be connected in one or more bridge arms. Further alternatively, one of the hydrophones **30—31** may be used as a reference impedance, as by encasing the same in sound-attenuating means, such as an air-filled envelope or blanket (schematically shown by the dotted lines **33**). The hydrophone **31** may then be subjected to all the conditions of operation to which the hydrophone **30** is subjected, except that the transient low-frequency variations to which the device is to respond will be excluded from transducer **31** by blanket **33**.

In Fig. 3, I illustrate an alternative method of modulating the high-frequency carrier in accordance with the variable-inductance characteristic of a transducer **35**, which may again be similar in construction to that described in Fig. 1. In Fig. 3, however, the modulation is a frequency modulation superimposed on the carrier frequency. In the present simplified showing, the oscillator comprises the tube **36** and a tank circuit including inductance **37** and capacitance **38**, the transducer **35** being connected across the tank circuit **37—38**. The frequency-

modulated carrier may be picked off inductively at **39** and appropriately treated by amplifier means **40** and filter means **41** prior to detection in a discriminator **42**, the output of which may feed a conventional display means, designated **43**.

It will be appreciated that I have described improved transducer and circuit means, whereby low-frequency response of substantially uniform sensitivity may be obtained over a relatively broad band. With my arrangements, signal levels may be made large enough for convenient use without excessive amplification by the use of a sufficiently powerful oscillator signal. Although the transducer will emit sound into the medium due to the electrical energy fed through the bridge circuit, this will ordinarily not be a serious detriment; in underwater use, high frequencies are attenuated more strongly than are the low frequencies of interest, and the radiated power will be normally less than 0.1 watt. The usual broadband hydrophone or microphone converts acoustical energy into electrical energy with an efficiency of less than one percent; however, with my invention, apparent efficiencies of several thousand percent are feasible, due to the locally supplied energy and to the fact that the incident acoustic energy exerts a control function, rather than a generating function. Whether my transducer is connected singly or in multiple-unit arrays, it will be seen that my circuit employment thereof not only makes possible inherent freedom from the static electrical interference ordinarily characteristic of low-frequency circuits and the freedom from A.-C. magnetic hum (inherent in toroidal windings), but the further opportunity is presented of rejecting all signals except those of the oscillator (carrier) frequency, so that only modulation products of the carrier frequency will reach the detector.

While I have described my invention in detail for the preferred forms shown, it will be understood that modifications may be made within the scope of the invention as defined in the appended claims.

I claim:

1. In a device of the character indicated, a low-frequency magnetostrictive transducer, an A.-C. bridge with said transducer connected in one arm thereof, a high-frequency source for exciting said bridge, ballast-impedance means in the bridge arm conjugate to the arm in which said transducer is connected, detector means responsive to the output of said bridge, and unbalance-responsive means responsive to the output of said bridge and including in the output thereof means for varying the reactance across one of said arms, said unbalance-responsive means having a longer time constant than said detector means, whereby said bridge may be balanced for maximum sensitivity even in the presence of changing ambient and other operating conditions.

2. A device according to claim 1, in which said ballast-impedance means includes a capacitance element.

3. A device according to claim 1, in which said ballast-impedance means includes an inductance.

4. An efficient low-frequency acoustic receiving transducer for response to incident relatively low-frequency sound, said transducer comprising an unpolarized magnetostrictive core and winding means electromagnetically coupled to part of said core, including a high-frequency source coupled to said winding means, and detection means coupled to said winding means and responsive to low-frequency modulations of the signal from said source, whereby low-frequency sound impinging upon said transducer may be detected with relatively high efficiency and whereby the frequency-doubling effect inherent in high-frequency excitation of an unpolarized magnetostrictive transducer may enhance the security of the device by doubling the frequency of said source, so that such little energy as is radiated from said transducer may be radiated at said double frequency.

(References on following page)

References Cited in the file of this patent

UNITED STATES PATENTS

1,807,658	Godsey	June 2, 1931
1,950,406	Hoorn	Mar. 13, 1934
2,155,509	Schroter	Apr. 25, 1939
2,170,206	Mason	Aug. 22, 1939
2,392,758	Minton	Jan. 8, 1946
2,418,132	Maxfield	Apr. 1, 1947
2,418,953	Raitt	Apr. 15, 1947
2,438,925	Krantz	Apr. 6, 1948
2,461,635	Feller	Feb. 15, 1949
2,521,136	Thuras	Sept. 5, 1950
2,562,640	Reason	July 31, 1951
2,631,271	Thuras	Mar. 10, 1953
2,641,741	Peterson	June 9, 1953
2,649,579	Alexander	Aug. 18, 1953
2,761,118	Wallace	Aug. 28, 1956