Jan. 11, 1944. W. J. POLYDOROFF 2,339,234

DIRECTIONAL ANTENNA SYSTEM

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Fig. 1.

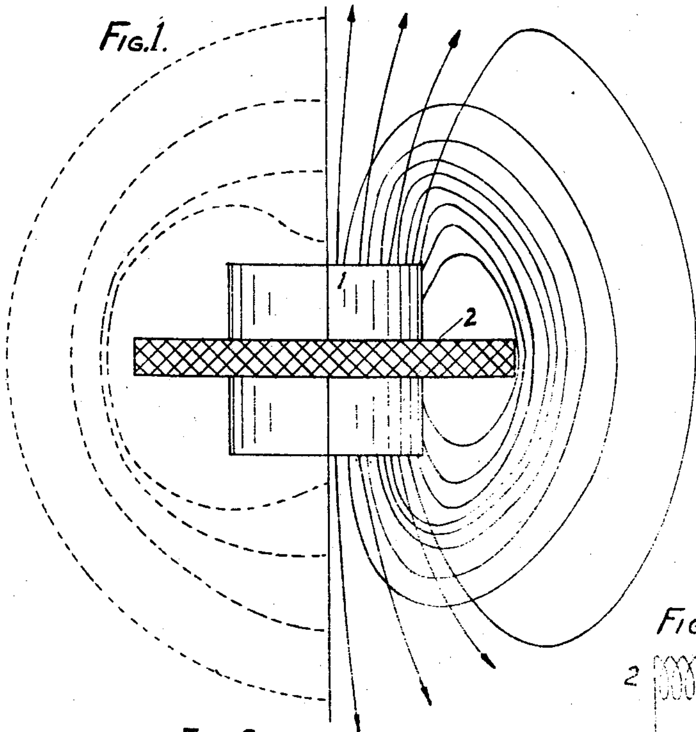

Fig 2

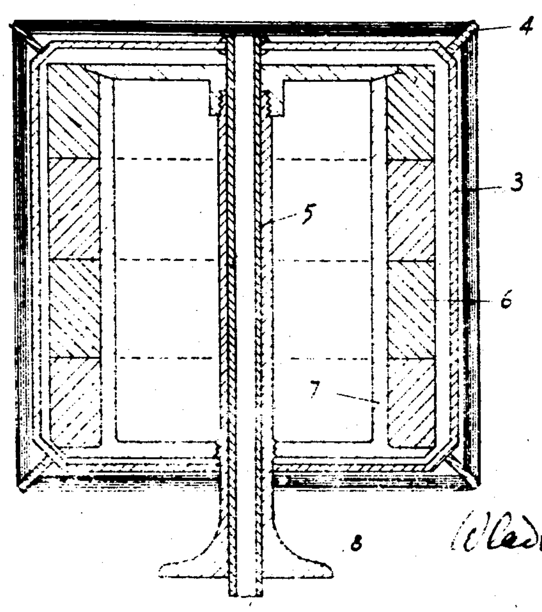

Fig. 2b.

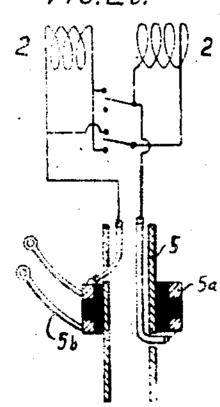

Fig 2a

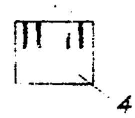

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FIG. 3.

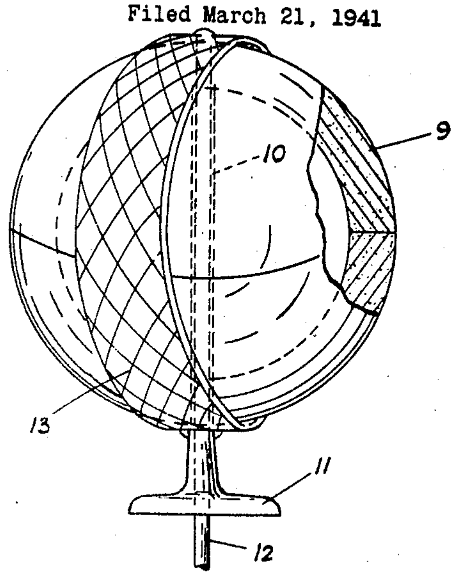


FIG. 4.

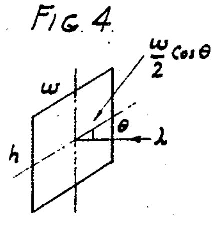


FIG. 5.

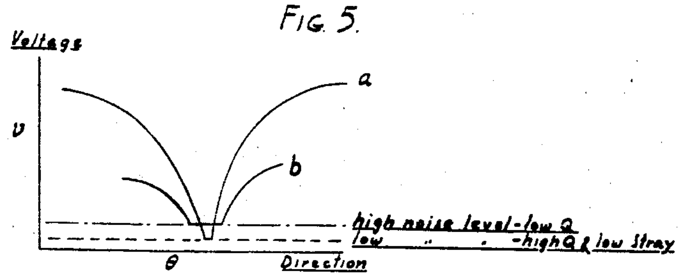


FIG. 6.

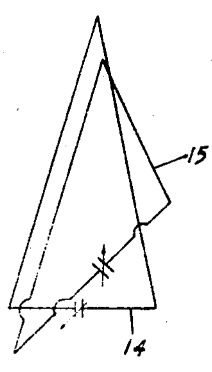
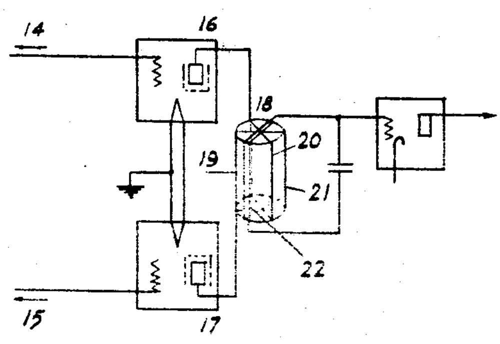


FIG. 7.



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UNITED STATES PATENT OFFICE

2,339,234

DIRECTIONAL ANTENNA SYSTEM

Wladimir J. Polydoroff, Wilmette, Ill.

Application March 21, 1941, Serial No. 384,525
In Great Britain March 21, 1940

6 Claims. (Cl. 250—33)

The present invention relates to frame or loop antennae for high frequency reception and/or transmission of electromagnetic waves. Until recently such antennae employed an appropriate number of turns wound on a frame of insulated material and may be termed "air cored" antennae, as distinguished from iron cored coil antennae as described in United States Letters Patent 2,266,262 of Dec. 16, 1941, to Polydoroff.

The present invention has for its object, new constructions and new uses of this type of coil antennae which employ high frequency comminuted magnetic materials in the form of magnet cores associated with the coils. As mentioned in the above patent such antennae are usually arranged to act substantially as collectors or radiators of the electromagnetic energy.

The invention will be better understood if reference is made to the accompanying drawings in which:

Fig. 1 diagrammatically shows field distribution around the device of the present invention;

Fig. 2 shows construction of a loop antenna in accordance with the invention and Figs. 2*a* and 2*b* constructional details of Fig. 2.

Fig. 3 shows a modification of the invention.

Figs. 4 and 5 diagrammatically show the directional functions of the devices of the invention and

Figs. 6 and 7 show an apparatus in which the invention is also applicable.

It has been shown in the above patent that the presence of a ferromagnetic mass in the field of a coil may substantially improve the electrical quality (Q) of the coil which improvement by itself increases pick-up and directional properties of the coil, provided that both coil and the core are proportioned in the way of choice of particle size, Litz wire and the spacings between the wires and the core. Moreover the effective height of the antenna is increased in direct proportion to the effective permeability of the core in the given coil; which phenomena may be explained by the increase, either by induction or by attraction, of magnetic lines threading through the core with the result that greater voltage is generated in the coil.

It follows from the above that the core need not be an integral part of the antenna. The magnetic mass may be now regarded as an inducer or final source of the electromagnetic energy and the coil merely as the collector from this source, if it happens in the vicinity of the mass. The core, however, produces another function if it is close enough to the coil, viz. it changes the configuration of the coil fields which in return affects the directional properties.

The examination of Fig. 1, which represents a plot of field intensities of a coil antenna (dotted lines on the left half of the coil) and a resultant line pattern of the fields plainly shows a directional condensation of the lines in such coil antenna. The removal of the core will result in spreading of the lines in all directions and greater number of "stray fields," of which three lines are shown in the figure when iron core 1 is inserted in the coil 2. This diagram explains the improvement in directional properties of a radio compass equipped with iron core antenna, where it is known to seek the direction by the null point or zero signal occurring when the plane of the coil is perpendicular to the source of radiation. This improvement of directional properties is apart from and additional to the improvement due to the increase of pick-up properties through increase of Q and effective height.

It is further evident that employment of an asymmetrical mass in the coil may displace the main directional axis of the coil towards the mass so that direction readings will be somewhat displaced with relation to the physical axis of the coil. If therefore a coil is arranged to rotate about an asymmetrical mass, at some positions where magnetic and physical axis coincide the reading will be correct, while at other positions a certain deviation may occur.

It is known that radio directional compass placed on board a ship or an aircraft may produce some errors of observation which are due to the deflection of the true direction of the wave front because of interfering metal parts in close vicinity of the compass.

Here it may be found useful to employ core pieces which are asymmetrical with respect to the coil, and which come closer to or further from the windings when the loop is rotated thus causing a deflection in direction finding of exactly opposite sense.

In a coil already equipped with an iron core, the core may be made stationary and the loop made rotatable around the core, as will be later described in detail, but the core will be slightly asymmetrical to produce a desired deviation.

Care should be taken that the compensating pieces or those parts of the main core which are asymmetrical, do not cause a substantial inductance variation and de-tuning of the circuits associated with the loop. Such deviation will not affect the tuning of the compasses employing an aperiodic loop coupled to a tuned circuit, and therefore is mostly suitable for such systems.

Further examination of the coil antennae shown in Fig. 1 establishes the fact that better directioning of lines of field results from an elongated core. A core of this type represents considerable added weight, particularly if the whole antenna is made rotatable. It is possible, however, to so re-distribute the mass of the core that substantially the same results are obtainable with less core material if the core is made with relatively thin walls adjoining the winding only and the core mass extended lengthwise so that the same or higher permeabilities will result, with improved directional properties. In line with the above discussion new constructions of rotatable loop antennae are shown in Fig. 2 and Fig. 3. Both figures show symmetrical type of cores, i. e. such that coil can be rotated around the core without any change in inductance, provided of course that the magnetic mass distribution is uniform throughout the magnetic structures.

Referring now to Fig. 2, the coil comprises a rectangular frame, preferably the square **3**, of good insulating material, having four diagonally placed spacers **4** with slots to provide for laying the wire in several sections. The wire may also be laid so as to form a loose basket weave of several layers. A cross-section through one of the spacers **4** is shown in Fig. 2*a*. A hollow shaft **5** is secured to the frame **3** to control rotation of the frame from a remote point. The hollow shaft **5** may carry inside lead-in-wires connected at the bottom to slip ring **5***a* which are in contact with the brushes **5***b* to which a cable could be attached, as shown in Fig. 2*b* from the coil. The magnetic core **6** is moulded in toroidal sections which in the present case are 4 inches external diameter, 3 inches internal diameter and 1 inch long so that four rings form a cylinder 4 x 4″ with a wall thickness of ½″. The core sections are cemented to a Bakelite drum **7**, preferably moulded in one piece, having an inner tube to house shaft **5** and a flange **8** for permanent installation on a ship or aircraft. If the magnetic mass is uniform, or is made uniform by rotating the individual core sections before they are cemented, the frame coil **3**, **4**, can be rotated 360 degrees without altering the inductance. Experiments prove that such arrangement provides a very satisfactory rotatable loop for a radio compass.

In the antennae of the frame type only the vertical wires contribute to directional quality, the balancing of the frame to zero signal resulting in two signals of equal strength but opposite phase in the vertical branches. Since the improvement in directional qualities as already explained is due to the iron in the immediate vicinity of the acting conductors, the distribution of the iron also appears to be a factor producing optimum conditions. The magnification factor or Q of the frame antenna with the thin walled iron core is about 400 when measured at 300 kc. A slight improvement in Q will result with a solid core. It is only at the null point where the greater signal strength of the loop is appreciated, because it enables the operator to obtain more accurate bearing due to the "zero signal" being well above the noise level, the signal off direction being usually ample in all cases to detect the presence of a radiating station. Therefore both the increase of signal due to permeability and sharper directional properties due to iron mass produce the results equivalent to a double loop. If in accordance with the findings of this invention we may assume the increase in total directional properties to be of the order of 100% it means that the results obtainable with the loop of Fig. 2 may be duplicated with an air-cored loop of much larger size.

Fig. 3 shows another form of rotatable loop with a fixed core. The core in this case is composed of two sections which when cemented and clamped together form a hollow sphere **9**. Both hemi-spheres may be moulded and are held together by a hollow bolt **10** with a foot **11**. A control shaft **12** passing through the bolt rotates the loop **13**, which in this case is wound on a ring of polystyrene, the wire being laid so as to form a loose basket weave of several layers resembling so-called universal coils.

There are known many cases of radio compass construction where aperiodic loop collectors are employed for directional finding. A few turns of wire are arranged in the form of a loop to pick-up the signal, the energy being delivered through a step-up transformer to a tuned circuit of high Q. The Q of the antenna coil is reflected into the tuned circuit but represents a small percentage of the total Q and is therefore relatively unimportant. However both the directivity and pick-up properties of the coil are very essential for the successful operation of such system. The above described constructions are particularly adaptable to aperiodic loops since with a small number of turns, laid close to the core much higher effective permeabilities are obtainable thus improving the operation of such system. A light-weight coil may be employed for automatic self-orientation.

I have found experimentally that directional selectivity does not depend upon the shape of the loop or frame and this agrees with the results obtainable from the mathematical analysis of directional properties of loop antennae.

If the intensity of an electromagnetic wave is E and the voltage generated in the coil is V the ratio

$$\frac{V}{E}$$

known as pickup factor is related to a coil antenna:

$$\frac{V}{E}=\frac{2\pi hwN\mu}{\lambda}\cos\theta$$

where h and w are coil dimensions, θ the angle between the plane of the loop and direction of wave front, as illustrated by Fig. 4; N is the number of turns of the coil and μ is effective permeability of the iron. Since hw represents the area A of the coil it is usual to designate the term:

$$\frac{2\pi AN\mu}{\lambda}$$

as the effective height h_{eff}; if additionally the loop or loop circuit is tuned then the voltage V is further magnified by Q. Thus we arrive to an expression for voltage

$$V=E.h_{eff}.Q.\cos\theta$$

This shows that for a given wavelength and E, the voltage V generated in the loop is directly proportional to h_{eff}Q and with loop rotation it will vary as an inverse cosine curve. In all cases a theoretical null point is limited by the noise limit of the circuits and of associated tube.

By plotting the voltage versus direction for a strong V resulted from high h_{eff}Q and limiting it at the bottom by the noise level we arrive to certain selective properties of the loop shown by the curve *a* in Fig. 5. On the same scale another voltage V' is plotted resulting from the same signal but lower product of $h_{eff}Q$ the curve *b* representing the directivity in this second case.

It is obvious that the higher product $h_{eff}Q$ is the sharper will be the direction. In particular Q is important since it increases the amplitude and decreases the noise level. Additional increase of μ by elongated shape of the core decreases the stray fields of the coil also contributing to the steepness of the curve.

In aperiodic loops a small number of turns is employed to form so-called low impedance loops which are usually coupled through a low impedence cable to the primary of a transformer, the secondary of which is tunable.

The signal generated by such system is again proportional to $Q''h_{eff}$; which affects the pick-up properties of the loop, as well as its directional properties in accordance with the diagram of Fig. 5. The effective height,

$$h_{eff}=\frac{2\pi N.A.\mu}{\lambda}$$

indicates that at lower wavelength h_{eff} is decreased. The inductance of aperiodic loops is usually kept small consistent with ability to tune the system to a shortest wavelength and it is usual in the directional finding systems to connect such a low impedance loop to a series of transformers each covering a certain range of wavelength (frequency), by means of suitable switching mechanism. Such system while producing a sufficient pick-up for the higher frequency range is detrimental for the lowest frequencies. The existing system employs a loop in which it is possible to improve the loop performance by providing a loop of an increased number of turns suitable for the lowest frequency ranges. When the same loop is switched to the higher frequency ranges the outer terminals of the loop are connected together thus forming a single loop which has two sections paralleled. This expedient enables to increase the efficiency of the system at all frequencies. Such arrangement is illustrated on Fig. 2*b*.

The value of Q'' which enter the above formula is now a compound quantity and is determined as follows:

Assume that a secondary winding of the transformer per se has a certain Q when the primary winding is open.

When the primary winding is connected to the low impedance loop the Q' drops down considerably, in some cases to such extent that it is no longer profitable to employ efficient coils. This drop of Q' is attributed to the transfer of losses from the primary circuit into the secondary circuit and to the short-circuiting effect which latter is additionally manifested by the accompanying drop in the inductance. If a certain E. M. F. is injected in the loop such as being the case of the actual operation this E. M. F. is firstly stepped up by the transformation ratio of the transformer, η and by the Q' of the secondary circuit so that $Q''=Q'.\eta$. This new value of Q'' enters into the equation for generated voltage V in the case of low impedance loop circuit and it has been found that in order to get high Q'' small number of turns of the primary winding should be employed in a tight coupling iron cored transformer of the closed type.

The constructions of Figs. 2 and 3 may be advantageously applied to the Bellini Tosi system. The advantage of Bellini Tosi system as against a single rotatable loop lies in the fact that the observation of maximum signal, rather than minimum signal, of the loop indicates the direction of the sending station.

Two vertically elongated loops are placed with their planes at right angles as shown in Fig. 6 and both loops are loosely coupled by auxiliary coils to a rotatable coil. The coupling must be weak and the efficiency poor to avoid reaction between two antennae, as such reaction will result in poor directional properties. The two loops **14** and **15** feed independently through screened grid type tubes **16** and **17** to a common goniometer **18**. Reaction is entirely eliminated and the plate windings **19** and **20** are wound close to an iron core **21** of cylindrical type, such as in Fig. 2, (or of spherical type as in Fig. 3). The third winding **22** constitutes a secondary of tunable type and is therefore capable of high gain and is made rotatable around the iron core cylinder, such as in the case of the coil **3**, **4** of Fig. 2. Of course the whole construction may be made considerably smaller, consistent with high Q of the rotatable coil in the small space. Experiment shows that if the two primary windings **19** and **20** are wound directly on the core **21** at exactly 90° there will be no reaction between two circuits.

A high degree of directional selectivity by maximum observation is obtainable due to the preamplification of the signals, additional high Q of the rotatable circuit and exact location of the fields at right angle without scattering of strays.

Having now described my invention, what I claim is:

1. A directional system for the reception of electromagnetic radiations including a rotatable coil antenna a stationary ferromagnetic core in the field of said coil and composed of comminuted magnetic particles, said core being of such shape relative to the coil that at any angular position of rotation of said coil the magnetic reluctance remains substantially constant.

2. A directional system for the reception of electromagnetic radiations including a rotatable coil antenna of a rectangular shape a stationary ferromagnetic core of cylindrical shape the axis of the cylinder and the axis of rotation of the coil being identical.

3. A directional antenna for the reception of electromagnetic radiated energy comprising a stationary ferromagnetic mass in the field of said radiations in the form of a body of rotation, pick-up coil antenna rotatable around said mass the axis of the body and of the coil being identical.

4. A directional system for wireless communication comprising a stationary ferromagnetic mass in the form of a hollow body of rotation a coil antenna arranged to rotate around said mass, the axis of rotation of the coil being identical with the axis of said body.

5. A directional system for the reception of electromatic radiations comprising a rotatable coil antenna, a ferromagnetic core disposed in the field of said coil symmetrically to the axis of rotation of said coil, additional ferromagnetic core means placed asymmetrically to said axis to thereby cause a deviation of bearings of said directional system in the desired position of said antenna.

6. Directional system as per claim 5 characterized in that said additional ferromagnetic core means are adjustable.

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