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HOMING SYSTEM FOR TORPEDO

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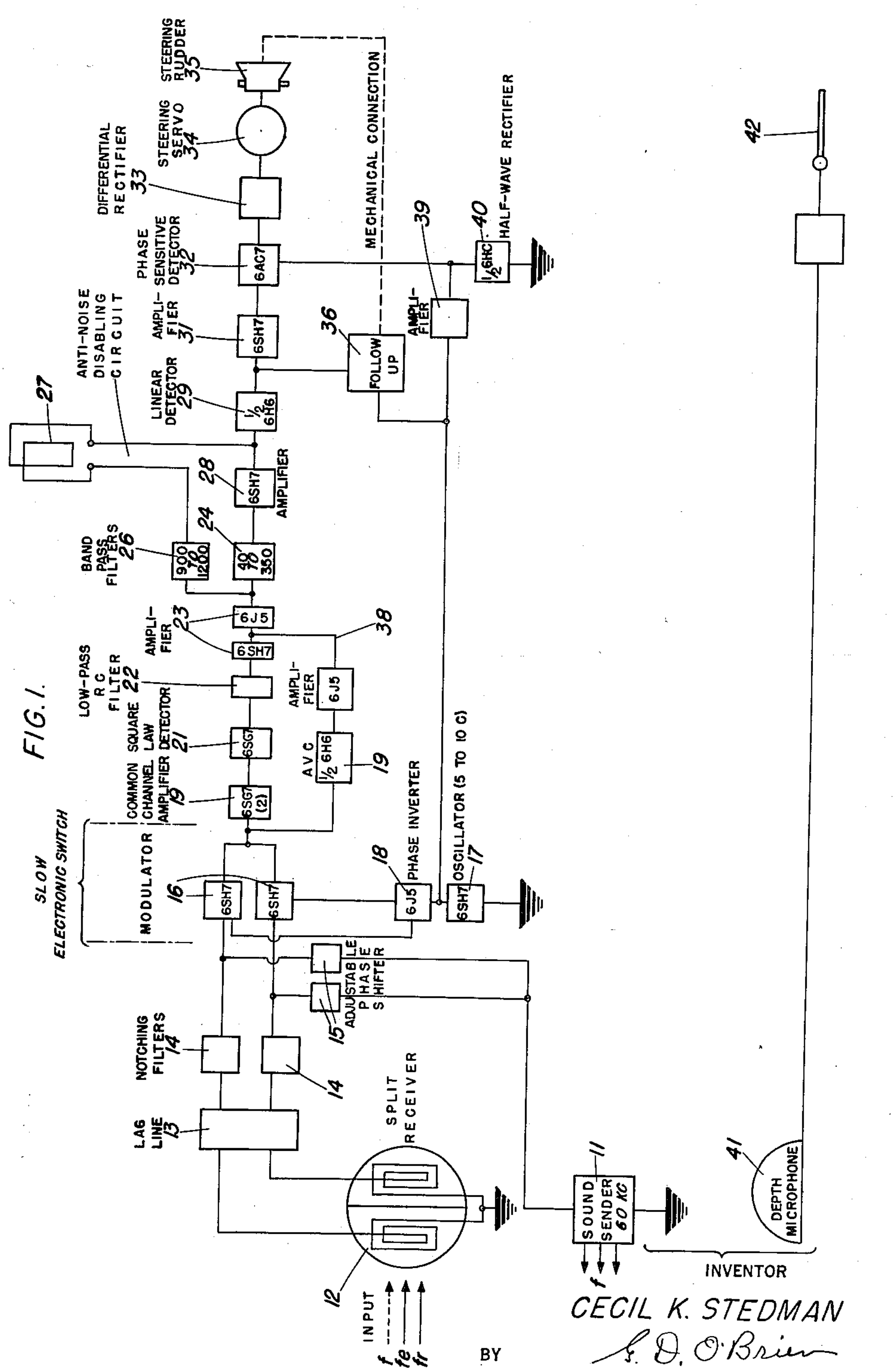

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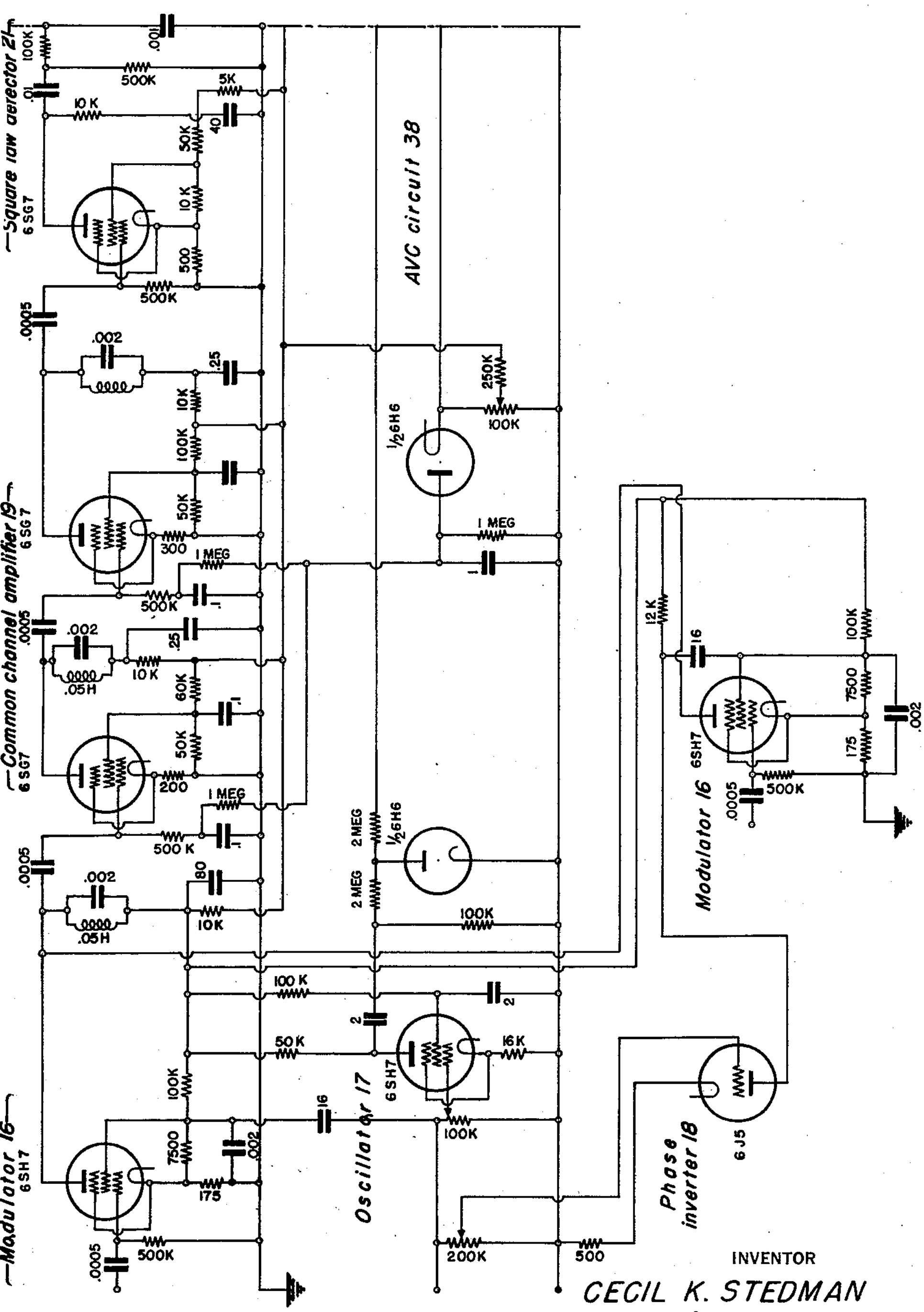
Filed May 1, 1946 3 Sheets-Sheet 2

FIG. 2.



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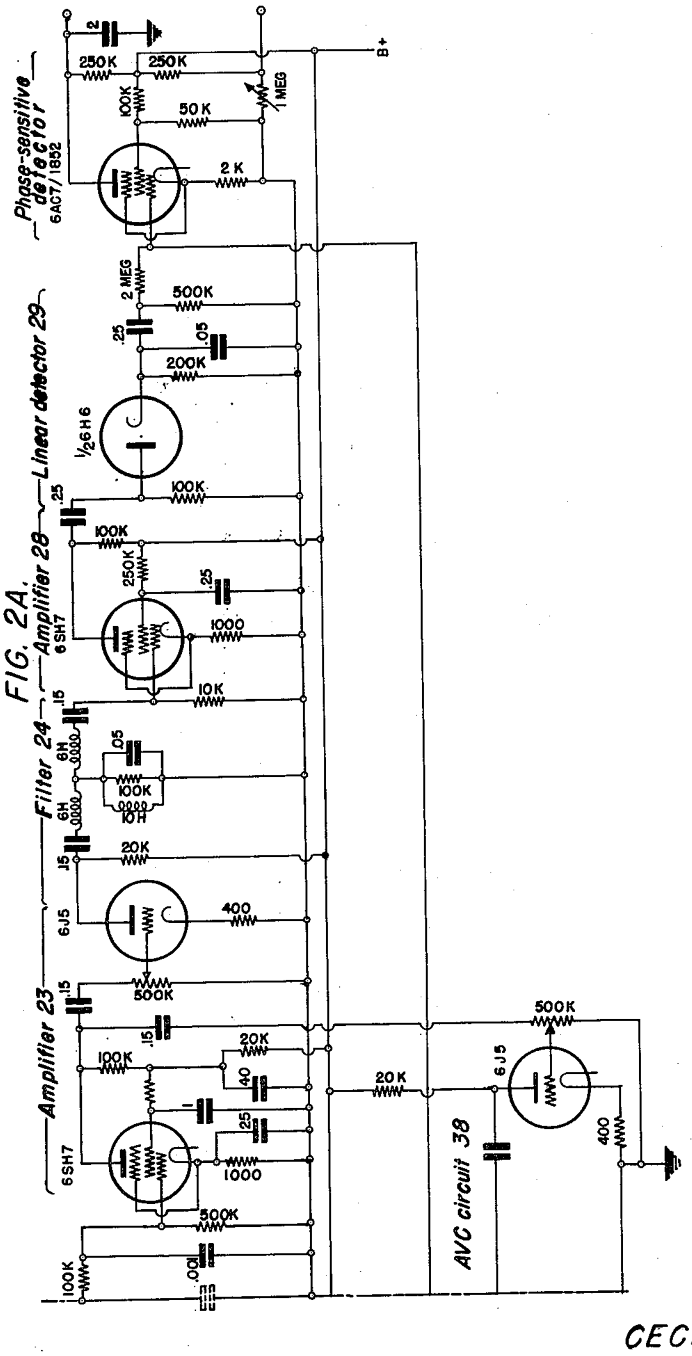

FIG. 2A.

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3,021,807
HOMING SYSTEM FOR TORPEDO

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This invention relates to an underwater explosive mine and more particularly to such a mine that can detect the presence of an enemy target within the predetermined range and that can propel itself toward that target.

The prior art has developed what is known as a sound ranging mine or torpedo. This weapon contains, in addition to its explosive charge, a storage battery and a motor for driving a propeller and is particularly designed for use against submarines. The mine also has a directionally selective sound receiving apparatus that receives sound or noise generated by the enemy submarine, and means whereby this apparatus guides the mine towards the submarine. As a countermeasure, the submarine may reduce its noise by proceeding slowly or stopping. Another countermeasure is the release of a noise-making decoy by which the mine is guided away from the submarine.

The present invention is intended to meet such countermeasures and to render the mine far more effective against enemy craft, both surface and sub-surface. The present invention may be used not only in mines laid by minelayers but also in torpedoes launched from aircraft, surface vessels, and submarines.

The weapon constructed in accordance with the principles of this invention is an improvement over the sound ranging torpedo hereinbefore mentioned. This, too, includes a battery and a motor for driving a propeller. In addition, it contains a transducer for emitting a continuous wave of supersonic signals. A target submarine that is within the range of this emitter will return an echo. In most cases the target will have a component of motion toward or away from the mine, and in accordance with the Doppler principle the echo will have a different frequency from that of the emitted signal. If the mine is in motion, the reverberation will also have a frequency shift due to the Doppler principle, and the frequency thereof will differ from that of the emitted frequency and from the echo frequency. Suitable electronic apparatus within the mine will react in accordance with the difference in frequency between the emitted signal, the echo, and the reverberation, and will guide the mine toward the source of the echo.

When the wave energy strikes a target, some of it is reflected, and a portion of the reflected energy reaches the transducer, which now functions as a receiver. If both the mine and the target are stationary, then the frequency of the echo will be the same as the transmitted frequency, and the mine will not be energized, for it is designed to be inoperative against stationary targets. If, however, there is relative movement between target and mine, the frequency of the echo will differ from the transmitted frequency by an amount that may be calculated from the equation of Doppler.

When an observer is stationary and a source of sound is approaching, the apparent pitch of the sound is expressed by the equation

$$P=f\frac{V}{V-S}$$

where P is the observed pitch, f is the ferquency of the source, S is the velocity of the source, and V is the velocity of wave propagation. When the observer is stationary

and the source of sound is moving away from him, the observed pitch will be

$$P=f\frac{V}{V+S}$$

If the observer is moving and the source of sound is stationary, the pitch of the sound heard by the observer when he approaches the stationary source will be

$$P=f\frac{V+O}{V}$$

where O represents the velocity of the observer.

When both the source of sound and the observer are moving, the pitch heard will be changed in the proportion

$$\frac{V}{V\mp S}$$

by motion of the source, and in the proportion

$$\frac{V\pm O}{V}$$

by motion of the observer. The pitch heard by the observer is, therefore,

$$P=f\times\frac{V}{V\mp S}\times\frac{V\pm O}{V}=f\frac{V\pm O}{V\mp S}$$

the signs in the numerator and the denominator being chosen to yield an increase in the observed pitch P when the source and the observer approach each other, and a decrease in the observed pitch when they recede.

In this invention, the source of the sound is the mine itself. Frequencies emitted by the enemy submarine will have no effect on the mine. Likewise, noise producing decoys will be ignored by the mine. The energy wave emitted by the transmitter in the mine will, if it impinges on a target movable relative to the mine, be reflected back, and the echo frequency f_e will differ from the initial frequency f in accordance with the Doppler principle. In addition to receiving the echo frequency f_e, the transducer will receive a reverberation frequency f_r. At least in part, this reverberation will be due to reflection and dispersion of the emitted sound at the water surface. When the mine is moving, this reverberation will also have a component of Doppler effect. If the target is approaching or receding, the echo frequency f_e will differ from the reverberation frequency f_r. At the same time, some of the emitted frequency f will also enter the receiving apparatus. As a result there will be a signal of three frequencies in the transducer.

In accordance with the principles of the invention, the mine contains directionally-selective sound-receiving apparatus which utilizes these three frequencies, f, f_e, and f_r, to guide the mine toward the submarine or other target. Whereas a listening type mine or torpedo depends on the sound emitted by the enemy target for energization, and is therefore useless against silent or relatively quiet targets, the instant weapon is capable of attacking a target which itself may emit less noise than the ambient background. Furthermore, it is capable of discriminating against certain types of decoys, namely, artificial noise generators and stationary echo producers such as anchored echo repeaters and false wakes.

To detect an underwater target that is quiet relative to its background, it is necessary to project sufficient energy from a sound sender into the water to bring the echo from that target above the background noise. Exploitation of the Doppler effect of moving targets eliminates the menace due to artificial noise generators and stationary echo producers. The instant system involves continuous transmission and reception, the device operating on the continuous beat note between echo and reverberation.

A principal object of the present invention, therefore, is the provision of an echo ranging mine or torpedo that when dropped or launched or otherwise positioned within a certain area of an enemy target will propel itself toward that target.

Another object of the invention is the provision of a mine or torpedo that will propel itself toward a target even when that target does not itself emit sound or other signals.

Another object of the invention is the provision of a mine or torpedo that is capable of discriminating against certain types of decoys.

Other objects will become apparent from a description of the invention, taken in conjunction with the accompanying drawings.

In these drawings, forming part of the specification:

FIG. 1 is a block schematic of a preferred system for utilizing the invention;

FIGS. 2 and 2A represent a wiring diagram for the main portion of the system.

With particular reference to FIG. 1, it will be noted that the apparatus comprises a sound sender **11** that emits a continuous signal of a frequency f. A frequency of the order of 60 kilocycles has been found to be quite satisfactory. When this wave of energy strikes a target, a continuous echo and a continuous reverberation will be picked up on a receiving transducer **12**, which is split for simultaneous lobe comparison. A receiver of this type has already been described in co-pending application Serial No. 531,490, filed April 17, 1944, for Apparatus for Determining the Direction of Underwater Targets in the name of Oscar Hugo Schuck and now Patent Number 2,524,180. The signal received in the transducer **12** contains several frequencies; one is the original transmitted frequency f that enters the receiver through electrical or acoustical cross talk; another is the reverberation frequency f_r that is shifted from the transmitter frequency f because of the motion of the mine or torpedo, which shift is known as the own Doppler of the mine; and the third is the echo frequency f_e, which, if the target is moving relative to the water, will differ from both the transmitter frequency f and the own Doppler frequency f_r. The receiver **12** has two antennas, one on either side of the axis of the missile. Depending on whether the target is to the right or to the left of the axis, the received signal on one antenna will be of greater amplitude than on the other antenna. A lag line **13** is provided for the purpose of introducing a lag in phase into one or both of the two received signals on the two halves of the transducer **12**, so that appropriate mechanisms may be energized to steer the mine to the target, as will be explained more particularly hereinafter.

From the lag line **13**, the two signals, one displaced in phase relative to the other, go to two notching filters **14**. The purpose of these filters **14** is to introduce a notch or similar blocking effect at the sending frequency f to block out any signals due to cross talk from the sender **11**. With the same object in view, the transmitting frequency f is introduced into the circuit by means of two adjustable phase shifters **15**. More particularly, either the notching filters **14** or the adjustable phase shifters **15** or both may be used, so that in any case the amplitude of the transmitter frequency f will be reduced well below that of the echo frequency f_e and the reverberation frequency f_r.

Unless the target is dead ahead, the signals in the two channels of the transducer **12** will be of different intensities. Two modulators **16** are provided whereby these currents are blocked alternately by means of a low frequency oscillator **17** and a phase inverter **18**. The oscillator **17** is of the order of 5 to 10 cycles per second. The modulators **16**, the oscillator **17**, and the phase inverter **18** constitute what is known as an electronic

switching means, and because of the relatively low frequency of the oscillator **17**, this particular form is referred to as a slow electronic switching means. The electronic switching means feeds both channels of the received signals alternately into a common channel amplifier **19**, and thence into a square law detector **21** in which the three component frequencies f, f_e, and f_r are beat against one another. The amplitude of the various signals in the output of the square law detector **21** will be a function of the beat frequencies. If, for example, the frequency f of the transmitter **11** is 60 kilocycles, the Doppler effect is approximately 42 cycles per knot. For a 14 knot mine or torpedo and various limiting cases of target speed, the amplitudes of the signal correspond ing to the various frequencies in the output of the square law detector **21** are shown in the following table:

Target Velocity	Resultant Beat Frequencies		
	f_r-f	f_e-f	f_e-f_r
Approaching, 8 knots	586	250	336
Stationary	586	586	0
Receding, 8 knots	586	922	336
Approaching, 1 knot	586	544	42
Receding, 1 knot	586	628	42
	Amplitudes		
	E_rE	E_eE	E_eE_r

E = voltage amplitude of transmitter signal.
E_e = voltage amplitude of echo signal.
E_r = voltage amplitude of reverberation signal.

In this table, E, E_c, and E_r represent amplitudes of cross talk, echo, and reverberation, respectively, and the head of each column represents resultant amplitude of the corresponding beat frequencies. Of these signals, only those in the last column are desired for steering the mine. Very low frequencies in the last column represent stationary targets, and these low frequencies are not desired.

A low pass RC filter **22** filters out harmonics due to additions of the frequencies and also the currents due to the carrier frequency of 60 kilocycles. After passing through another amplifier **23**, the signal is fed into a band pass filter **24**. This filter **24**, which passes frequencies from 40 to 350 cycles, removes to a large extent the beat frequency f_r-f, and also in many cases the beat frequency f_e-f, as will be evident from the preceding table. In other words, the beat frequencies due to the transmitted frequency f are eliminated or minimized. Of greater importance, the band pass filter **24** removes the beat frequency f_e-f_r if the radial component of the target velocity is less than one knot. This means that if the target is stationary, or substantially so, the self-propelling mechanism of the mine will not be energized. The band pass filter **24** will also remove beats due to the frequency spread of reverberation provided the latter does not exceed a predetermined extent such as 40 cycles on either side of center. Similarly, it will remove echos from fixed decoys or wakes provided they are not more than, say, 24 degrees off the axis of the transmitter beam, and if they are this far off the beam, the signal will probably be too weak for the action in any case provided the receiving transducer **12** is of the proper pattern.

At the same time that the signal is fed into the band pass filter **24** it is fed into a second filter **26**. This second filter **26** has a pass band from 900 to 1200 cycles per second, whereas the first filter **24** has a pass from 40 to 350 cycles per second. Only if the output of the second filter **26** is much lower than that of the first filter **24** will the steering circuits be operative. Echoes will not pass through the filter **26** and hence will not disable the steering circuits, but if a noise decoy is in use, the outputs from the two filters will be equal and the steering circuits will be disabled. This second band pass filter

26 constitutes an element of the anti-noise-decoy circuit and is adapted to receive the decoy signal through an antenna 27.

The output of the filter 24 is passed to an amplifier 28, and if not neutralized by the anti-noise disabler will go to a linear detector 29, thence to an amplifier 31, and finally to a phase-sensitive detector 32. The detector 32 separates the output of the amplifier 31 in accordance with phase, to obtain a right operating current or left operating current. These currents are passed to a bridge 33 constituting a differential rectifier, that operates a steering servo 34. The servo 34 operates a steering rudder 35. A mechanical connection from the rudder 35 to a follow-up 36 terminates energization of the servo 34 after the latter has operated in accordance with the main steering circuit.

An automatic volume control circuit 38 goes from the amplifier 23 to the input of the common amplifier 19. The automatic volume control operates on the output of the square law detector 21 in such a way that the amplifier gain is controlled essentially by the product of E_e and E_r, the cross-talk E being assumed small. Since the output of the filter 24 is also proportional to this product E_e and E_r, the automatic volume control connection 38 assures that the output of the system as a whole is independent of the reverberation level E_r. On the other hand, the automatic volume control cannot be connected to the output of the filter 24 as it would neutralize the action of the filter. The purpose of the automatic volume control is to provide an output signal that depends only on the target angle to the torpedo axis and not on the signal level.

It should be noted that after the signals leave the notching filters 14 and are switched by the modulators 16, the oscillator 17, and the phase inverter 18, new side bands may be introduced into the amplifier 19, which in turn introduce new beat frequencies at the output of the square law detector 21. The switching side bands will introduce signals the amplitude of which is proportional to E_e squared and E_r squared in the output of the filter 24, unless the switching frequency is sufficiently low so that the important side bands lie below the pass band of the filter 24 (E_e and E_r represent respectively the voltage amplitude of the echo signal and the reverberation signal). This requires a very low rate of switching, in the neighborhood of 5 to 10 cycles per second, and the low switching rate in turn requires long time constants in the net-work of the phase-sensitive detector 32.

One form of circuit diagram, showing the system from the modulator 16 to the phase sensitive detector 33, is shown in FIGS. 2 and 2A. The modulators 16 comprise two 6SH7 tubes, the plates of the tubes being tied together. The oscillator 17 may comprise a 6SH7 tube, and the phase inverter 18 may be a 6J5 tube.

The modulator 16, the oscillator 17, and the phase inverter 18 constitutes an electronic switching means. From the plates of the modulator tubes the signal is fed into a common channel amplifier comprising two 6SG7 tubes and thence to a square law detector 21 comprising another 6SG7 tube. Such a detector is quite sensitive, for the voltage appearing across the plate circuit load is proportional to the square of the input signal voltage. The signal desired to be amplified is, of course, the beat frequency between the echo and the reverberation. The square law detector 21 is followed by a low pass RC filter 22 for the purpose of removing the RF components from the output of the square law detector 21. Some low frequencies due to reverberation will pass through the RC filter 22, but since most of the reverberation is of close origin these frequencies will be equalized in the two channels and will neutralize each other. This leaves two frequency components that pass through the low pass RC filter 22. The first component comprises the modulation frequencies and their harmonics, which are undesired, and the second comprises the beat frequencies due to the echo and the reverberation, which are desired.

From the low pass RC filter 22, the signals pass into an amplifier 23 comprising a 6SH7 tube and a 6J5 tube. From the 6SH7 amplifier, the signals pass to both an automatic volume control circuit and the band pass filter 24 which passes the 40 to 350 cycle band. The filter 24 eliminates the signal due to the modulation frequency components because the latter lie outside the pass band. The filter 24, however, passes the signal due to the beat frequency components of the echo and the reverberation, provided the beat frequency lies within the pass band of 40 to 350 cycles per second. From the filter 24 the beat frequency signal goes to an amplifier 28 comprising a 6SH7 tube and thence goes to a linear detector 29 comprising half a 6H6 tube. The load of the detector 29 has its time constants adjusted to follow the modulation frequency and is capacity coupled to the next stage, comprising a 6AC7 tube, so that the D.C. rectified component does not come through. Accordingly, a modulation frequency signal is impressed on the grid of the 6AC7 tube.

The negative half waves of the modulation frequency are used to bias the 6AC7 beyond cutoff for half the cycle, so that it functions as a phase sensitive detector 32 while during the remainder of the time it acts as an ordinary amplifier 31. Because only half the cycle of the modulation frequency is amplified, there results a change in average plate current proportional to the time average of the modulation frequency signal over half a cycle. This average is in turn proportional to the difference of signal in the two channels and to the amplitude of the reverberation. If the signals due to the reverberation are not balanced to the two channels, an additional output occurs in the phase sensitive detector 32 that gives a steering bias due to the assymmetry of the reverberation. This, however, will tend to disappear as the echo becomes weaker and will therefore not steer the mine completely off its target.

If desired, a separate amplifier tube, such as a 6SH7, may be used prior to the 6AC7 phase-sensitive tube 32.

The automatic volume control circuit 38 exercises a modifying influence on the output. The AVC circuit leads from the amplifier 23 to the input of the common channel amplifier 19. More particularly it leads from the output of the 6SH7 tube of the amplifier 23 to the input of the 6SG7 tube, acting as the common channel amplifier 19, that precedes the square law detector 21. An idealized AVC would operate to keep the peak rectified output of the low pass RC filter 22 independent of input level. Actually the AVC rectifier, which may comprise half a 6H6 tube, is a peak rectifier with time constant and additional filtering such as not to feed back any of the modulation frequency into the earlier stages of the circuit. The AVC circuit 38 also includes a 6J5 amplifier.

As previously indicated the band pass filter 26 is joined to an auxiliary circuit 27 for disabling the steering mechanism in the case that the enemy uses a noise decoy; in this event the output from the filter 26 will be substantially equal to the output of the filter 24 and the steering circuits will not operate.

The oscillator 17 is connected to an amplifier 39 and thence to the phase-sensitive detector 32 and the follow-up 36 to control the timing of these members. The phase-sensitive detector 32 is also connected by way of half a 6H6 tube 40 to ground.

If desired, a microphone 41 may be utilized to activate a depth circuit for the purpose of energizing a vane 42 so as to give an up and down steering motion to the mine. The body microphone 41 may be one sided or two sided. Alternatively the body microphone 41 may be omitted and the mine set to operate at a predetermined depth.

It is apparent that as used in this application the term "mine" also includes what is commonly known as a torpedo. Furthermore, this invention may be utilized to divulge the bearing of an enemy target either visually or orally to an observer. The observer, of course, may be in a stationary post or on a moving vessel.

In operation the novel mine incorporating the principles of this invention is dropped from an aircraft or from a surface vessel. Preferably a hydrostatic device is set so that the mine sinks below the depth of the enemy target. The sound sender 11 will emit the supersonic signal continuously, and the receiver 12 will receive the echo and reverberation if the target is within the range of the device. The continuous beat frequency between the echo and the reverberation will be amplified to activate the steering servo 24 to steer the missile toward the target. Noise decoys will be ignored. At the same time the microphone 41 will operate the depth vane 42 to raise or lower the mine as required.

I claim:

1. In a self-propelled mine, a sound sender, a directionally selective sound receiver for receiving sound echoes from underwater targets and sound reverberations from the water and further adapted to convert said sound echoes to target signals having characteristics defining target direction, a square law detector connected to said receiving means for producing beat frequency signals between said target signals and sound reverberations, a band-pass filter connected to the detector output for selecting beat frequency signals produced by echoes from moving targets, said selected beat frequency signals similarly having characteristics defining target direction, and control means connected to said filter responsive to said characteristics of the selected signals to steer the torpedo toward the echo-reflecting moving target.

2. In a self-propelled mine, a sound sender, a directionally selective sound receiver for receiving sound echoes from underwater targets and sound reverberations from the water and further adapted to convert said sound echoes to target signals having characteristics defining target direction, a square law detector connected to said receiving means for producing beat frequency signals between said target signals and sound reverberations, a band-pass filter connected to the detector output for selecting beat frequency signals produced by echoes from moving targets, said selected beat frequency signals similarly having characteristics defining target direction, control means connected to said filter responsive to said characteristics of the selected signals to steer the torpedo toward the echo-reflecting moving target, and an automatic volume control channel connected between the filter output and the receiver for controlling the receiver gain in response to the level of the selected signal.

3. In an underwater-target locating apparatus having means for transmitting search-signals at frequency f and which, impinging upon a moving target, give rise to echo-signals which are received at said apparatus at frequency f_e differing from frequency f because of Doppler effect, and two-channel means adapted to convert said received echo-signals to a first pair of signals also at frequency f_e but having amplitudes which differ in accordance with departure of target direction from a reference direction defined in said apparatus, wherein said echo signals and correspondingly each of said first pair of signals at frequency f_e are accompanied by reverberation signals at a frequency f_r differing from frequency f and f_e, said reverberation signals tending to mask said first pair of signals, the improvement comprising, in combination, detector means adapted to beat each of said first pair of signals with the reverberation component therein and to yield a second pair of signals each having a component at beat-frequency $f_e - f_r$ therein of relative amplitudes corresponding to the relative amplitudes of said first pair of signals, and filter means adapted to pass only said components at beat-frequency $f_e - f_r$ as an output pair of signals which define departure of target direction by the sense and magnitude of their difference in amplitude.

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