Dec. 16, 1941. W. J. POLYDOROFF 2,266,262

ANTENNA SYSTEM FOR WIRELESS COMMUNICATION

Filed Sept. 13, 1939 2 Sheets-Sheet 1

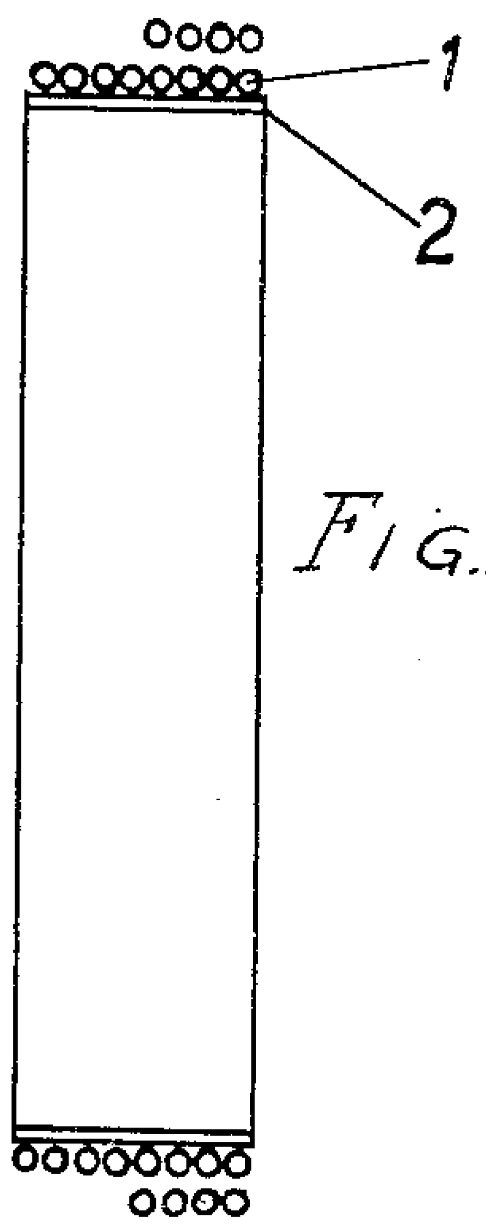


FIG. 1.

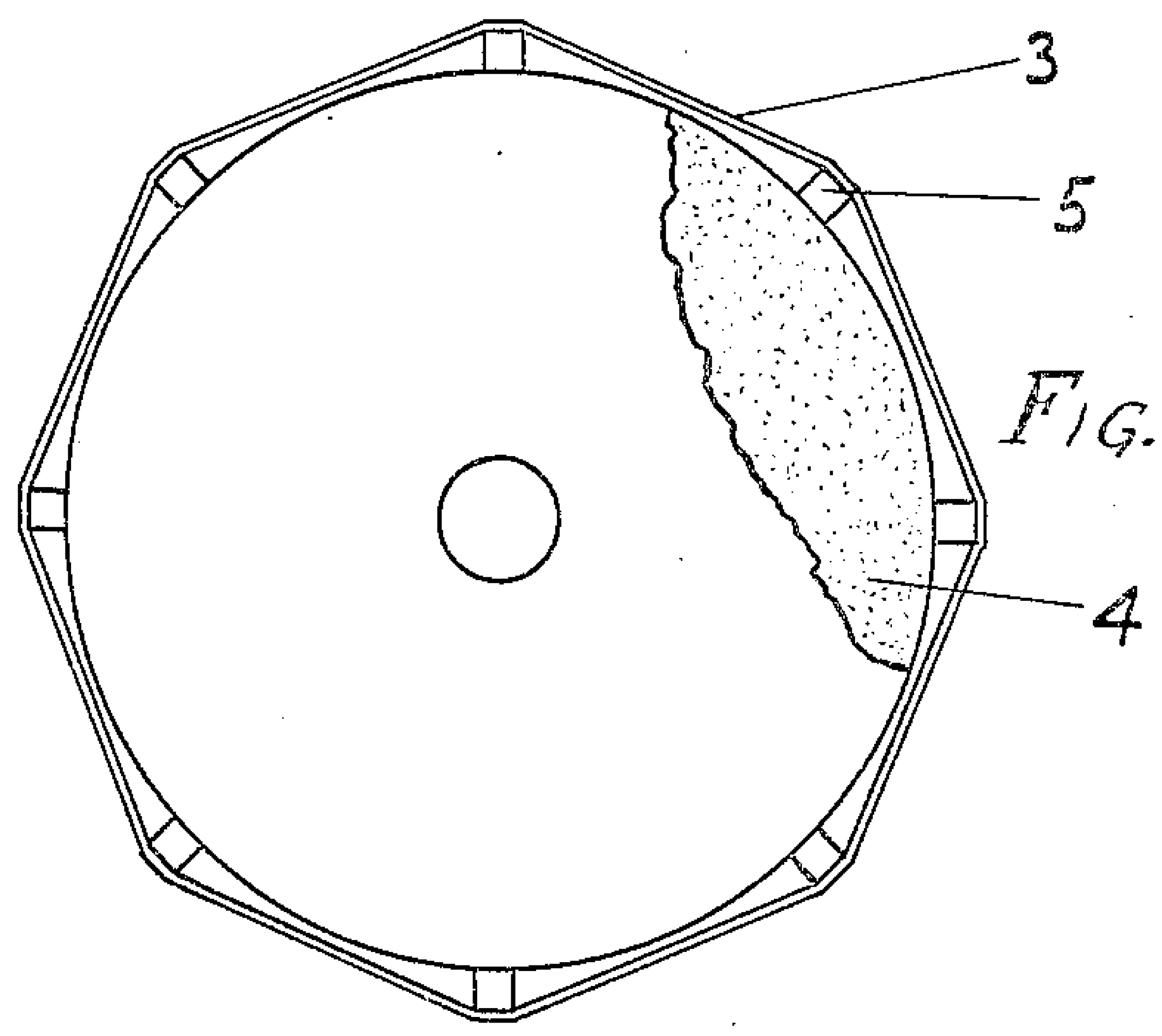


FIG. 2.

FIG. 3.

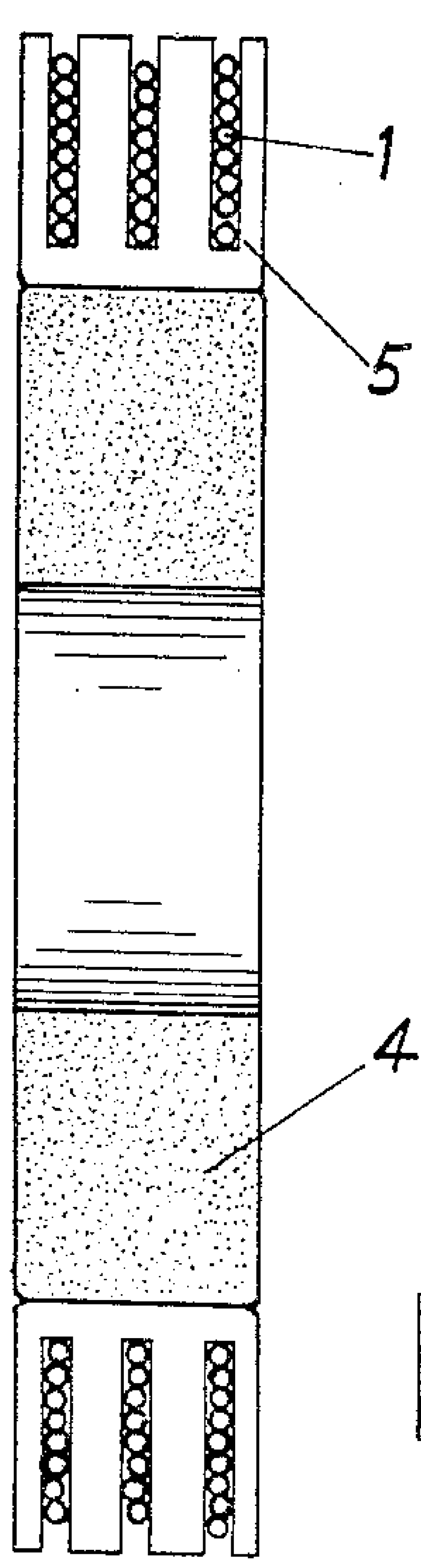


FIG. 4.

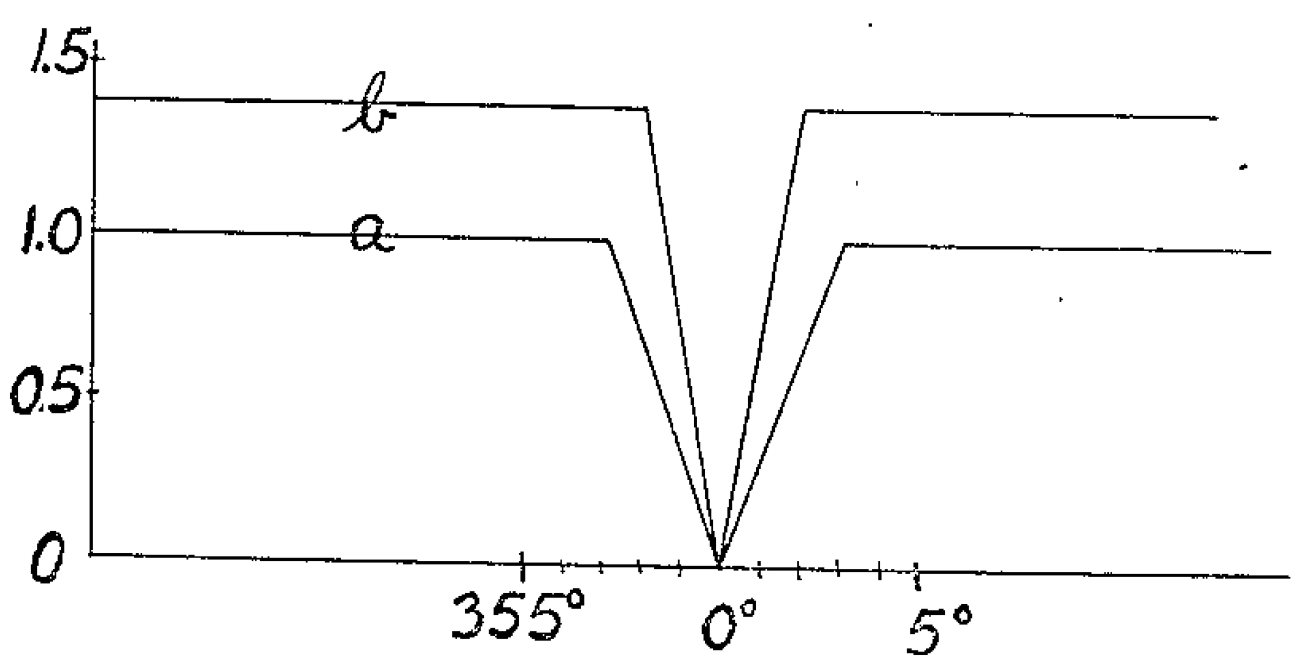
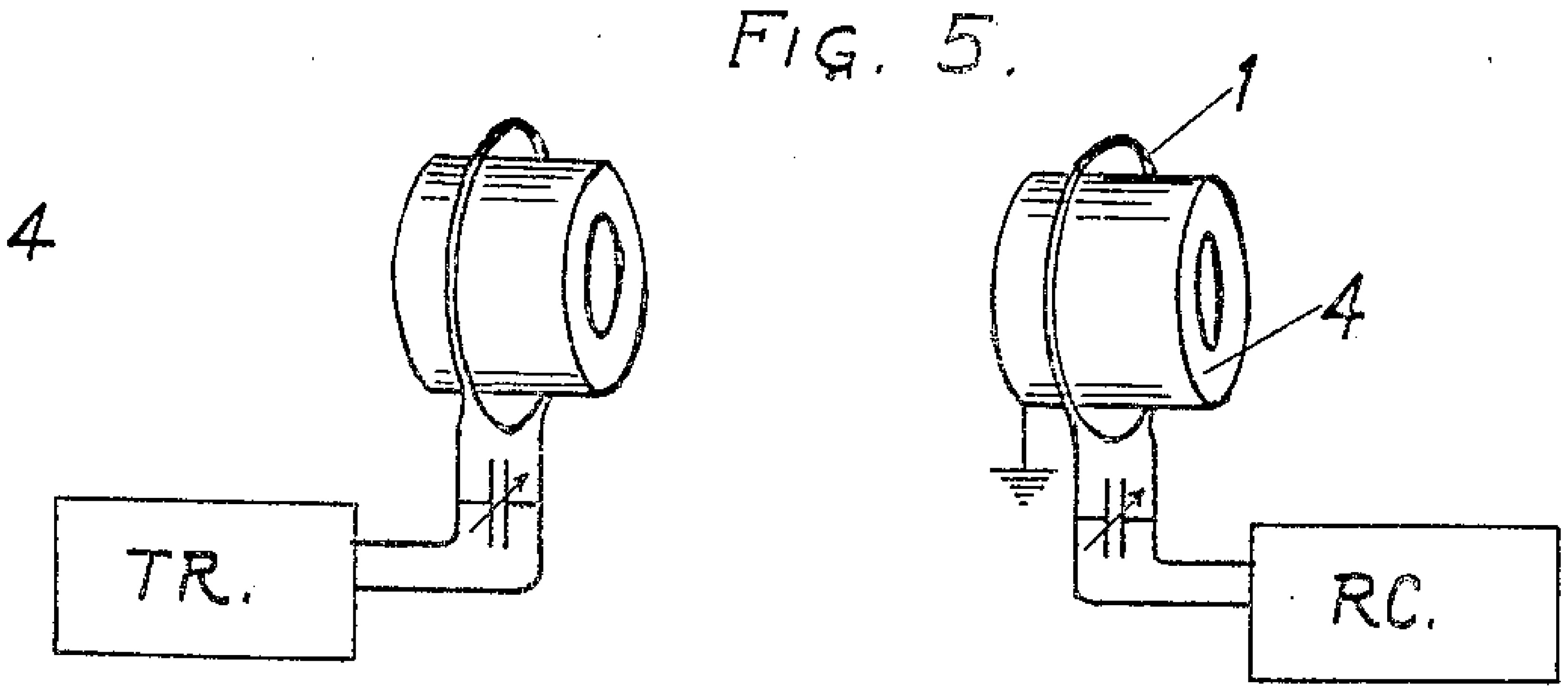


FIG. 5.



INVENTOR.

Wladimir J. Polydoroff

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ANTENNA SYSTEM FOR WIRELESS COMMUNICATION

Filed Sept. 13, 1939 2 Sheets-Sheet 2

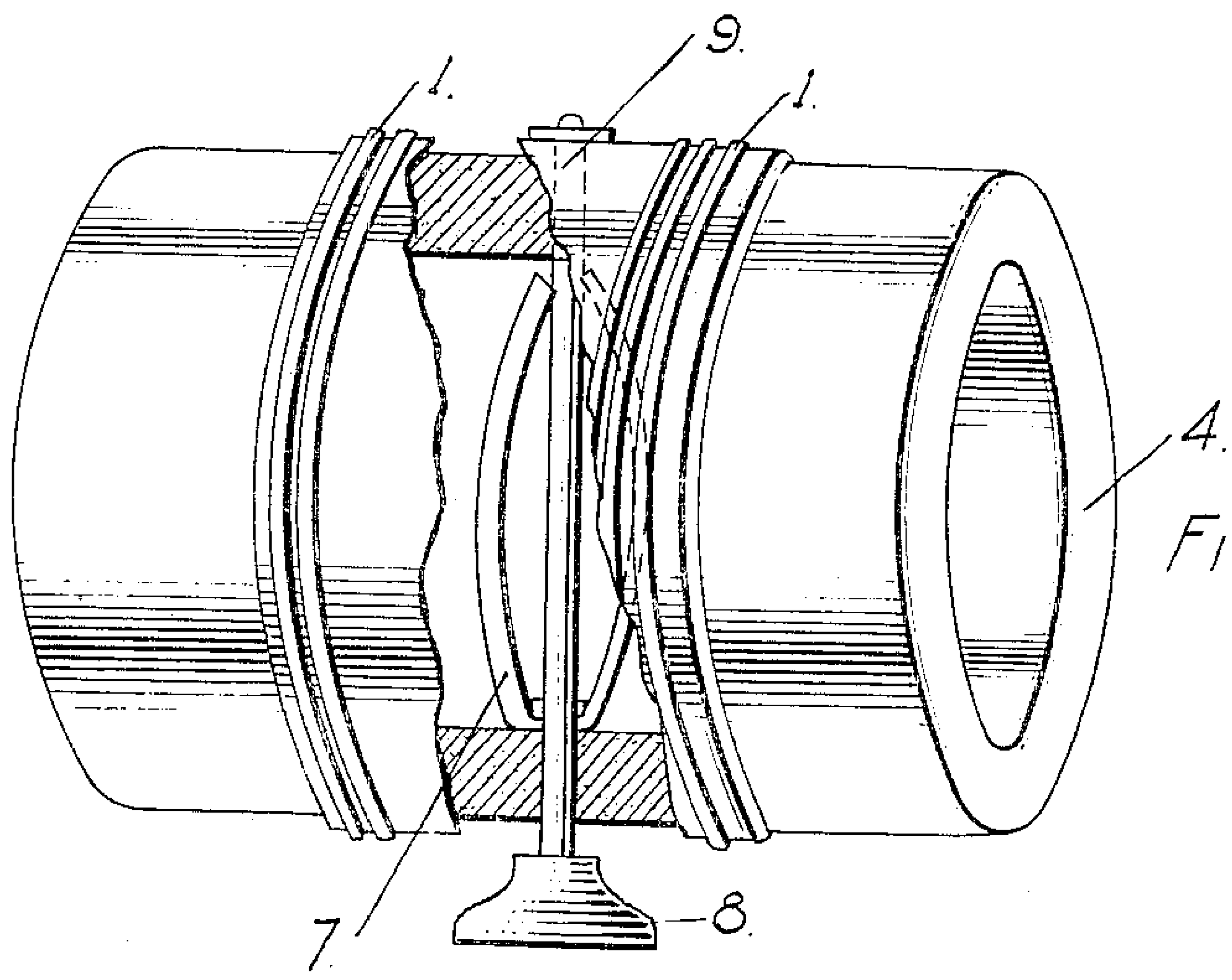
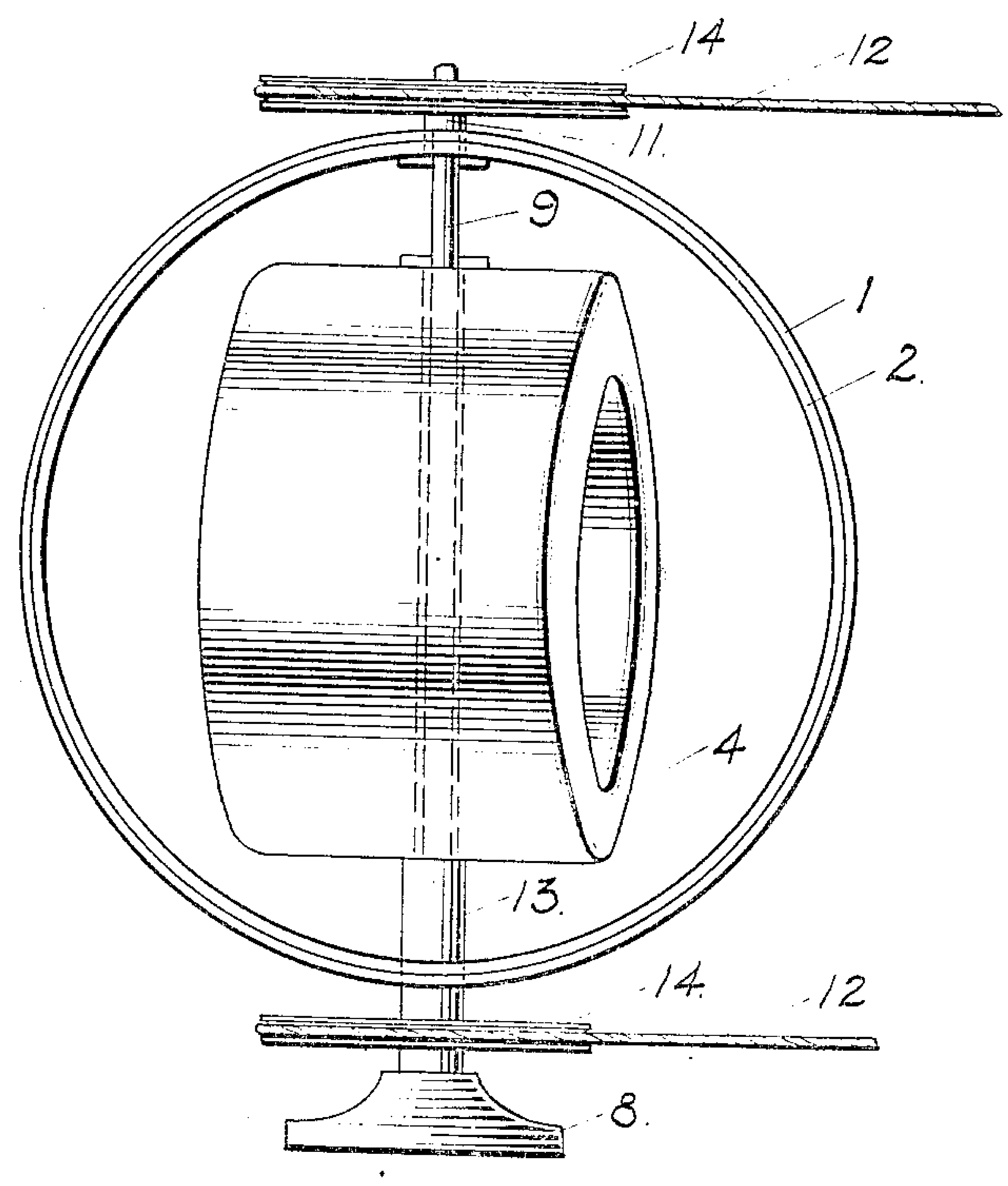


FIG 6

FIG. 7.



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UNITED STATES PATENT OFFICE

2,266,262

ANTENNA SYSTEM FOR WIRELESS COMMUNICATION

Wladimir J. Polydoroff, Wilmette, Ill.

Application September 13, 1939, Serial No. 294,723
In Great Britain December 13, 1938

11 Claims. (Cl. 250—33)

This invention relates to a "frame aerial", or loop antenna, which consists of several turns of wire wound on a frame. Such an antenna is often connected with a capacitor and thus forms an oscillatory circuit capable, when properly adjusted, of being more responsive to a desired frequency than to other frequencies. A similar oscillatory circuit may be used in the transmitting stations radiating an electromagnetic wave in which case a loop antenna may serve as a radiator.

Furthermore, this type of aerial possesses directional properties which are manifested by minimum or zero signal when the plane of the aerial is perpendicular to the direction of propagation of the received electromagnetic waves, i. e. when the plane of the aerial is normal to the wavefront of electromagnetic waves. This type of aerial, although not as efficient as a straight antenna, finds its use in portable receivers, direction finders, transmitting beacons, airplane installations, etc. where a straight antenna cannot be conveniently employed, but where the antenna should be responsive to waves whose wavelengths are relatively long compared with the linear dimensions of the antenna.

Usually the coil of a frame aerial is designed to have a desired natural period of electrical oscillation or fundamental wave-length below the wave-length of the waves to be received, and from the viewpoint of efficiency it is advantageous to employ a large turn-area, which, on the other hand, is limited by the distributed capacity of the coil. This capacity is usually large in coils of large dimensions with small spacing between the turns. The distributed capacity limits the tuning range unless very large and bulky tuning condensers are employed, and their use reduces the efficiency of the system and increases the dimensions of the system.

The invention has for one of its objects the production of a frame aerial of high efficiency and in which distributed capacity is minimized. In accordance with the invention the high efficiency and low distributed capacity are attained by the employment of ferromagnetic mass in the field of the loop antenna.

The efficiency of a frame aerial, having an area A and number of turns N may be expressed in terms of "pick-up factor", i. e. the ratio of voltage developed across the coil terminals and the intensity of the electromagnetic wave at the receiver and may be expressed as follows:

$$\frac{V}{e}=\frac{\omega L}{R}\times\frac{2\pi AN}{\lambda}$$

where L and R represent inductance and high frequency resistance of the coil respectively and ω and λ are 2π times frequency and the wavelength of oscillations respectively.

The first term $\omega L/R$ is commonly known as the "Q" of the coil and an increase in "Q" results in greater pick-up and improved selectivity. The second term $2\pi AN/\lambda$ is known as the effective height of the antenna and while an increase in its value due to an increase in AN improves the pick-up of electromagnetic energy, the electrostatic pick-up also simultaneously increases, a fact which is sometimes undesirable. The same formula, a priori, would apply to the transmitting station having a frame aerial as a radiator, in which case the power transmitted in the space will be proportional to the efficiency of the radiator loop and to the turn-area of the frame aerial.

If in the above formula both ω and λ are expressed in terms of frequency, it will be observed that the received signal is proportional to the second power of the frequency, so that the aerial will not have the same performance when used at different frequencies.

Another object of the invention is to equalize the pick-up properties of a loop antenna by the employment of iron or ferromagnetic masses in the field of the coil of such antenna.

Still another object of the invention is to improve the directional properties of a loop antenna which is accomplished by a properly shaped core composed of a ferro-magnetic mass in the field of the coil, said mass materially changing the configuration of the magnetic fields of the coil and reducing the "stray fields" partly responsible to poor directional selectivity. Due to the fact that the losses in the iron rapidly change with frequency it is possible by the use of the iron substantially to equalize the pick-up properties of the frame aerial for all frequencies within the tuning range. The present invention materially improves the Q of the frame aerial and increases its pick-up, while at the same time rendering this latter more uniform throughout the frequency range.

While in theory the improvement of Q and simultaneous reduction of AN tend to maintain the electromagnetic pick-up at the same magnitude, the above stated increase of pick-up is very prominently established by actual observation on comparison of electrically identical loops, which may only be attributed to the new and hitherto unknown behavior of the iron in the coil antenna.

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

Figs. 1 and 2 schematically represent two identical coil antennae, the one of Fig. 2 being equipped with an iron core.

Fig. 3 represents two identical air and iron cored loops of modified construction.

Fig. 4 represents the diagrams of signal strength and directional properties of the invention.

Fig. 5 represents a general layout of the system.

Fig. 6 shows a grounding strip and its application to the invention, and Fig. 7 shows another modification of the invention.

Referring now to Figs. 1 and 2 there are shown two loop antennae of identical dimensions, both wound to the same inductance, the coil 1 of Fig. 1 being wound on a coil form 2 and the coil 3 of the loop antenna of Fig. 2 being wound on a 4 inch core 4 composed of finely divided particles of iron, whose dimensions are of the order of 3 microns and which are compressed and bound together in the well known manner. Bakelite ribs 5 are cemented to the core in order to provide an adequate spacing of the turns from the iron core. It should be noted that both loops have their axial length of 1 inch and for the same inductance, the air core loop of Fig. 1 had 52 turns of Litz cable made of 12 strands of No. 32 wire, while the iron cored loop had 40 turns of the same cable. Since the mean cross section A of both coils is substantially the same, the effective permeability of the core in Fig. 2 can be computed from the ratio of square number of turns, $52^2/40^2$ which is equal to 1.7. The same was additionally verified by measuring the inductance of the second coil with and without the iron core.

The $Q(\omega L/R)$ was then measured in the well known manner at a frequency of 300 kilocycles for which the above loop was designed and it was found to be 190 for the coil of Fig. 1 and 250 for the second coil. Thus an appreciable increase in Q was obtained due to the employment of iron in the coil.

This means that the selectivity of a receiving loop and signal to noise ratio are improved by 30 percent. Further consideration of the term AN of the above stated equation indicates that since A remained the same the second term of this equation is reduced by the ratio of turns. In fact we may write that the pick-up factor ratio for both loops is related as Q_1N_1/Q_2N_2, which yields approximately unity.

$$\frac{190\times 52}{250\times 40}=0.99$$

Both loops should have the same pick-up, or, in other words, the signal received by both antenna from the same source should produce of the same magnitude voltage on the same receiver. Yet the iron cored loop showed an increase in signal strength by approximately 70 percent which increase numerically corresponds to the effective permeability.

To substantiate and verify these findings, two highly efficient loops were built in accordance with Fig. 3. This figure, identical for both new loop antennae, shows a winding 1 arranged in three sections on a 4 inch form (air core) or on a 4 inch iron core. The windings are made of Litz cable composed of 110 strands of No. 42 wire. The coils thus made, one with the air core and the other with the iron core, had an inductance of 680 micro-henries respectively with 60 and 50 turns. The effective permeability of the core in the second example is 1.4, being smaller on account of less complete utilization of the iron. The Q measured at 300 kilocycles was 390 for the air core loop and 470 for the iron core loop. This again yields a 20 percent increase in Q with a resultant increase of selectivity and signal to noise ratio.

As previously figured, the ratio of signal strength of both loops would be substantially unity.

$$\frac{390\times 60}{470\times 50}=0.98$$

The actual measurements again indicated an increase of signal strength in favor of the iron core loop of approximately 40 percent.

The summary of both observations clearly show that the increase of pick-up is numerically equal to the effective permeability of the core. Consequently the above formula for the pick-up in the case of loops (coil antennae) having iron in their magnetic path should be modified by the inclusion of the effective permeability μ, or in other words, the effective height of the antenna is increased by the effective permeability.

$$\frac{V}{e}=\frac{\omega L}{R}\times\frac{2\pi AN}{\lambda}\times\mu$$

In practice, as both examples show, it is easy at certain frequencies to improve the Q of the coil by the insertion of a proper iron core. This will increase the inductance so that less turns will be employed. Both expedients will tend to neutralize each other from the standpoint of resultant pick-up, but the pick-up will be additionally increased by the amount of the effective permeability.

On the other hand, as previously explained, the insertion of an iron core does not materially increase the distributed capacity of the coil so that higher inductance will be permissible. In such a case the increased pick-up will result from a combined increase of Q and of the effective permeability.

It also means that for the same pick-up properties the already existing air core loop antenna may be decreased in diameter (mean turn), this reduction being of the same order as the increase of permeability due to the core. This application is of particular importance in an aircraft antenna where the reduction of the loop size and of the overall dimensions of its cover will reduce the drag or air resistance at high speeds.

Additionally it was found that a loop antenna equipped with a core is more directional and less affected by adjoining metal parts. While an air core loop should be mounted at least 6 inches from the metal surface of aircraft, the iron cored loop could be mounted as close as 2 inches from the same surface without affecting its Q.

Fig. 4 shows the measurements of directional properties of the two loops of Fig. 3, associated with radio frequency receiver, having a partial automatic volume control. The ordinates indicate the signal strength received under identical conditions and the abscissae represent the degree of rotation of the loops from the null point, i. e. when the loop's plane is perpendicular to the source of radiation. Curve *a* represents the part of a polar diagram of an air core loop, while curve *b* shows the same for an iron core loop.

It is evident from the diagram that the directional properties for the second loop are 50 percent better, which is another important advantage derived from the employment of the iron core.

Fig. 5 shows a schematic arrangement of a wireless transmitting-receiving system in which two closed circuits are employed for transmission TR and reception RC respectively. Both coils are equipped with iron cores so that double advantage is to be expected. The transmitter may of course be in the form of a straight radiator, such as was the case in the measurements of directional properties.

While Fig. 2 shows a solid pellet of iron inserted in the coils, in the case of larger loops, from 6 inches to 12 inches in diameter, the core itself takes the shape of a toroidal ring so that its weight is materially reduced, as compared with a solid cylindrical core. It was found that the toroidal ring core produces improved Q of the coil owing to the particular distribution of magnetic fields. Core 4 of Fig. 3 shows such ring.

In the actual construction the frame aerial coil may also be wound in the form of a flat spiral or in the form of a short solenoid or in the form of multi-layer windings. In all cases the open-type iron core may consist of a toroidal ring, its thickness being greater than the axial length of the winding. While in the first example the core may approach the inner turn of the coil very closely, in the second and third examples the spacing of about ½ inch should be allotted between the coil and core and the axial length of the coil should be smaller than the coil diameter so as to not to increase the distributed capacity. The effective permeability of the iron is not greater than 2 but a marked improvement in Q is attributed not so much to the reduction of copper but rather to the particular distribution of the coil field and to a consequent reduction of losses in the surrounding medium.

In this connection an investigation of new field patterns reveals a marked condensation of fields through the core, the return line fields being drawn closer to the winding than is usual with the air core coils, both direct and return path being of more defined mean direction, with lesser amounts of stray fields, particularly those which do not close but extend to infinity. The resultant directioning or focusing of the coil's main field produces sharper indication of the position at which both sides of the coil balance each other so that no potential difference exists in the coil which should occur when the plane of the loop is normal to the wave front.

For more effective utilization of the iron in the case of a solenoid winding a groove may be provided in the outer surface of the ring and the whole winding placed over the groove. This or other above described arrangements of open type core provides the means for collecting or enhancing the pick-up of radiated electromagnetic energy.

Several ways are known in the construction of frame aerials for reducing objectional electrostatic pick-up when these aerials are used for direction finding or for static reduction. It is customary to provide auxiliary means for this purpose, for instance, split condensers with center tap or auxiliary antennae to balance out or reduce the said pick-up, or in order to completely eliminate electrostatic pick-up the aerial may be completely screened, which usually results in a reduction of Q.

The construction according to a feature of the present invention allows simple means for balancing out electrostatic influences. The core itself has a certain conductivity and may be considered as a poor antenna. The core may then be connected to earth potential of the circuit, thus reducing to zero the effective height of the electrostatic factor of the antenna. Fig. 5 shows such an arrangement where the core of the receiver is shown grounded. To increase the conductivity of the core a metal strip may be employed on the inner surface of the core ring without detriment to the efficiency of the coil, in which case the strip should be split. Fig. 6 shows this construction. A core 4 similar to one shown on Fig. 5 is used in connection with coil 1 to form an antenna. A metal conductive strip 7 is placed on the inner surface of the hollow core. This strip may be made of copper or other highly conductive metal or may be deposited on the surface of the core, for example by spraying. To avoid the short circuiting effects this strip is discontinued or left open at the top. At the bottom the strip is connected to the ground or other points of the circuit. The shaft 9 and the supporting bracket 8 are used for rotating the loop. Coil winding 1 is made in two sections. The employment of a ring core produces the beneficial effect of improving the efficiency of the coil even in the case when the coil is completely surrounded by an electrostatic screen. In such a case the core may be placed between the screen and the coil.

Usually the frame aerial is made rotatable in order that its directional properties may be utilized (minimum signal when the plane of the loop is perpendicular to the direction of the transmitter). It is then convenient to rotate the core together with the loop for which purpose both coil and core are assembled together.

However, either or both elements may be rotated separately in which case a certain inductance variation may occur depending on the shape of the core so that the coil may be set at the minimum signal position with the plane of the core parallel to the plane of the coil and the system tuned to the transmitter. The subsequent rotation of the coil will produce de-tuning so that the signal strength diminishes when the plane of the coil points toward the station. A study of the polar diagram obtained when the receiver was tuned to the frequency at the minimum position shows two pronounced peaks on each side of the minima. It is obvious that in such an arrangement a rotatable frame aerial permits periodic pick-up of two or more signals of different frequencies, or operation through a certain band is possible.

Fig. 7 shows an arrangement where a coil antenna 1 may rotate around the core 4. Coil winding is placed on a coil-former 2 made of insulating material. A bushing 11 attached to the former 2 allows a free rotation of the loop coil around its shaft 9, fixed to a supporting stand 8. A pulley 14 attached to the bushing with a cable 12 provides the means of manual control for rotation of the loop. The core 4 is provided with a tubular shaft 13 which is placed around the shaft 9 and another pulley 14 at the bottom is used for the rotation of the core. Both coil and core may be rotated independently or simultaneously by the operator.

The invention is not limited to the employment in periodic or tunable aerials but may be equally well applied to "aperiodic loops" in which the energy is transferred to selective circuit through a current transformer, having primary and secondary windings, the primary being connected across the loop coil.

The invention is applicable to all cases of transmission of electromagnetic waves where it is now possible to improve, direct or condense the energy of radiations by means of the employment of suitable magnetic material, in substantially the same manner as has been recently developed for the propagation of electrostatic waves through dielectrics.

It is to be observed that since the inclusion of the effective permeability of the medium surrounding the coil proves to be essential in the formula of electromagnetic pick-up of a loop antenna, the behavior of paramagnetic substances for electromagnetic waves becomes somewhat identical to the behavior for electromagnetic fields. The inclusion of iron in the coils of an inductor is equivalent to the reduction of magnetic reluctance of the surrounding medium ad infinitum, by the figure of the effective permeability of the core in that coil. Likewise the inclusion of iron in radiating or receiving coil antennae results in effective reduction of radiation reluctance of the electromagnetic waves within the space between the radiator and the receiving coil.

What I claim is:

1. An antenna system for the reception of radiated electromagnetic waves including a coil having a diameter greater than its axial length, a ferromagnetic open-type cylindrical core inside of said coil and spaced therefrom to reduce the effective permeability of said core in said coil, said core comprising finely divided particles insulated from each other and of a size of the order of three microns, whereby the effective height and directional properties of said system are improved.

2. An antenna system for the reception of radiated electromagnetic waves including a low-cost high-inductance coil having a diameter greater than its axial length, a ferromagnetic cylindrical core of the open-type inside of said coil and spaced therefrom, said core comprising finely divided magnetic particles insulated from each other, the size of said particles being of the order of several microns to preserve the low loss characteristics of said antenna system whereby the pick-up factor and directional properties of said system are improved.

3. An antenna system for the reception of electromagnetic waves, including a pick-up coil, having a diameter greater than its axial length, an open-type ferromagnetic core in the field of said coil for improving the electromagnetic pick-up properties of said system, and means for suppressing the electrostatic pick-up, said means comprising a layer of conductive material placed around said core and connected to the ground of said system.

4. An antenna system for the reception of electromagnetic radiations, said system having a pick-up coil whose diameter is greater than its axial length, an open-type ferromagnetic core in the field of said radiations for improving the efficiency of said system, and means for rotating said coil around said core in order to obtain directional bearings of the source of said radiations.

5. An antenna system for the reception of electromagnetic radiations, said system having a pick-up coil whose diameter is greater than its axial length, an open-type ferromagnetic core in the field of said radiations for improving the efficiency of the system, means for simultaneously rotating and varying the inductance of said coil in order to obtain directional bearings on a plurality of sources of said radiations.

6. A system for the reception of electromagnetic radiations comprising a loop coil-antenna the diameter of which is greater than its axial length, and a ferromagnetic mass in the fields of said radiations, said mass being in the form of an open type core for said coil and composed of finely divided and insulated magnetic particles, the maximum dimension of said core transverse to the coil axis not exceeding the minimum coil diameter.

7. A system for the reception of electromagnetic radiations comprising a coil antenna whose axial length is less than its maximum dimension transverse to its axis, and a ferromagnetic open type core the dimension of said core in any direction transverse to said axis being less than the dimension of the coil in the same direction, said core being composed of compressed insulated magnetic particles of the order of three microns and being exposed to the field of said radiations.

8. An antenna system for the reception of electromagnetic radiations including a pick-up coil wound with spaced sections, said sections having axial length not exceeding the inner diameter of said coil, and an open type cylindrical ferromagnetic core inside of said coil, said core being composed of finely divided and insulated magnetic particles and being exposed to the field of said radiations.

9. An antenna system for the reception of electromagnetic radiations comprising a coil and a ferromagnetic core, said coil having a high Q value and spacedly wound with a multi-stranded cable, the length of said coil not exceeding the diameter thereof, said core being composed of insulated magnetic particles of the order of three microns, the maximum dimension of said core transverse to the coil axis not exceeding the minimum coil diameter, said core being of toroidal shape of the length greater than that of said coil, whereby the directional selectivity of said system is improved.

10. An antenna system for the reception of electromagnetic radiations comprising a coil and a ferromagnetic core, said coil being composed of spaced sections having axial length not exceeding the minimum diameter of the coil, said core being composed of insulated magnetic particles of the order of several microns, the maximum dimension of said core transverse to the coil axis not exceeding the said minimum diameter, said core being of toroidal shape of the length greater than the total length of the coil, whereby the directional selectivity of said system is improved.

11. An antenna system for wireless communication comprising a coil the diameter of which is greater than its length, and a ferromagnetic core composed of finely divided and insulated magnetic particles in the field of said coil, said core being of the open type and having its maximum dimension transverse to the coil axis not exceeding the minimum diameter of said coil and its length being greater than that of said coil.

WLADIMIR J. POLYDOROFF.