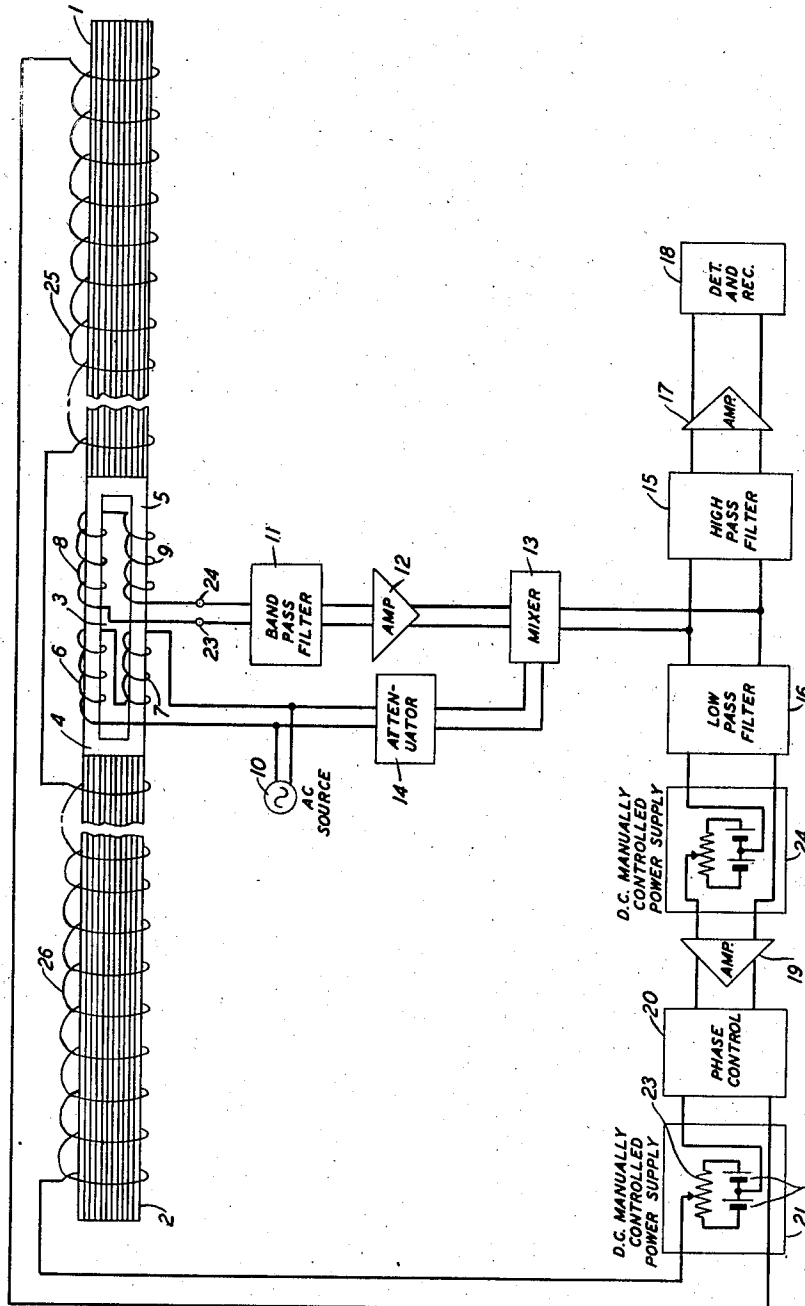


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COMMUNICATION BETWEEN SHIPS

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This invention relates to communication systems and more particularly communication systems employing low frequency electromagnetic fields.

An object of this invention is to provide an improved communication system employing low or audio frequency alternating magnetic fields.

In accordance with the present invention an improved receiving device is provided capable of responding to extremely weak alternating current electromagnetic fields in the audio frequency range and giving an amplified output.

In accordance with an exemplary embodiment of the present invention an elongated core of magnetic material is placed in the electromagnetic field. The core has a center section of suitable magnetic material which is provided with windings for producing voltages in accordance with the electromagnetic field. In order to improve the sensitivity of the device a source of alternating current is applied to certain of the windings and the output voltage derived from other of the windings.

Magnetic detectors and amplifiers provided with somewhat similar cores and windings have been employed in the past to detect and produce amplified voltages in response to electromagnetic fields. In the devices employed for this purpose in the past, the alternating current or the alternating current field has been sufficient to, or exceeded, that required for saturation of the magnetic material. However, the devices of the prior art are not suitable for detecting weak fields; first, because they are not sensitive to weak fields; and second, because they generate appreciable noise which tends to mask or interfere with the received signals.

In accordance with the present invention the alternating current supplied to the device does not tend to saturate the magnetic material of the cores employed. Instead the magnitude of the alternating current is maintained sufficiently small so that the flux in the material does not saturate the material or even approach the so-called "knee" of the magnetization curve. The magnetic material is operated exclusively in the low flux density region where the magnetization curve or the hysteresis loop is approximately defined by Rayleigh's law. The manners and modes of operation of magnetic material in the low flux region is described in greater detail in a paper by E. Peterson entitled "Harmonic Production in ferromagnetic materials at low frequencies and low flux densities" and published in the Bell System Technical Journal for Octo-

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ber 1928, vol. 7, pp. 762-796. See also "Magnetic hysteresis at low flux densities" by Ellwood, published in Physics for July 1935, vol. 6, pp. 215-226, and "Study of magnetic losses at low flux densities in permalloy sheets" by Ellwood and Legg, published in the Journal of Applied Physics for May 1937, vol. 8, pp. 313-358.

One possible explanation for the improved results obtained at low fields is that the Barkhausen steps are much smaller at low fields than at high fields. Consequently, the material responds to smaller changes in the applied field. Furthermore, since the steps are smaller the amplitude of the noise due to this effect is smaller.

When a magnetic device in accordance with this invention is operated in this region it becomes extremely sensitive to small applied fields, produces a considerably greater voltage output for said small fields, and produces less noise than is produced by the magnetic devices of the prior art.

However, since it is necessary to operate the material at extremely low values of applied field and flux, it is necessary to accurately control the bias or operating point on the magnetization curve and to balance out the core flux from sources other than the source from which it is desired to receive signals. Devices of this type are capable of responding to electromagnetic fields considerably weaker than the earth's magnetic field. Consequently, it is also necessary to balance out the flux of the earth's magnetic field from the core or cores of the present device. In order to provide the necessary balancing currents or voltages, the output of the device is amplified and the amplified components of the output having frequencies below the signaling frequency, including direct current, are employed to neutralize the earth's field and other stray low frequency fields having frequencies below the signaling frequency.

The foregoing objects and features and other objects and features of the present invention may be more fully understood from the following description of an exemplary embodiment thereof when said description is read with reference to the drawing which shows in schematic form the various elements which cooperate to provide an improved receiving device for receiving audio frequency electromagnetic waves. The following description is not in any way intended to limit or increase the scope of the claims appended hereto which specifically point out the novel features of this invention.

Referring now to the drawing 1 and 2 repre-

sent an elongated core of magnetic material. This core is placed in the region where the magnetic field is to be detected. For the purpose of illustration, it is assumed that it is desired to receive an electromagnetic field of 25 cycles. It will be apparent to persons skilled in the art that the invention is not limited to any particular frequency or frequency range but may be employed in magnetic fields of any suitable frequency. Inasmuch as such low frequency fields are frequently employed in communication between ships the core will be made relatively long and mounted aboard ship preferably above deck and away from the major portion of the magnetic material and structure of the ship, as for example, 10 to 15 feet above the deck of the ship. When desired this core and coil structure may be made in the form of a cable and towed by the ship. It may be necessary to float the device in quiet water if extreme range is desired.

The core is composed of a plurality of sections 1, 2 and 3, as shown in Fig. 1. These core sections may be made of any suitable magnetic material as, for example, any of the various iron-nickel alloys which have a high permeability at low magnetic fields.

The core sections 1 and 2 are separated by center section 3 comprising a magnetic core having at least two legs 4 and 5. The center section 3 is made of magnetic material which possesses either a high hysteresis coefficient or a high rate of change of permeability with field at low values of applied field or flux or both. A particularly suitable type of core material is described in detail in the United States Patent 1,768,443 granted to Elmen June 24, 1930, which patent is hereby made part of the present application by reference as if fully included herein. However, it can be shown that the device is most effective when the permeabilities of sections 1, 2 and 3 are high and approximately equal while the material of the center section 3 should have either as high a hysteresis coefficient or as high a rate of change of permeability with field as possible or both.

Each of the legs 4 and 5 of the center section of the core is provided with two windings, 6 and 8, and 7 and 9, respectively. Windings 6 and 7 are connected to a source of alternating current 10 having a frequency which is high compared to the highest signaling frequency or component thereof to be transmitted while windings 8 and 9 are connected to the receiving system as will be described hereinafter.

The windings 6, 7, 8 and 9 are so connected relative to each other that when no external magnetic field is applied to the composite core structure comprising sections 1, 2 and 3, no voltage appears across the output terminals 23 and 24 of coils 8 and 9 even when the windings 6 and 7 are connected to source 10. However, when an external field is applied to the core structure comprising elements 1, 2 and 3, a voltage is produced between terminals 23 and 24. This output voltage may be due to either the hysteresis of the core material or due to the change in the permeability of the core material or both as described in the above-identified publication by Peterson. All of the above-identified publications are hereby made a part of this application as if fully included herein.

For a more detailed description of the response of ferromagnetic material in weak magnetic fields and the application of Rayleigh's law, reference is made to a paper published in Physics for July 1935, vol. 6, pp. 215-226 by Ellwood, entitled

"Magnetic hysteresis at low flux densities" and to a paper published in Journal of Applied Physics for May 1937, vol. 8, pp. 313-358 by Ellwood and Legg entitled "Study of magnetic losses at low flux densities in permalloy sheets."

Output terminals 23 and 24 are connected to band-pass filter 11. The band-pass filter 11 may be of any suitable type and as shown in Fig. 1 is designed to pass a frequency range of from 940 cycles to 1060 cycles. This band-pass filter is employed to prevent the higher harmonics and extraneous noise from affecting the operation of the remainder of the system. Band-pass filter 11 may be of any suitable type typical examples of which are described in detail in United States Patents 1,227,113 and 1,227,114 granted to Campbell on May 22, 1917, or any suitable modification of such filters. The output of the filter 11 is connected to an amplifier 12 which is capable of amplifying the frequency band passed by filter 11. Such amplifiers are well known and operate in their usual manner when employed in combination with the other elements of the present invention. The output of amplifier 12 is connected to the input circuit of a mixer or modulating device 13. A source of alternating current 10, which may be 1000 cycles in the specific embodiment shown in the drawing, is also connected to the mixer 13 through a suitable attenuator 14. The attenuator 14 may be of any suitable type and usually comprises a resistance network, certain elements of which are usually variable.

Mixer 13 combines the output of amplifier 12 and the output of the attenuator 14 so as to obtain an output which is a product of the input from the amplifier 12 and the attenuator 14. The mixer or modulator 13 may be of any suitable type which are well known as mixers or first detectors in the so-called "heterodyne" or "super-heterodyne" radio receivers. Receivers of these types are described in greater detail in "Principles of Radio Communication" by Morecroft, third edition, 1933, on pages 1035 through 1040, also pages 634 through 646 and 765 through 774. For more modern mixer circuits reference is made to chapter 15, pages 99 through 114 of "The Radiotron Designer's Handbook," third edition, by F. L. Smith.

The output of mixer 13 is connected to two filters 15 and 16. Filter 15 is a high-pass filter while filter 16 is a low-pass filter. These two filters may be designed and connected together in any suitable manner, as for example, as described in greater detail in United States Patent 2,076,248 granted April 6, 1937, to Norton which patent is hereby made a part of the present disclosure as if fully included herein. The high-pass filter 15 is connected to an output amplifier 17 which is in turn connected to any suitable detector or receiving device 18 responsive to the low frequency signalling current. In the exemplary embodiment of the invention described herein this low frequency current may be either a 25 or 50-cycle current or both depending upon the bias or operating point of the core. Device 18 may include any suitable receiver such as a headset, sounder, recorder, or printer, as for example, a printer of the type shown in United States Patent 1,904,164 granted to S. Morton et al. on April 18, 1933.

Low-pass filter 16 is designed to pass all frequencies below some critical frequency which critical frequency is below the desired signalling frequency. Assume for purpose of illustration that filter 16 passes all frequencies below 10 cycles. In view of the fact that the interfer-

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ence usually encountered in systems of this type is of a low frequency, high and low-pass filters will be sufficient to separate the signals and interference. In case high frequency interference is also encountered a band-pass filter may be employed for filter 15 and a band elimination filter for filter 16 as will be readily understood by persons skilled in the art.

The output of filter 16 is connected through a manually controlled direct current power supply device 24 to amplifier 19 which amplifier is a so-called direct current amplifier because it will amplify continuous as well as alternating current voltages and produce a continuous as well as an alternating current voltage or current output. The output of amplifier 19 is connected to a phase control circuit 20 which is provided to properly control the phase of the current to be fed back to the windings 25 and 26 on the core sections 1 and 2 respectively so the entire detecting arrangement will be stable. For a more complete description of a phase control equipment 20 and the requirements thereof, reference is made to an article entitled "Relation between attenuation and phase in feedback amplifier design," by H. W. Bode, in the Bell System Technical Journal, vol. 19, July 1940, beginning on page 421, which article is hereby made a part of the present application as if fully included herein.

As shown in the drawing, the output of the phase control apparatus 20 is connected to a manually controlled direct current power supply. In the exemplary embodiment of this invention shown in the drawing, the manually controlled power supply comprises two batteries 22 or other suitable source of direct current and a manually controlled potentiometer 23. The manually controlled power supplies 21 and 24 may be employed to control the bias or operating point of the core of the device. The manually controlled supply 21 may also be used to relieve the amplifier 19 and the remainder of the system of a large part of the burden of providing the very low frequency and direct current necessary to counter-balance the earth's field. Usually supply 21 will be employed to reduce the output required from amplifier while supply 24 will be used to accurately control the bias or operating point of the magnetic material of the core structure of the entire device. If the device is located aboard ship and supply 21 is used to reduce the burden on amplifier 19 it will be necessary to provide a chart or table or both, showing the position of the ship as well as its bearing and indicate the proper setting of the manually controlled power supply system.

As will be readily understood by persons skilled in the art, the manually controlled supply 21 may be completely eliminated by providing properly designed amplifier, filters, and phase control circuits if it is so desired.

The output of the phase control and manual supply system is connected to coils 25 and 26 surrounding the core sections 1 and 2 respectively and are so connected as to produce a flux which is in opposition to and neutralizes the flux produced by the external magnetic field applied to the core structure 1, 2 and 3.

In operation, the core structure 1, 2 and 3 is mounted in a position so as to be subjected to the electromagnetic field which it is desired to receive from. When an external field is applied to this core structure, voltages will be induced in leads 23 and 24 which voltages are amplified by amplifier 12 and then demodulated by mixer 23 so that

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a voltage related to the value of the applied field is obtained from the output of mixer 13. The high frequency or signalling component of this voltage passes through the high-pass 15 and amplifier 17 to the receiver 18 while the low frequency component passes through filter 16, amplifier 19, manually controlled power supply 24, phase control apparatus 20, the manually controlled direct current supply circuit 21 to windings 26 and 27, where these currents tend to balance out the steady and low frequency components of the applied field. In this manner cores 4 and 5 are in effect subjected to only the signal field or fields having frequencies of the desired signalling frequency band. In this manner it is possible to maintain the total flux through the cores 4 and 5 to an extremely low value and thus provide the maximum sensitivity for the device.

In case it is desirable to apply a small bias to the core structure it will be necessary to accurately control the magnitude of the bias so that the total net or effective field applied to the core will not extend beyond the desired region. Furthermore, it is necessary to accurately control the operating point to increase the stability and reliability of operation of the device.

In order to apply a bias to the core source 21 or more usually 24 will be adjusted to supply a small voltage which will either add to or oppose the earth's field. The effect of this voltage will be reduced due to the operation of the feedback circuit. However, a small fraction of this voltage will still be effective and act as a small bias for the core structure. Under these circumstances the operation of the remainder of the circuits and apparatus will be as described above.

Due to the degenerative action of the feedback arrangement the effect of small changes in the magnitude of sources 21 and 24 are reduced so that the bias is accurately maintained at the desired level and at the same time the effects of stray fields and currents, including the earth's field, is largely balanced out of the core so its sensitivity to the desired field or signals will be maintained.

In the foregoing description reference has been made to specific types of equipment suitable for use in combination with the other elements of the present invention. Persons skilled in the art, however, will readily appreciate that many other types of equipment and apparatus are suitable for the various components of the present invention and may be employed therein without material modification. This invention is accordingly not limited to any of the specific devices specifically referred to above.

What is claimed is:

1. In a communication system a receiving device comprising an elongated core of ferromagnetic material, a center portion thereof having a high rate of change of permeability with low values of field intensity, means for applying a low amplitude high frequency field to said core, a receiving amplifier, windings on said core connected to said amplifier, and feedback windings also upon said core connected to said amplifier for neutralizing the effects upon said core of all fields applied thereto except a field having the same frequency as the signalling frequency of said system and except said high frequency field.

2. A receiving device responsive to electromagnetic waves comprising a core of ferromagnetic material, means for providing a plurality of magnetic paths through a portion of said core, apparatus for applying a low intensity high fre-

quency field to each of said paths in different directions or phases, output windings interlinking said magnetic paths and connected in such a manner that no output voltage is developed across said windings when no external field is applied to said core, an amplifier connected to said output windings, feedback windings also interlinking the said core, operative connections between said amplifier and said feedback windings for neutralizing the effects of all external fields upon said core and means rendering said neutralizing windings ineffective at the signalling frequency of said system.

3. In a telegraph system a receiving device comprising a long core of ferromagnetic material, a center portion thereof having a plurality of magnetic paths and composed of ferromagnetic alloy having a high rate of change of permeability at low values of field intensity, a source of relatively high frequency alternating current, windings interlinking said plurality of paths connected to said source of high frequency current for applying to said magnetic paths an alternating current field of low intensity in the region where the hysteresis loop of said material is defined by Rayleigh's law, output windings interlinking said magnetic paths, a receiving amplifier connected to said windings, filter networks connected to said amplifier, a receiving device connected to said filter networks, and feedback windings interlinking said core also connected to said network for maintaining the total field within said magnetic material in all except the signalling frequency range and the frequency of said source within the region wherein the hysteresis loss is defined by Rayleigh's law.

4. In a telegraph system a receiving device comprising a long core of ferromagnetic material, a center portion thereto having a plurality of magnetic paths and composed of ferromagnetic alloy having a high hysteresis coefficient at low values of field intensity, a source of relatively high frequency alternating current, windings interlinking said plurality of paths connected to said source of high frequency current for applying to said magnetic paths an alternating current field of low intensity in the region where the hysteresis loop of said material is defined by Rayleigh's law, output windings interlinking said magnetic paths, a receiving amplifier connected to said windings, filter networks connected to said amplifier, a receiving device connected to said filter networks, feedback windings interlinking said core also connected to said networks for maintaining the total field within said magnetic material in all except the signalling frequency and the frequency of said source range within the region wherein the hysteresis loss is defined by Rayleigh's law, and a manually controlled source of direct current connected in said feedback windings for neutralizing the effect of the constant portion of earth's magnetic field upon said core.

5. Apparatus responsive to electromagnetic fields comprising a core structure including end sections and a center section, a plurality of magnetic paths extending between each of said end sections through said center section, alternating current power supply windings interlinking said paths through said center section, a source of relatively high frequency alternating current, interconnections between said source and said windings for supplying a relatively high frequency alternating current field of low intensity to each of said plurality of paths in a different phase relation, output windings also interlink-

ing the plurality of said paths and connected so that no output potential difference is developed across the output terminals thereof when no external field is applied to said core, an amplifier connected to said output terminal, a mixing or modulating device connected to the output of said amplifier and to said high frequency source for developing a voltage having a frequency which is the difference between the frequency of said output voltage and the frequency of said high frequency current, filter equipment connected to the output of said mixing equipment for selecting the signal frequency thereof, feedback windings also interlinking said core, connected equipment for connecting said feedback winding to said feedback equipment so as to feedback all frequencies except said signal frequency and the frequency of said source, and phase control equipment for causing the phase of all of the feedback currents to substantially neutralize all the external fields applied to said core except the signaling frequency.

6. A magnetic device responsive to magnetic fields comprising a core structure of laminated ferromagnetic material, a source of high frequency alternating current power supply for said device, power windings connected to said source and interlinking said core, output windings also interlinking said core and connected to output terminals for developing a voltage between the output terminals which is a function of the external field applied to said core, a mixer or demodulator connected to said output winding terminals and to said source of high frequency alternating current for deriving an output having a wave form substantially the same as the wave form of the applied external magnetic field.

7. A signal receiving device, comprising a core of ferromagnetic material, alternating current power supply windings interlinking said core, output windings interlinking said core and connected to develop an output which is jointly a function of said power supply alternating current and all other magnetic fields to which said core is subjected, a mixer or demodulator connected to said output windings and provided with a power input terminal for deriving an output having a wave form substantially the same as the wave form of the magnetic field to which said core is subjected exclusive of the field created by said power supply windings, feedback windings interlinking said core, filter and phase control networks connected between said mixer and said feedback windings for reducing the field to which said core is subjected except for specified frequencies or frequency ranges.

8. A magnetic device responsive to external magnetic fields comprising a core of ferromagnetic material, a source of alternating current having a frequency which is high compared to the frequencies of said external field to which said device is responsive, power windings interlinking said core, output windings also interlinking said core for developing a voltage which is a function of the external field applied to said core, feedback windings also interlinking said core, a feedback circuit extending from said output terminals and including said feedback windings to supply current to said feedback windings to neutralize a portion of the effect of the external field applied to said core, a direct current source of potential connected in said feedback circuit to apply a bias to said core through said feedback windings.