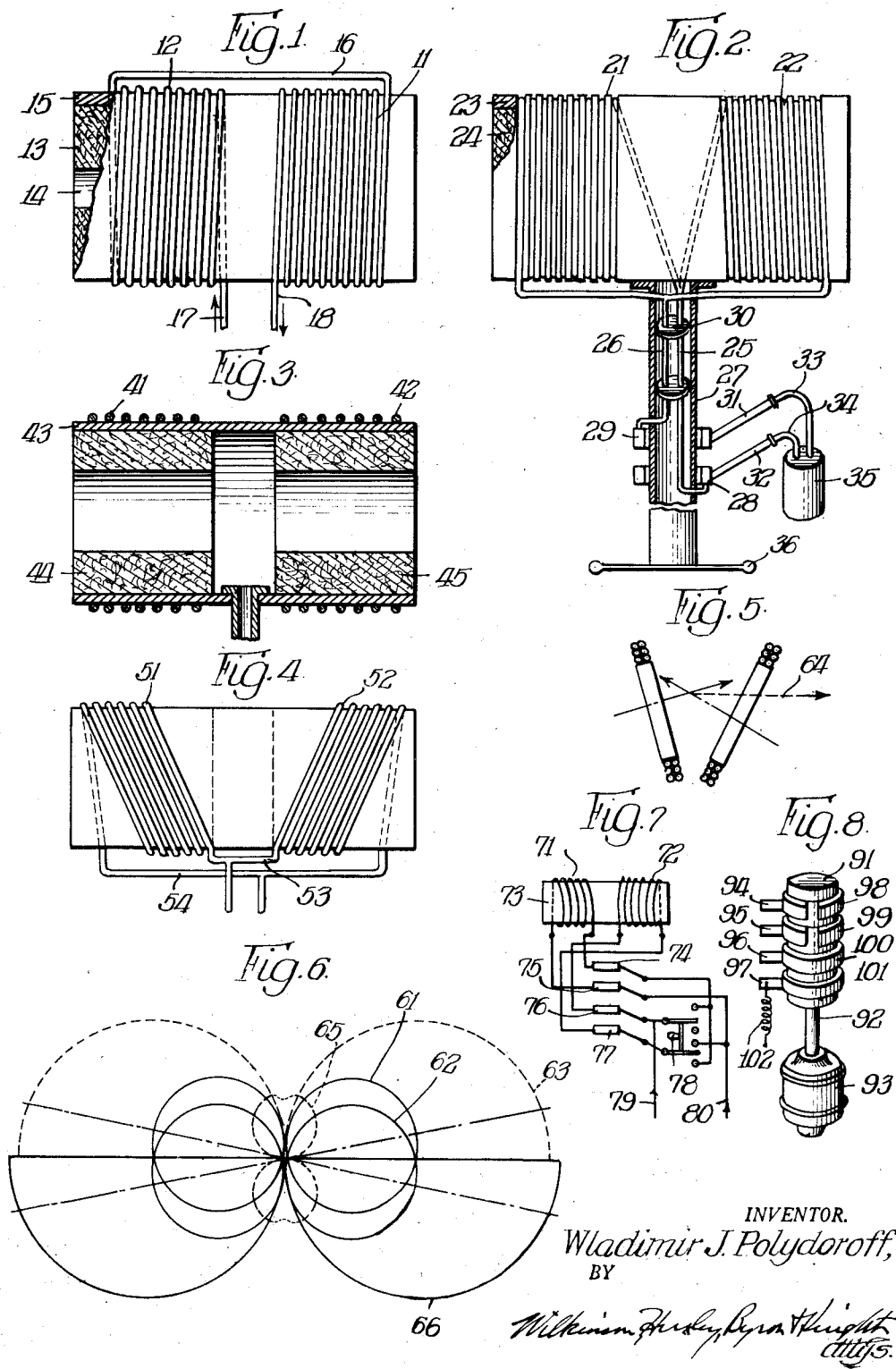


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LOOP ANTENNA

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This invention relates to a new and improved loop antenna, and more particularly to an antenna of the character having an associated core of finely divided magnetic material. While such antennae are of general application, they are of especial importance in connection with direction finding apparatus used on ships or planes.

Antennae of this type have been disclosed in my prior Patent No. 2,266,262, granted December 16, 1941. This prior patent describes the advantages derived from the use of iron cores in the field of the antenna coil, namely, that the effective height of the antenna may be considerably increased, the amount depending upon the degree of utilization of the iron or the effective permeability of the core.

While this prior patent deals generally with the application of finely divided iron or ferromagnetic masses to such coils, the present invention is directed more specifically to elongated antennae, in which greater effective use of the iron is possible, with consequent greater resultant increase in effective height.

The effectiveness or efficiency of a loop antenna as a means for picking up the energy of radio waves is stated in terms of its effective height, which is the resultant voltage in the loop divided by the field strength of the radiated wave. When considered with the loop directed parallel with the direction of wave travel, the equation simplifies to read

$$H_{eff} = \frac{2\pi AN}{\lambda}$$

where A is the mean turn area, N the number of turns, and λ the wave length of the radio wave in meters.

This equation is based on an air core coil with an effective permeability of one. If an iron core is used, the effective permeability is increased, dependent upon the efficiency and relationship of the coil and core. The effective height is multiplied by the effective permeability and consequently it is desirable to use a coil and core combination in which the effective permeability is the maximum consistent with the other requirements of the installation. For example, since the coil is to be used as a pickup, it must not be shielded by the core and consequently a closed core affording the maximum effective permeability cannot be used. Also the particular uses of the coil impose limitations as to the inductance which may be effectively utilized. These various considerations lead to the employ-

ment of an elongated core in the form of a long cylinder or rectangular parallelepiped.

In order to realize the maximum utilization of the iron core it is also advisable to keep the coil windings as close to the core as possible and to spread them throughout substantially the entire length of the core. It is to be considered that for a given inductance, the number of turns N on the iron core may be increased if greater spacing is provided between the turns. Since a greater number of turns gives a greater effective height, other factors being constant, it is important to increase the number of turns.

It is an object of the present invention to provide a new and improved loop adapted to serve as pickup apparatus for reception of radio waves.

It is also an object to provide a construction in which the effective height of the loop increases with an elongated loop.

It is an additional object to provide a loop of this character so designed as to cancel the effects of displacement currents.

It is a further object to provide a loop construction which may be selectively connected to cover a plurality of frequency ranges.

It is another object to provide a loop construction having small physical dimensions with multiple section windings having the electrical characteristics and efficiency of a substantially larger loops of standard construction.

It is also an object to provide a loop which is simple in design and adapted for commercial production and use.

Other and further objects will appear as the description proceeds.

I have shown certain preferred embodiments of my invention in the accompanying drawing, in which

Figure 1 is an elevation of one form of coil and core according to the present invention, the core and coil spacer and former being partly broken away to show the construction;

Figure 2 is a view similar to Figure 1, but showing a modified form of construction, and showing the coil mounting, partly in section;

Figure 3 is a vertical section through a further modified form;

Figure 4 is a view similar to Figure 1, showing an additional form of construction;

Figure 5 is a diagrammatic showing of another modification;

Figure 6 is a polar diagram showing the effective pickup of the loops of Figures 3 and 4;

Figure 7 is a schematic diagram of a form of connecting circuit for a loop; and

Figure 8 is a schematic diagram of a rotary loop connection.

Referring first to the form of construction shown in Figure 1, the pickup coil comprises a pair of separated space wound solenoids 11 and 12, spaced to cover substantially the entire length of the core 13. The core is shown as tubular in construction, with a central opening 14, and may comprise a plurality of sections placed end to end. The core 13 is retained within a tubular sheath 15, which may be formed of Bakelite or other insulating material. The tube 15 may be provided with spiral grooves to receive the wire coils for the purpose of definitely spacing and locating them, and more particularly for permitting them to more closely approach the core.

The two coils 11 and 12 have their outer ends connected by the wire 16; while their adjacent ends are connected to wires 17 and 18 by means of which the loop is connected in the receiving circuit.

The windings of the coil explained above, for the purpose of increasing effective height, are spaced and extend the length of the core. This construction usually produces undesirable displacement currents which somewhat distort the directional pattern of the loop by masking the null points so that accurate direction finding by null observation is no longer possible. To overcome this effect the winding is made in several sections, two being shown in Figure 1, which sections are reversely wound and connected in the manner shown to cancel the effects of displacement currents while retaining the other desirable properties of elongated loop with the iron core.

Another method of winding and connecting coils to cancel the displacement currents is shown in Figure 2. The windings 21 and 22 are carried in grooves in the insulating tube 23 which encloses the ferromagnetic core 24. The coils 21 and 22 are wound in the opposite direction and parallel, rather than in series, as shown in Figure 1. The inner ends of the coils 21 and 22 are connected to the wire 25 while their outer ends are connected to wire 26. These wires 25 and 26 extend downwardly through the rotatable tubular mount 27 and are connected to collector rings 28 and 29 respectively. The wires 25 and 26 are insulated and spaced in fixed relationship by the beads 30. The brushes 31 and 32 connect to fixed conductors 33 and 34 carried in cable 35 to the radio apparatus. The tubular mount 27 is shown as provided with a wheel or handle 36 for rotating the antenna in use.

It is usual in multi-range loop receivers to employ a single loop to cover a plurality of frequency ranges, the inductance, and number of turns, being limited by the highest frequency range so that at that highest frequency the loop still presents inductive reactance. Such a system is inefficient at the lower frequency range, where a much greater number of turns may be tolerated. Referring now to both Figures 1 and 2, it is easily conceived that the windings of Figure 1 may be more adaptable for high inductance and that by switching the two sections from series to parallel connection a greater efficiency may result at higher frequency ranges. Such a change of connection is shown schematically in Figure 7 and will be explained hereinafter.

The construction shown in Figure 2 may be

still further improved if two parallel sections are placed on separate portions of the core material forming one mechanical structure with a gap between the core sections. Such a modification is shown in Figure 3, where two parallel windings 41, 42 are wound on an insulating tube 43 about separate portions 44, 45 of the core and connected in parallel as in Figure 2. Comparison of the performance of a single loop section and of two parallel sections of the same inductance indicates a net gain in efficiency of the order of 4 db. Parallel winding as a rule maintains high Q ($\omega L/R$) of the coil, which also contributes to greater efficiency and better directional properties.

Referring next to the construction of Figure 4, a double loop comprising sections 51 and 52 is shown, the loops being mounted upon separated core sections in the same manner as shown in Figure 3. The inner ends of the loops are connected to wire 53 and their outer ends to wire 54. It will be noted that the loops are wound obliquely on the cylindrical core so that they are inclined away from each other.

If two loop sections are wound obliquely to the main axis of the structure of Figure 3, a construction is provided in which two parallel sections are laid with a definite angle between the axis of the coils, as now shown in Figure 4. Such a construction increases the effective area of each turn and is equivalent to two separate loops connected in parallel and placed in angular relation to each other, as shown diagrammatically in Figure 5.

The two loops of Figure 4 or Figure 5 may be rotated as a single structure and in such a way the directional pattern of the structure has been investigated. It has been found that if the two loops form a small angle from 10 to 25 degrees and are connected in the additive sense, such as shown in Figure 2, the directional pattern approaches the normal figure-8 pattern obtainable with a single loop, with as sharp null indication as in the normal pattern. This is shown by a polar directional diagram in Figure 6. This figure shows two figure-8 patterns, 61 and 62, displaced by 20 degrees, the upper half also showing in broken lines two large near-circles 63 resulting from the addition of the two displaced smaller circles, 61, 62, taking in consideration their proper phase relation.

The bottom part of the diagram of Figure 6 shows two great circles resulting from the addition of two smaller circles having a common axis, such as two loop sections of Figure 3. The examination of both upper and lower resultant field patterns indicates that particularly at near zero signal position, the two patterns are alike. Actual observations with pairs of loops of the character of Figure 4 and Figure 5 indicate very sharp null points comparable with the conventional loops.

When the direction to the transmitter comes in line with the major axis of Figure 4, the transmitter direction in the structure of Figure 5 comes in the direction of bisecting line 64 of the angle between two loops. When zero signal was thus obtained, it was observed that the reversal of one winding with respect to the other would produce a very strong signal, although the loops remained in their zero position; and by further rotation of either structure (Figure 4 or Figure 5), a new null point was observed at right angles to the previous position. The investigation of the polar diagram of Figure 6 reveals that if two small figure-8 patterns are now added with reversed

phase, the resultant pattern forms a still smaller figure-8 pattern 65, rotated 90 degrees from the previous additive pattern. This new pattern is shown on the diagram by broken lines. With a 20-degree angle between two loops, the pattern shows a slight distortion near the maximum field strength, which distortion will increase with larger angles. Smaller angles will produce a more regular pattern rapidly diminishing in field strength as the angle approaches 0-degrees, from which considerations it may be seen that the optimum angle lays somewhere between 15 and 25 degrees. This phenomenon may be utilized for the direction finding purposes in several useful applications, and is particularly adaptable to aircraft because of the smallness of the antenna of the present invention.

One application of the loop in aircraft is for "homing" purposes where the loop is fixed with its axis along the direction of travel, or from front to rear of the plane. In that case the pilot picks up a desired signal and turns the ship until he gets a null indication of the station and continues on that course of "silent signal" until he reaches the station. Since the pattern is symmetrical in two opposite directions, one can never be sure that the direction picked by a null point will lead to the station and not away from it. The method heretofore has been known of determining the proper sense of the station by placing the loop, by altering the course of the ship, at right angles to the station for maximum signal and then applying to this signal an additional signal derived from a small vertical rod antenna in proper phase. The increase or decrease of the total signal indicates the direction to the station or away from it.

With the displaced loops of the present invention, it is possible to quickly determine the sense without taking the ship off the course or rotating the loop. When a signal is located and the direction found in the usual manner, the loops are switched to the opposing phase which brings back a strong signal, which is then compared with the signal derived from the rod. The signal from the rod antenna may be so adjusted that the simultaneous switching of loop and rod will result in a loud signal when on course toward the station, or in no signal when on opposite course away from the station. It is also now possible to use this pair of displaced loops as a single rotatable element for the station and sense indication, the loop and the rod being arranged symmetrically at any given bearing of the loop, for instance, by placing the rod through the center of loop rotation, thus enabling the pilot to take the bearing and the sense of a station off the ship's course.

In the so-called crossed coil system for "on and off course" indication, two stationary crossed loops are fixed on an aircraft at a right angle to each other, the main loop pointing toward the station and the auxiliary loop producing no signal when the ship is on the course. The auxiliary loop in addition is alternately switched on in adding or subtracting phase. Combining the action of the two loops a right and left indicator is operated.

In Figures 7 and 8 means for switching loop connections have been shown somewhat diagrammatically. In Figure 7 a pair of windings 71 and 72 are shown wound on a common form 73, which may be similar to the forms of Figures 1, 2 or 3, and contain similar cores. The four terminals of the two coils are connected to collector rings 74, 75, 76 and 77, these rings being each engaged

by a separate spring contact or brush, as shown. The double pole switch is provided, connected as shown, so that the two windings 71 and 72 may be selectively connected in series or parallel to the lines 79 and 80. The switch is preferably located close to the collector rings and brushes and may be operated by remote control in any usual manner.

Figure 8 shows a rotating commutator or arrangement particularly adaptable to the coils of Fig. 4. The structure includes split collecting rings carried on a rotor 91, connected by shaft 92 to motor 93, by which the rotor may be continuously rotated. Brushes 94, 95, 96 and 97 engage split rings 98, 99, 100 and 101 respectively. The conducting split rings are so connected to the loop sections 51 and 52 that every half revolution one loop section is alternately switched from aiding to opposing phase with respect to another loop section and vice versa. The small inductance 102 is so connected in the circuit as to compensate for inductance variation upon the shift in phase connection and maintain a substantially constant inductance of the total loop.

If a pair of displaced loops is arranged by means of a rotatable commutator to switch the loops alternatively in aiding and opposing phase, two patterns of Figure 6 will appear alternatively, the smaller figure-8 at right angles to the larger figure-8. If the ship is brought on the course corresponding to the vertical of the diagram of Figure 6, the signal from smaller pattern will alternate with zero signal from the larger pattern. At any deviation from the course during the alternation corresponding to the functioning of the aiding phase connection, a signal will appear, which will vary in phase if the ship is to the right or to the left of the vertical. If this varying phase signal is then added to the signal resulting from the other opposing phase alternation, a noticeable increase or decrease of total signal will appear, which after its detection may be applied to a right and left indicating meter. In order to add two alternating signals in due phase, the properties of an undamped circuit can be utilized, whereby such circuit, when once excited during first alternations, continues to oscillate during the second alternation, and the second signal in its turn either reinforces the oscillations when in phase or dampens the same when in opposite phase. Also, it is possible to apply to the signal of either alternation a time delay (transmission line) of such magnitude that two signals arrive to the receiver simultaneously.

When a pair of displaced loops is switched in aiding or opposing phase, the inductance of the combination may slightly vary due to the change of the sign of mutual inductance. This variation may be easily compensated by adding small compensating coils to the oppositely connected loops in order to maintain the loops of the same inductance. It is, of course, possible to wind on the same form, two pairs of displaced coils, one connected in aiding phase, the other in opposing phase, and combining both loops with or without commutation to the input of the circuit actuating a left and right indicator.

If the loops of Figure 4 and Figure 5 are used for direction finding by the usual null method, it is preferable to employ them in aiding phase relation as shown in the large figure-8 pattern 66 of diagram of Figure 6, as the loop of greater sensitivity will produce sharper null indication. It has been known, however, that during night observations considerable error may result from

the horizontal polarization of an incoming signal, which will equally affect both aiding loops. When the loops are reversed into opposing phase connection, this polarization error, known as "night effect" will affect the two loops in the opposite sense, and therefore cancel itself. While under the usual conditions the reception on reversed loops will be approximately 15 db. down as compared with a normal loop, the error due to reduced reception may be considerably less than the one due to the night effect. A quick check by reversal of connection one way or the other way may indicate the presence or absence of night effect and thus insure a certainty of correct observations.

While I have shown and described certain preferred embodiments of my invention, they may be modified to meet different conditions and requirements, and I contemplate such modifications as come within the spirit and scope of the appended claims.

What is claimed is:

1. In a loop antenna system, an elongated core member comprising finely divided insulated magnetic particles, a pair of pickup coils wound on the core member to extend over a major portion of the length of said member and having close association with said core member, said coils being wound symmetrically and in opposite directions and being connected in parallel with terminal connections taken from the adjacent ends and the outer ends of the coils.

2. In a loop antenna system, an elongated coil supporting form, a pair of core sections fitted in said form and spaced apart therein, said cores comprising finely divided insulated particles of ferromagnetic material, a pair of pickup coils, one wound upon the form about each core section and spaced to extend substantially the length of the core member.

3. In a loop antenna system, an elongated coil supporting form, a pair of core sections fitted in said form and spaced apart therein, said cores comprising finely divided insulated particles of ferromagnetic material, a pair of pickup coils, one wound upon the form about each core section and spaced to extend substantially the

length of the core member, said coils being wound symmetrically and in opposite direction and connected in aiding sense.

4. In a loop antenna system, a unitary rotary assembly comprising a pair of coils, the axes of the coils being displaced approximately twenty degrees from each other, said coils being wound symmetrically to each other to cancel displacement currents, and means for selectively interconnecting said coils in aiding or opposing sense.

5. In a loop antenna system, an elongated core member comprising finely divided insulated magnetic particles, a pair of pickup coils closely associated with said core member, said coils being wound upon the core member so that the plane of each turn of one coil makes an acute angle with plane of each turn of the other coil.

6. In a loop antenna system, an elongated core member comprising finely divided insulated magnetic particles, a pair of pick-up coils wound on the core member to extend over a major portion of the length of said member and having close association with said core member, said coils being wound symmetrically and in opposite directions, and switching means for connecting said coils in parallel in aiding sense.

7. In a loop antenna system, an elongated core member comprising finely divided insulated magnetic particles, a pair of pick-up coils wound on the core member to extend over a major portion of the length of said member and having close association with said core member, said coils being wound symmetrically and in opposite directions, and switching means for connecting said coils in series or for connecting said coils in parallel with the terminal connections being taken from the adjacent ends and the outer ends of the coils.

8. In a loop antenna system, a unitary rotary assembly comprising a pair of coils, the axes of the coils being displaced at an angle to each other which may range from 15 to 25 degrees, said coils being wound symmetrically to each other to cancel displacement currents, and means for selectively interconnecting the coils in an aiding or opposing sense.

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