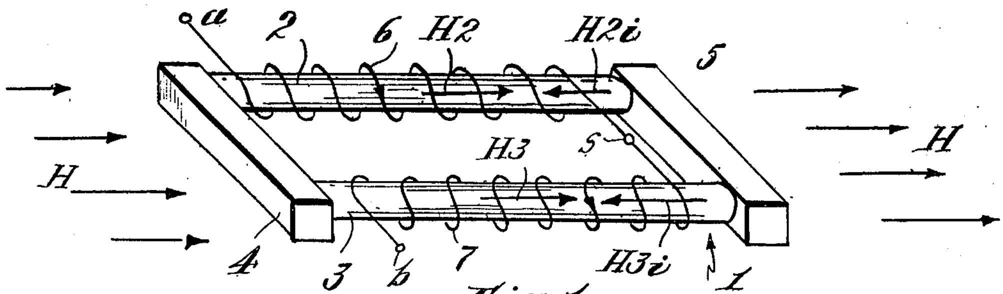

Fig. 1

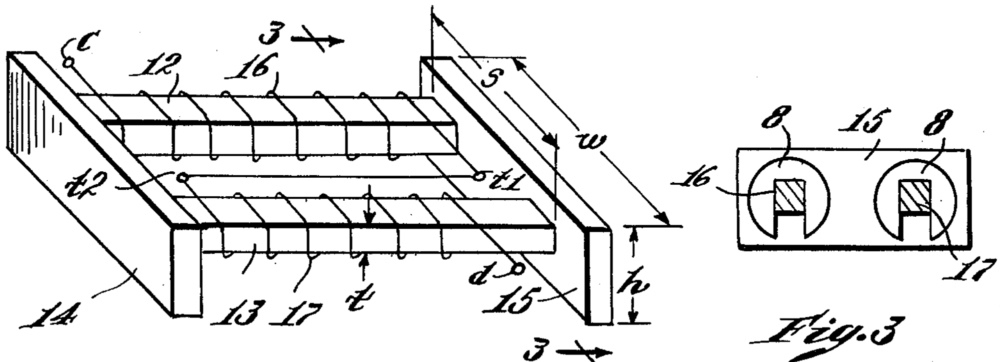

Fig. 2

Fig. 3

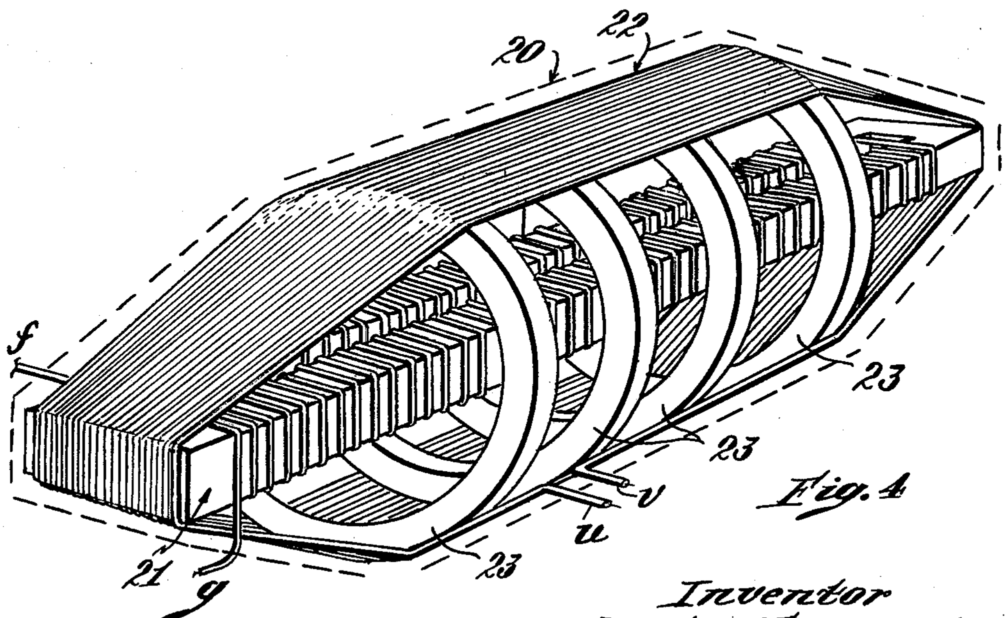

Fig. 4

Inventor
Morton F. Spears
by Roberts, Cushman & Grover
Att'ys.

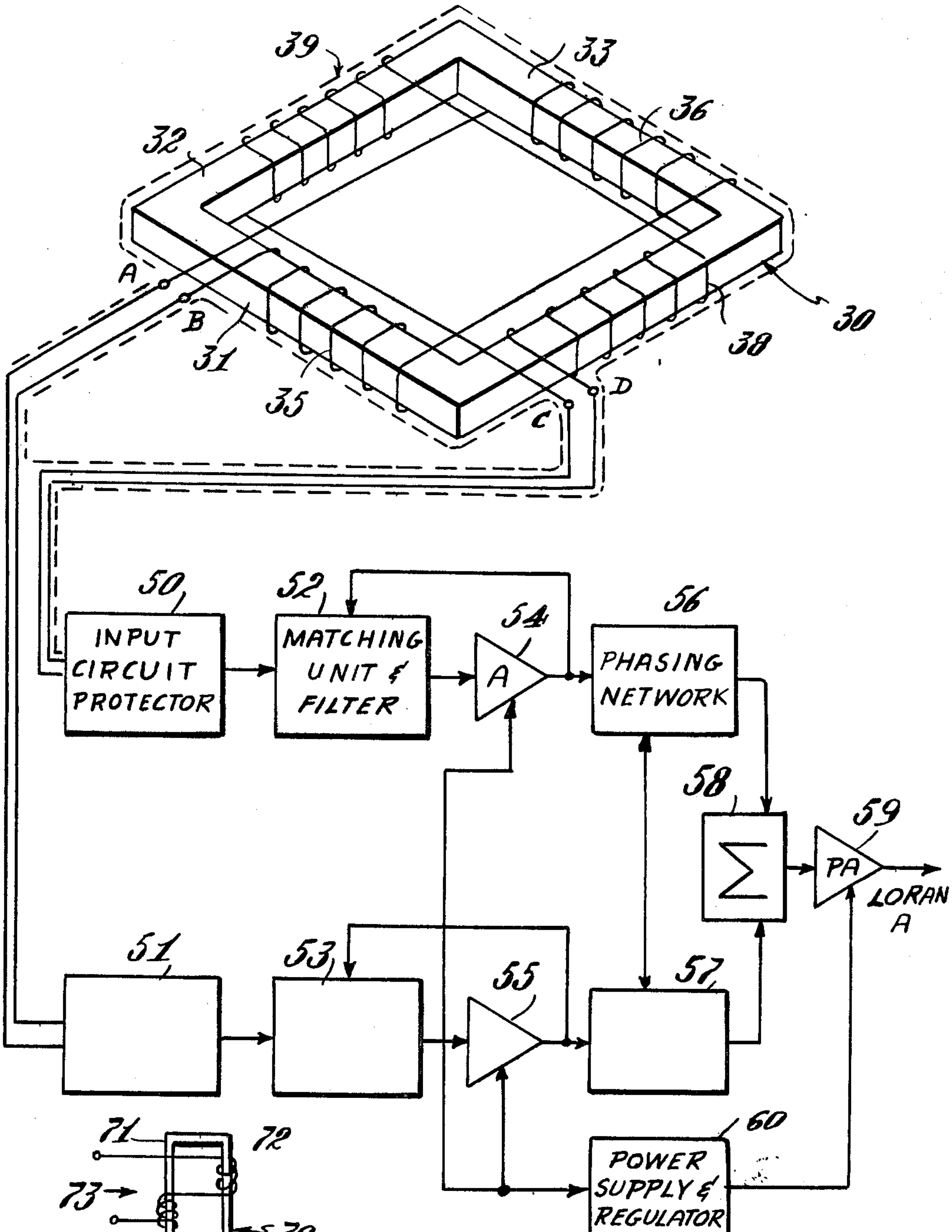
39
33
36
32
30
A
B
31
38
35
D
C
50
52
54
56
INPUT CIRCUIT PROTECTOR
MATCHING UNIT & FILTER
A
PHASING NETWORK
58
59
PA
LORAN A
51
53
55
57
60
POWER SUPPLY & REGULATOR

Fig. 5

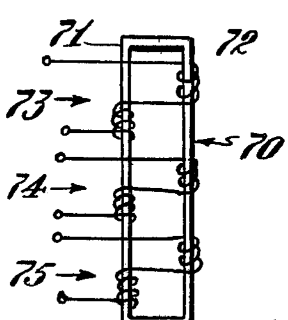
71
72
73
70
74
75

Fig. 6

Feb. 10, 1970 M. F. SPEARS 3,495,264

LOOP ANTENNA COMPRISING PLURAL HELICAL COILS ON CLOSED MAGNETIC CORE

Filed Dec. 9, 1966 4 Sheets-Sheet 3

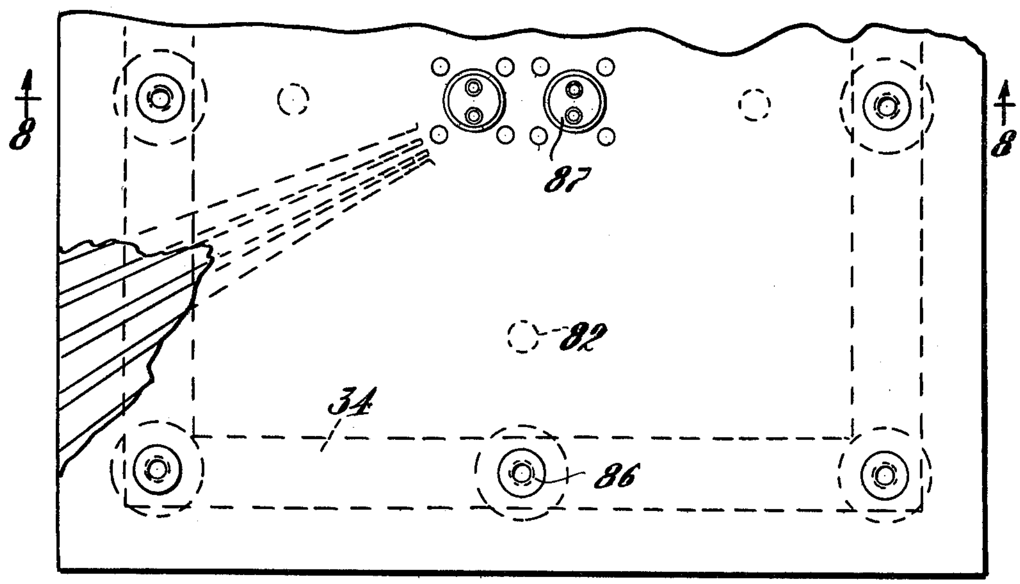

Fig. 7

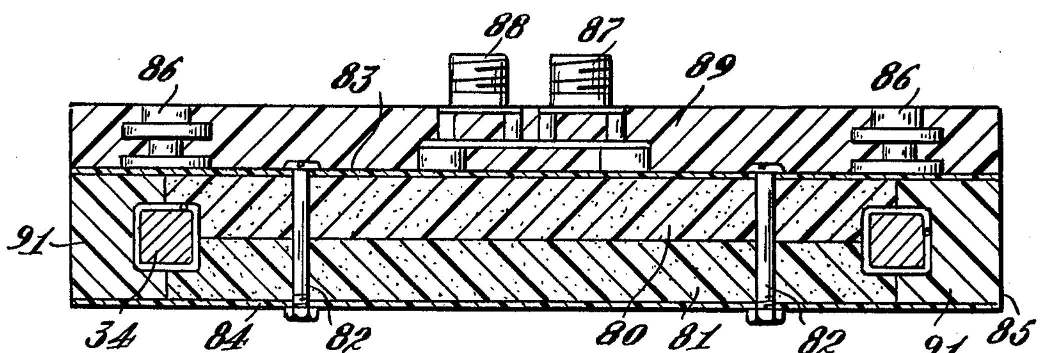

Fig. 8

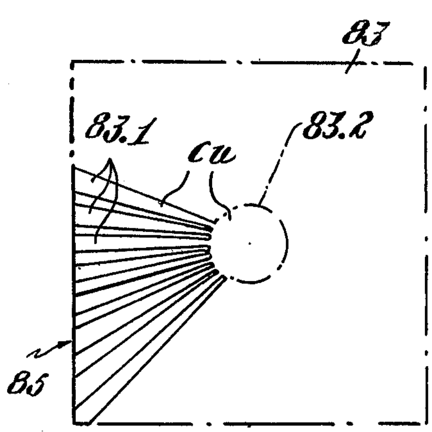

Fig. 9

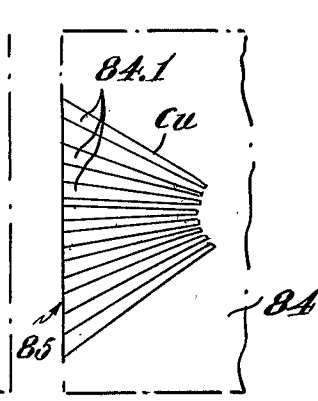

Fig. 10

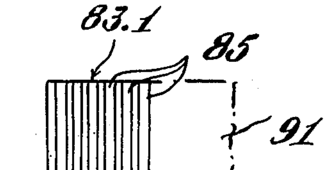

Fig. 11

Fig. 15

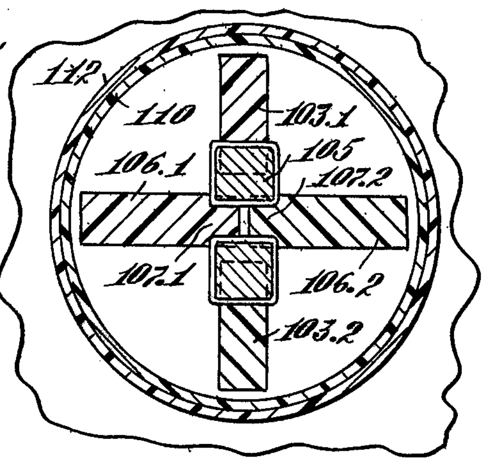

Fig. 13

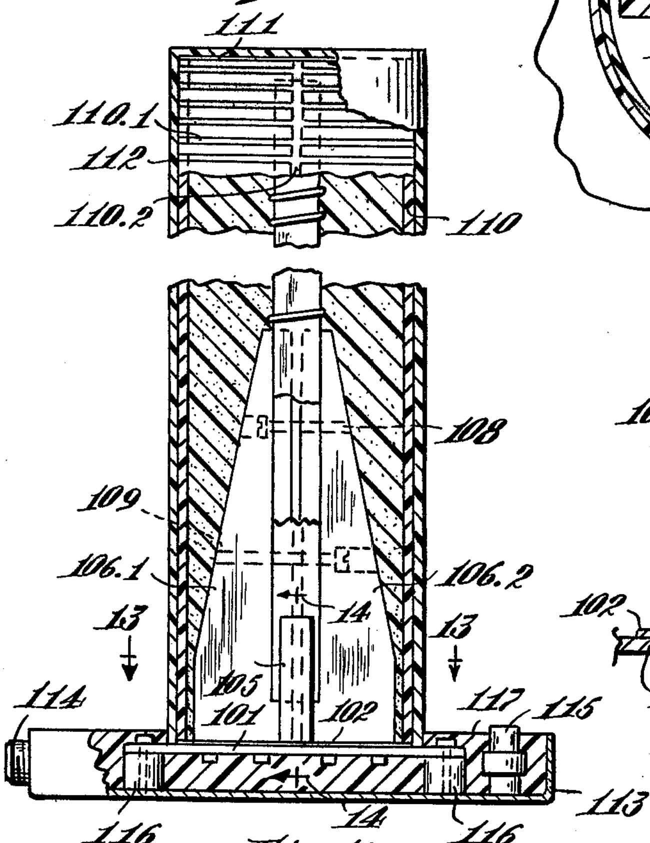

Fig. 12

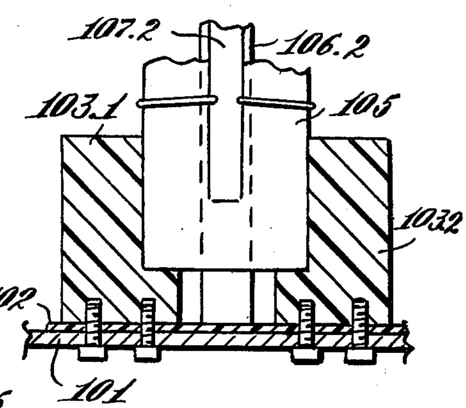

Fig. 14

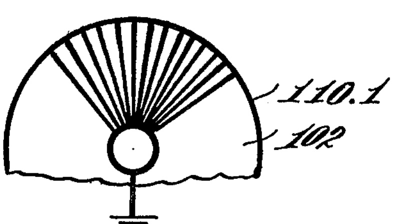

Fig. 16

United States Patent Office

3,495,264
Patented Feb. 10, 1970

3,495,264

LOOP ANTENNA COMPRISING PLURAL HELICAL COILS ON CLOSED MAGNETIC CORE

Morton F. Spears, Westwood, Mass., assignor, by mesne assignments, to Continental Electronics Manufacturing Company, Dallas, Tex., a corporation of Texas

Filed Dec. 9, 1966, Ser. No. 600,466
Int. Cl. H01q 7/08
U.S. Cl. 343—788 **7 Claims**

ABSTRACT OF THE DISCLOSURE

A ferromagnetic core in the form of a closed frame carries a pair of coils constituting loops which are helically oriented on individual sections of the core and series connected such that the signal flux, which is concentrated in the core, induces in the individual coils voltages which appear additively at the output terminals of the series coils whereas the current flow in the coils induces core flux components that cancel each other. Several pairs of series connected coils can be applied to a single core for independent operation of each pair.

BACKGROUND OF THE INVENTION

Field of the invention

The invention relates to antennas which include magnetic material and are of the loop type.

Description of the prior art

In designing antennas of this general type, several considerations must be recognized.

First, the configuration, weight, size and amount of the necessary flux conducting material are important, because these largely determine the cost of the antenna and its utility in a given special environment.

Second, the electrical characteristics of the antenna must be considered. Generally, the greater the output for a given impedance, the better the antenna is. A greater output furnishes a greater signal-to-noise ratio in circuits that follow the antenna. The output can be increased or decreased by simply adding or taking away turns from the windings, or by tuning the antenna to resonance or detuning it. Both of these operations produce accompanying changes in impedance which offset any changes in the basic sensitivity. The sensitivity is determined by the ratio of the signal-to-noise voltages, and the noise is proportional to the square root of the resistance component in the antenna. Therefore, at a given frequency and inductance, the quality factor (Q) which is determined by the ratio of inductance to resistance should be made as high as possible to reduce the resistance component. A limit to Q, however, occurs for tuned circuits, when the information frequency bandwidth is reduced below that which will pass the information desired.

Finally, for an antenna of given impedance, there must be considered the output capability of the antenna, which may be characterized by its effective height. For any antenna, the expression $V_S = h_e E_S$ (where V_s is the output voltage of the antenna, E_s is the electric field strength of the transmitted signal, and h_e is the effective height of the antenna) is a measure of the antenna's efficiency. Heretofore, in ferrite core antennas, it has been possible to gain increases in effective height only at the expense of comparable increases in weight, inductance and noise, or with reductions in bandwidth.

SUMMARY OF THE INVENTION

Antennas according to the invention have a core forming a closed path of flux conducting material and a pair of coils wound one each on a section of the closed core

and connected in series. Characteristically, the coils are wound in opposite directions, that is so oriented that the received, signal carrying, wave energy appears as magnetic flux of the same direction for each core section, varying corresponding to signal and inducing additive signal output voltages across the series connected coils that are linked to the core sections. However, flux induced in the core by the current in the coils is oppositely directed in the closed core path, and cancels. Preferably the opposite sides of the core frame are parallel rods of any convenient cross-sectional shape, and preferably each coil has the same number of turns, thereby providing balanced cancellation. In further aspects of the invention, it is preferable that the rods be substantially elongate to produce a high effective height to antenna weight ratio, and it is preferable that each coil be wound substantially the entire length of the rod, to produce the maximum effective height.

In some practical applications, it is preferable to make the end pieces, or portions of the core which join the core sections such as the rod which carry the coils, higher than the thickness of the rods and wider than the spacing between the rods, to increase the end area of the core and to increase the effective height of the antenna.

In another practical aspect, slotted conducting discs are placed over the ends of the rods between the coils and the end pieces, in order further to increase the effective height of the antenna.

A very useful practical embodiment of the invention has a rectangular core, a first pair of coils wound one each on opposite sides of the core in opposite directions and connected in series, and a second pair of coils wound one each on the other two opposite sides of the core in opposite directions and connected in series, whereby the antenna can function as a direction finder or provide, with appropriate coupling, omniazimuthal reception.

In a still further aspect, a plurality of series connected oppositely wound coils can be mounted on opposite sections of the continuous core, whereby each coil unit will receive signals independently of the others, due to the induced flux cancellation principle inherent in the invention.

In this manner, there are provided a higher antenna output for any given inductance and a greater effective height per unit volume of flux conducting material used than heretofore possible. These antennas are simply and inexpensively constructed and can be adapted for various special purposes such as direction finding, omniazimuthal reception, and independent multiple signal reception; they are compact and suited for installation in confined environments and durable and reliable in use.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an axonometric view of one embodiment of the invention;

FIG. 2 is a similar view of a second embodiment of the invention;

FIG. 3 is a vertical section such as on plane 3—3 of FIG. 2, showing a modification of the invention;

FIG. 4 is a view of a composite antenna incorporating the invention;

FIG. 5 is a view of another embodiment of the invention and a circuit for utilizing the output signal thereof;

FIG. 6 is a view of a further embodiment of the invention;

FIG. 7 is a top view of mounting structure for embodiments such as of FIG. 5, of the antenna according to the present invention;

FIG. 8 is a section on line 8—8 of FIG. 7;

FIGS. 9, 10 and 11 are views of shielding means used in the mounting structure of FIGS. 7 and 8;

FIG. 12 is a sectional view of a mounting structure especially suited for embodiments of the invention such as according to FIG. 1, but with a core according to FIG. 4;

FIG. 13 is a partial section on line **13—13** of FIG. 12;

FIG. 14 is a partial section on line **14—14** of FIG. 12; and

FIGS. 15 and 16 are views of shielding means used in the mounting structure of FIGS. 12 to 14.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The antenna according to FIG. 1 has a core **1** forming a closed frame of magnetic flux conducting material. This core has four sides here consisting of two substantially parallel rods **2** and **3** joined at their ends by flux conducting end pieces **4** and **5**. As described below with reference to other embodiments, the core structure can be mechanically different, such as composed of bars of uniform cross section and equal length. On opposite sides of the core **1**, coils **6** and **7** preferably having equal numbers of turns are wound on rod **2** and on rod **3**, respectively. These coils constitute antenna loops.

The coils **6** and **7** are wound in opposite directions on the rods **2** and **3** and are connected in series between output terminals *a* and *b*. "Wound in opposite directions" here means that looking at the series connected coils along their axes such as from the left of FIG. 1, and taking as a starting point for determining the winding direction of each coil the outer terminal associated with a respective coil, one coil winds clockwise from its outer terminal and the other coil winds counterclockwise from its outer terminal, each towards its inner series connection. Thus, looking from the left of FIG. 1, coil **6** winds clockwise around rod **2** from terminal *a* towards the far end of the rod with connection *s* and coil **7** winds conuterclockwise around rod **3** from terminal *b* also towards *s* at the far end of the rod. Another example of coils "wound in opposite directions" is incorporated in the antenna of FIG. 2. In this figure, again looking at the coils from the left of FIG. 2, coil **16** proceeds clockwise from terminal *c* towards the right and series connection *t***1** and coil **17** proceeds counterclockwise from terminal *d* towards the left and *t***2**.

Referring to FIG. 1, the antenna is shown disposed in a wave energy field carrying the signal to be received, indicated by the arrows H. The correspondingly varying magnetic flux H2, H3 appearing according to well known principles in the rods **2** and **3** of the core will induce voltages across the series coils which will additively appear at output terminals *a, b*. The output, then, is equal to twice the output of a single rod antenna with a single coil. The voltage induced across the terminals *a* and *b* with current flow indicated by arrows on the coils, will induce in the core sections single flux H2*i*, H3*i* components which tend to oppose the flux caused in the respective sections by the signal H. Because the coils **6** and **7** are wound in opposite directions on the core as explained above, this induced flux will appear in opposite directions in the core sections and cancel to the extent the coils are effectively coupled by the core. This cancellation is a maximum when the number of turns is the same on both sections. The inductance appearing at output terminals *a, b* of the antenna is correspondingly reduced by this cancellation, to a value far below that of two single rod antennas with coils connected in series. It should be observed that while the inductance of the antenna is thus reduced, the voltage across the terminals *a, b* and the effective height of the antenna remains substantially equivalent to twice the voltage produced by a single rod antenna. In effect then, by winding the coils oppositely and linking them with a closed core of flux-conducting material as shown, it is possible to obtain a virtual height twice the effective height of a single rod antenna while substantially reducing the inductance of two single rod antennas in series. With inductance reduced at constant Q, a better signal-to-noise ratio in the antenna itself is obtained, and greater output is achieved relative to the noise of circuits following the antenna.

It will be evident that the above explanation with reference to FIG. 1 applies analogously to FIGS. 2, 4, 5 and 6.

The amount of inductance reduction depends on the amount of coupling that occurs in the core **1**. Thus highly permeable substances make the best materials for the core. Commercially available ferrite having a toroidal permeability μ_0 of approximately 2400 has been used with excellent results, although materials of lower or higher permeability can obviously be used if desired.

Several refinements of the basic invention have been found to contribute to enhanced results.

It has been found that increasing the length to diameter ratio of the rods **2** and **3** increases the effective height to antenna weight ratio. Thus, in other words, elongate rods produce a greater effective height for a given amount of ferrite than short rods. Where they can be used, long rods will therefore be less expensive for a given effective height. Such an antenna is shown in FIGS. 13 to 16.

A further refinement which increases effective height concerns the winding of the coils **6** and **7**. It has been found that maximum effective height is obtained when the coils are wound on substantially the entire length of the rods **2** and **3**.

It has also been found that by providing enlarged end pieces **14** and **15**, as shown in FIG. 2, the effective height of the antenna can be substantially increased with a less than proportional increase in inductance. As shown, the end pieces **14** and **15** are each of height *h* greater than the thickness *t* of the rods, and of width *w* greater than the outside spacing *s* of the rods **16** and **17**.

A refinement which has been found useful in eliminating unwanted air coupling or leakage of flux is shown in FIG. 3. Slotted conducting discs **8** of aluminum for example, placed over one or more ends of the rods **2** and **3** between the end pieces **14** and **15** and the coils **6** and **7** to act as shorted loops, have helped to reduce the amount of stray coupling that takes place, thereby further reducing the inductance of the antenna without appreciable effect on the signal flux and hence without appreciably reducing its effective height.

FIG. 4 shows a composite antenna utilizing the present invention. This antenna is enclosed in a streamlined housing of any suitable construction represented symbolically by a dotted line **20**. One component of the antenna is a balanced antenna **21** as heretofore described with reference to FIG. 1, having the form of a frame with long bars and short end pieces, bars and end pieces being of similar cross sections. To pick up transverse signals and thereby provide omniazimuthal reception, a simple loop antenna coil **22** is wound as a second component over the antenna **21** and over a plurality of toroidal ferrite frames such as rings **23** disposed around the antenna **21**. The output terminals are indicated at *f, g* for antenna **21**, and at *u, v* for antenna **22**. The long, narrow antenna **21** is well suited for placement in the longitudinal direction of the shell **20** and it has been found to work well in conjunction with the loop antenna **22** disposed with its cores in the shorter transverse direction and of equal length.

In a practical embodiment, this composite antenna was 21 inches long with all core cross sections one inch square, with one-half inch separation between the long rods, and with a diameter of the ferrite toroids **23** of about 6 inches. The balanced antenna component had 2 x 44 turns, and the loop antenna component 27 turns, both of 120/36*s* litz wire. As a core material, Stackpole **24**, with a mμ rating of 2400 was satisfactory.

FIG. 5 shows another embodiment of the invention. This antenna has four bars **31, 32, 33, 34** joined to form a rectangular, here square, core **30** forming a closed frame of flux-conducting material. On two opposite rods, such as **31, 33**, a first pair of coils **35, 36** are wound in opposite directions and connected in series with output terminals A, B. Similarly, on the other two opposite rods **32, 34**, a second pair of coils **37, 38** are wound in opposite directions and connected in series with output terminals C, D. An electrostatic shield indicated schematically at **39** and preferably combined with a housing as shown in FIG. 7 encloses the antenna.

The antenna of FIG. 5 incorporates in essence two identical antennas of the type described with reference to FIG. 1, both of which use the same core for induced flux cancellation, and which can be used individually, or, with appropriate phase additive circuitry, together constitute a crossed loop antenna for omniazimuthal reception. In accordance with the above explained principle, flux induced in the core by current in any one pair of series coils will have no net effect on the other pair, and thus the signals appearing at the two output terminal pairs A, B, and C, D will be entirely independent of each other. This aspect of the antenna of FIG. 5 renders it highly useful in direction-finding applications and in systems such as described in copending application Ser. No. 525,970, filed Feb. 8, 1966 now Patent No. 3,369,235. For example, the outputs of the orthogonal coils can be fed to two orthogonal fixed windings of a resolver or goniometer. The output is then a double figure eight pattern which can be rotated in azimuth by simply turning the resolver rotor, which can be kept in proper azimuth relation to the transmitting station either manually or by automatic tracking from a gyro compass system.

The circuitry shown schematically in FIG. 5 illustrates another way in which the two antenna outputs of this embodiment can be coupled, namely for utilization in omniazimuthal Loran-A reception.

For a given carrier signal of the form $k_1 \sin \omega t$, received from any azimuth angle ϕ relative to the positioning of one pair of coils such as **35, 36**, the output signal at terminals A, B will be of the form $k_2 \sin \omega t \cos \phi$ and the output signal at terminals C, D will be of the form $k_2 \sin \omega t \sin \phi$, where k_1 and k_2 are arbitarary constants.

These antenna output signals are led, preferably by shielded twisted cable, to the coupler circuit shown in FIG. 5. The two antenna signals go first to input circuit protectors **50, 51** which protect further circuitry from high spurious signals, and then through matching units and filters **52, 53** to feedback preamplifiers **54, 55**. The two amplified antenna outputs go from these preamplifiers to coupled phasing networks **56, 57** which introduce a 90 degree phase difference between the signals. The output signals from the phasing networks, which are then of the form $k_3 \cos \omega t \cos \phi$ and $k_3 \sin \omega t \sin \phi$, respectively, are summed at **58** to produce a signal of the form $k_3 \cos \omega t \cos \phi + k_3 \sin \omega t \sin \phi = k_3 \cos (\omega t - \phi)$. The summed signal is then amplified by power amplifier **59** for use in Loran-A apparatus of known construction. A single power supply and regulator **60** supplies the three amplifiers **54, 55** and **59**.

The output from the antenna and circiut of FIG. 5 is of the form $k_4 \cos (\omega t - \phi)$ and it is thus apparent that a carrier phase alteration directly related to the direction of reception is introduced. For systems such as Loran-A, which compares the time of arrival of pulse envelopes from various directions, a shift in the carrier phase is unimportant, and therefore the antenna of FIG. 5 can be used to advantage. Its low weight and flat configuration (compare FIGS. 7 to 11) enable it to be mounted without protruding and thereby causing drag, on aircraft and the like. Its low impedance and noise enable it to be matched into an amplifier with little increase in noise so that limiting noise in a practical case is primarily determined not by following amplifiers, but by the thermal noise of the antenna alone. A high Q antenna can be used, therefore, even though the bandwidth desired is relatively broad, and broadband atmospheric noise is the final limitation of sensitivity rather than the antenna.

FIG. 6 illustrates a further aspect of the present invention. In this embodiment a core **70** forming a frame of flux conducting material has parallel rods **71, 72** upon which a plurality of series connected oppositely-wound coil pairs **73, 74, 75** are "wound in opposite directions" as above explained. The current in any one coil pair produces oppositely directed fluxes which cancel; it therefore follows that the current in any coil pair has no net effect on any other coil pair and the output terminals of a coil pair can be loaded, shorted, or energized without affecting the operation of the core **70** for other signals. Thus a plurality of coil pairs can be used as shown and multiple frequencies for multiple receivers can be utilized on the same core, with the advantages that will be evident to those skilled in this art.

While the above-described embodiments incorporate rectangular core frames which can be easily fabricated, it should be understood that toroidal core shapes of any desirable configuration can be used if desired. For example, an elongate frame with rounded ends may be used to advantage for a streamlined structure similar to FIG. 4. Also, polygonal such as triangular core frames can be used, with sharp or rounded corners.

FIGS. 7 to 11 illustrate the previously mentioned practical mounting structure for the square core antenna shown in FIG. 5.

The core **34** is held between two foam sheets **80, 81** which have chamfered edges to receive and hold the inner portion of the core and which together completely fill the open center of the core. Fastened to the sheets **80, 81** by bolts **82** are printed circuit board electrostatic shields **83** and **84**, which overhang beyond the core. These shields, as shown in FIGS. 9 and 10, have strips or copper **83.1, 84.1** spaced by strips of board. Strips **83.1** are interconnected as shown at **83.2**. The copper strips of the boards are connected by copper tapes **85** as shown in FIGS. 9, 10 and 11. Cemented to one of the shield boards, such as **83**, is a plurality of sockets **86** for fastening the antenna assembly to its support. Also cemented to the board **83** are conduit connectors **87, 88**, for leads from the two pairs of coils of the antenna. Plastic material, such as solid polyurethane, is then applied by casting around the fastening means **86** and connectors **87, 88** to form a plate **89** on top of and coterminous with the board **83**. The same plastic is cast into the space outside the sheets **80, 81** and between the boards **83, 84** to form a secure collar **91** around the core **34**. The antenna is supported virtually vibration-free by this mounting structure.

FIGS. 12 to 16 illustrate a practical structure for mounting rectangular antennas such as according to FIGS. 1 and 2.

Fastened to a base plate **101**, on top of which is a bottom printed circuit board shield **102** (FIG. 16), are two opposed L-shaped support members **103.1, 103.2** which receive one end of the antenna core **105**. Transverse to the L-shaped members are two opposed supports **106.1, 106.2** which have tongues **107.1, 107.2** fitting into the open center of the core **105** to hold it securely. The supports **106.1, 106.2** are fastened together by screws **108, 109** and have their bases resting on the shield board **102**. These supports are made from syntheic dielectric material. A cylindrical printed circuit shield **110** rests around the antenna with its bottom rim cemented to the bottom shield board **102**. The cylindrical shield **110** consists of printed circuit elements **110.1** which encircle the board of the shield proper, are joined by a spine **110.2**, and open at diametrically opposite points (not shown). The shield elements are properly interconnected and if desired grounded. Using the cylindrical shield board **110** as a mold, a foam forming liquid is poured around the antenna to fill the cylinder completely. A top printed circuit board shield **111** (FIG. 15) is placed at the top of the cylindrical shield **110**. All parts of the assembly above the base plate **101** are then placed in a mold and embedded in a cover **112** made from solidifying plastic, such as polyurethane. A metal tray **113**, to which a lead connector **114** and fastening sockets **115** are attached, is then secured to base plate **101** across spacers **116** cemented to the tray. The tray is filled with cast foam **117** which hardens to embed the baseplate **101** as well as the sockets **115** to form a solid, vibrationless structure.

It should be understood that the present disclosure is for the purpose of illustration only and that this invention includes all modifications and equivalents which fall within the scope of the appended claims.

I claim:

1. An antenna comprising:

a core forming a closed path of flux conducting material having two parallel, high permeability flux-conducting rods upon which the coils are wound, and two enlarged likewise high permeability flux-conducting end pieces for connecting the adjacent ends of the rods; and

a pair of coils wound on opposite sections of the core and connected in series, the coils being wound in opposite directions on their respective sections, so that signal-carrying wave energy appears within the core sections as correspondingly varying flux of one direction inducing additive voltages across the series coils, whereas the opposite flux induced in the core sections by the currents in the respective oppositely wound series coils cancels;

said enlarged end pieces being of essentially similar magnetic material as the rods, of height greater than the thickness of a rod, and of width greater than the outside spacing of the rods.

2. An antenna comprising:

a core forming a closed path of flux conducting material having two parallel flux-conducting rods upon which the coils are wound and flux conducting means for connecting the adjacent ends of the rods;

a pair of coils wound on opposite sections of the core and connected in series, the coils being wound in opposite directions on their respective sections, so that signal-carrying wave energy appears within the core sections as correspondingly varying flux of one direction inducing additive voltages across the series coils, whereas the opposite flux induced in the core sections by the currents in the respective oppositely wound series coils cancels; and

slotted disc means placed at the end of a rod between the coil and the end piece, for reducing air coupling of flux.

3. An antenna comprising:

a core forming a closed path of flux conducting material;

a pair of coils wound on opposite sections of the core and connected in series, the coils being wound in opposite directions on their respective sections, so that signal-carrying wave energy appears within the core sections are correspondingly varying flux of one direction inducing additive voltages across the series coils, whereas the opposite flux induced in the core sections by the currents in the respective oppositely wound series coils cancels;

a plurality of flux conducting frames disposed around the core; and

a loop coil wound over the frames and the core with it axis intersecting the direction of the axes of the pair of coils on the core.

4. Antenna according to claim **3** wherein:

the core sections are elongate and connected by comparatively short end pieces,

the frames are essentially annular, and

the loop coil is wound over the end pieces and over corresponding frame portions.

5. An antenna comprising:

a core forming a closed path of flux conducting material; and

a plurality of pairs of coils similarly wound on each one of opposite sections of the core and connected in series, the coils of each pair being wound in opposite directions on their respective sections, so that signal-carrying wave energy appears within the core sections as correspondingly varying flux of one direction inducing additive voltages across the series coils, whereas the opposite flux induced in the core sections by the currents in the respective oppositely wound series coils cancels each of the pairs of coils constituting an individual antenna with individual output terminals.

6. A composite antenna comprising:

a core having a first and second pair of rods forming opposite sides of a closed frame of flux conducting material;

a first pair of coils one coil wound on each rod of the first pair of rods in opposite directions and connected in series; and

a second pair of coils one coil wound on each rod of the second pair of rods in opposite directions and connected in series,

whereby signal carrying wave energy appears within respective pairs of opposite rods as correspondingly varying flux of one direction inducing additive voltages across the series coils on said pairs of rods, whereas the opposite flux induced in the core sections by the currents in the respective oppositely wound series coils cancels, and whereby the composite antenna constitutes two individual antennas which can be used separately or as orthogonal components for omniazimuthal reception.

7. Antenna according to claim **6** wherein the pairs of rods are of equal length and at right angles to each other, the coils of identical electrical dimensions, and the coil terminals are connected to form a crossed loop system.

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ELI LIEBERMAN, Primary Examiner

U.S. Cl. X.R.

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