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[11] **3,623,116**

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[73] Assignee **The United States of America as represented by the Secretary of the Navy**

[54] FERRITE CORE CROSSED SPACED LOOP ANTENNA

10 Claims, 9 Drawing Figs.

[52] **U.S. Cl.** **343/788,** 343/842, 343/872, 343/879
[51] **Int. Cl.** **H01q 7/08**
[50] **Field of Search** 343/788, 842, 872, 879, 878

[56] **References Cited**
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ABSTRACT: Disclosed herewith is an antenna having an upper tier field sensor of four ferrite core loop antennas connected in crossed simple-loop mode disposed at 90° intervals around a center support pipe and a lower tier direction finder of eight ferrite core loop antennas connected in crossed spaced loop mode likewise disposed around said center support pipe but at 45° intervals. The electrical leads of each of said ferrite core loop antennas of both of the aforesaid tiers are respectively connected to each other and a compatible data processing receiver in such manner and as necessary as to effect a bearing readout therefrom of predetermined electromagnetic energy sensed by the entire antenna.

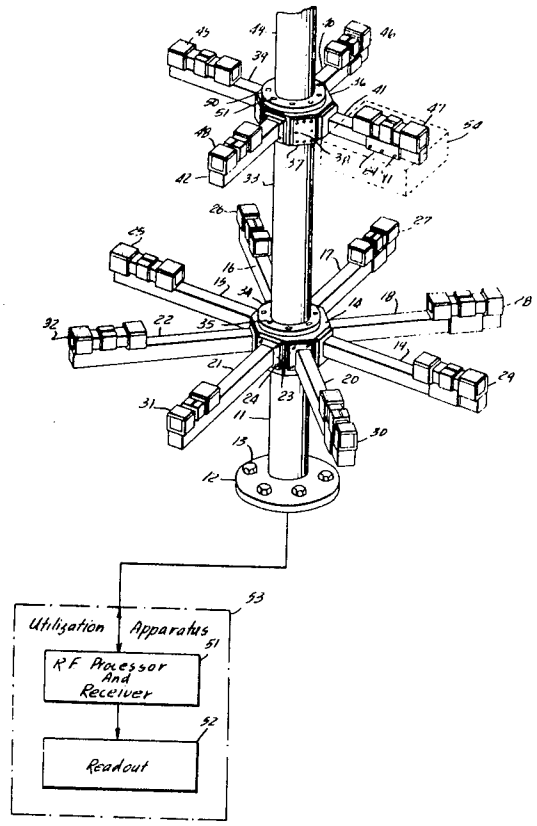
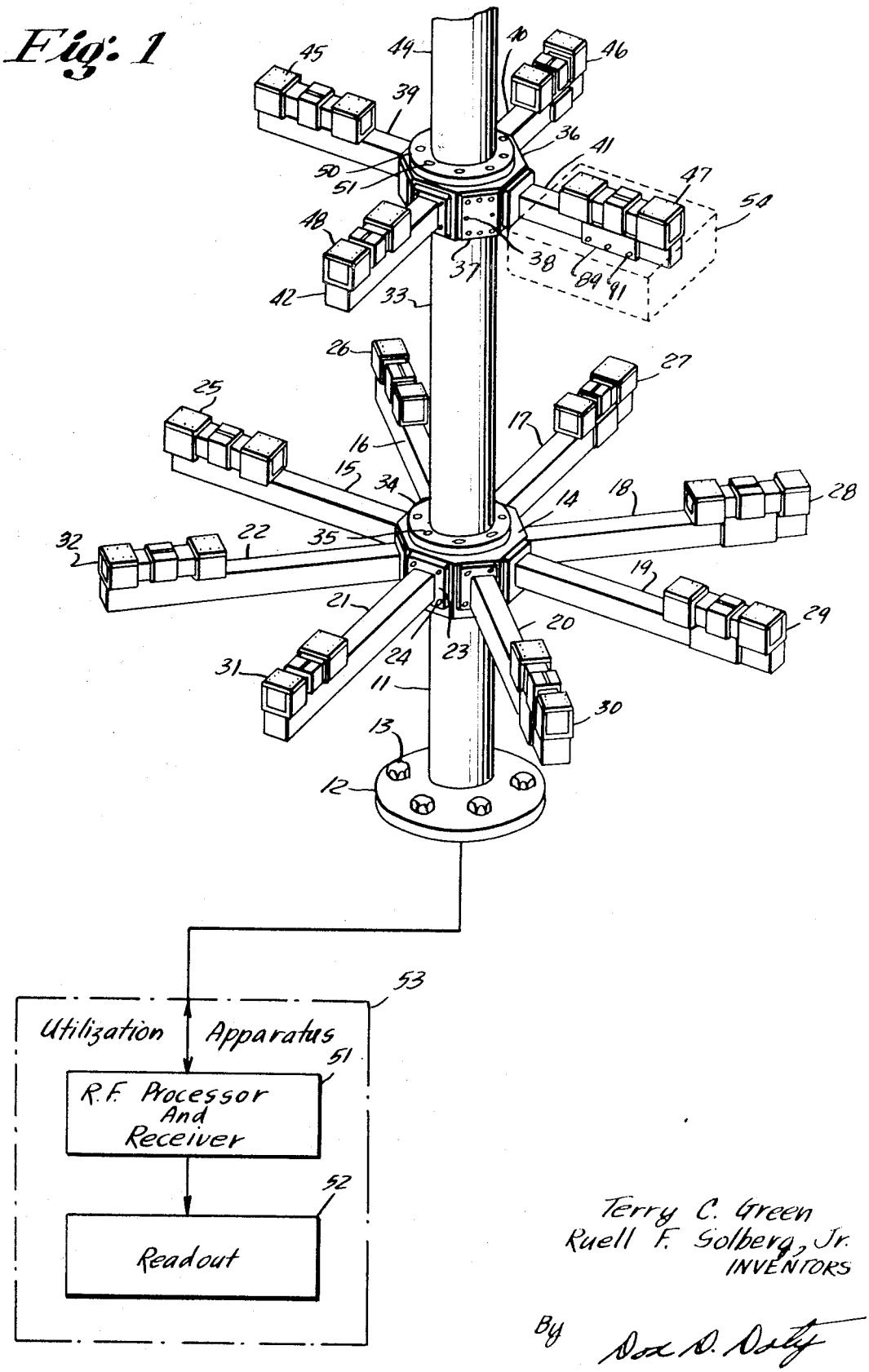


Fig. 1



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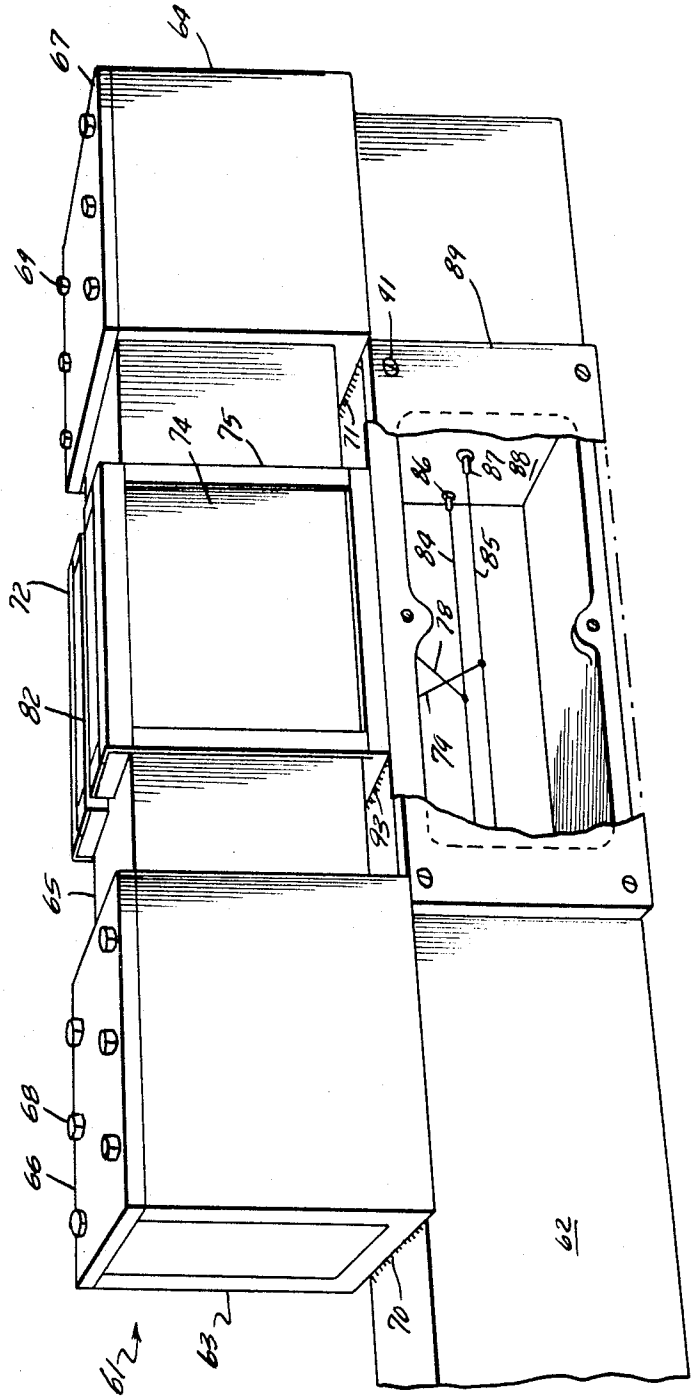


Fig. 2

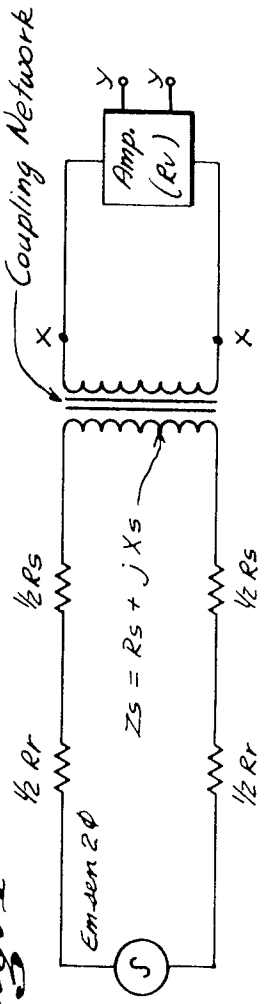


Fig. 1

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Fig. 3

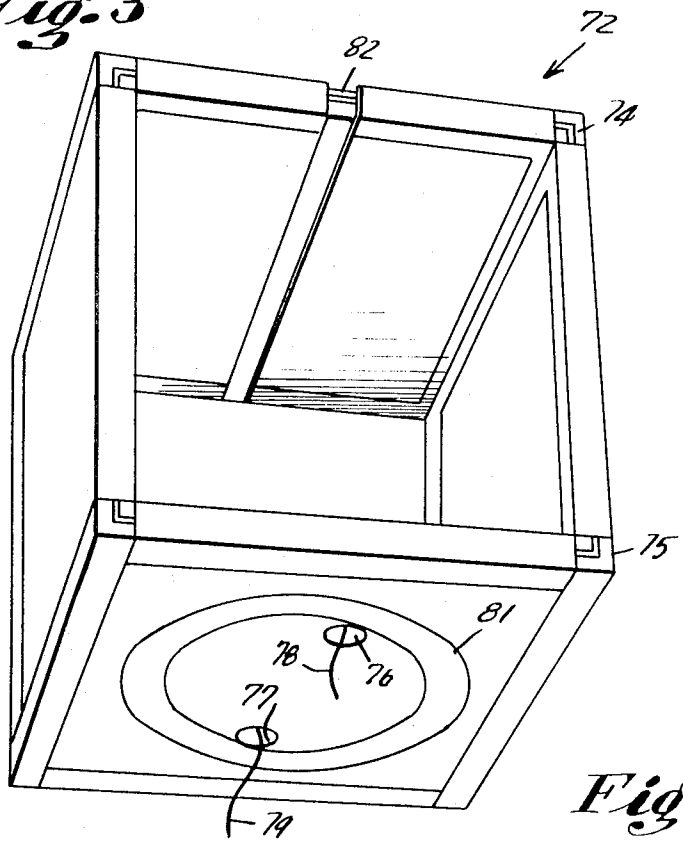


Fig. 4

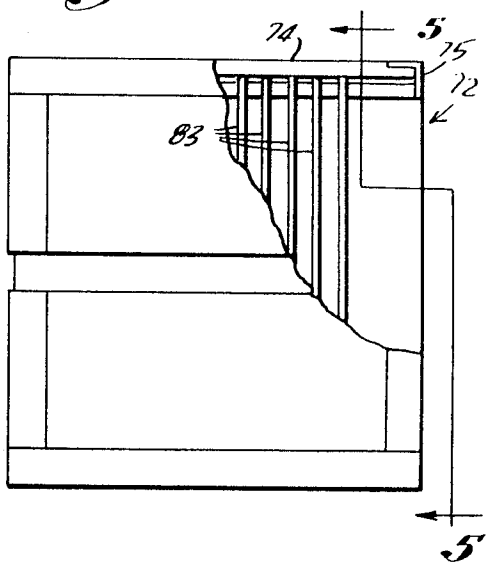
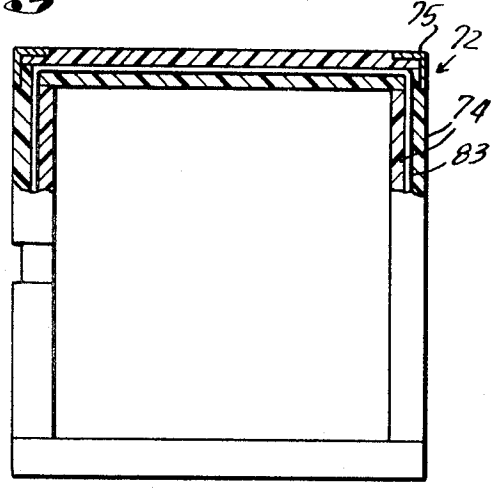


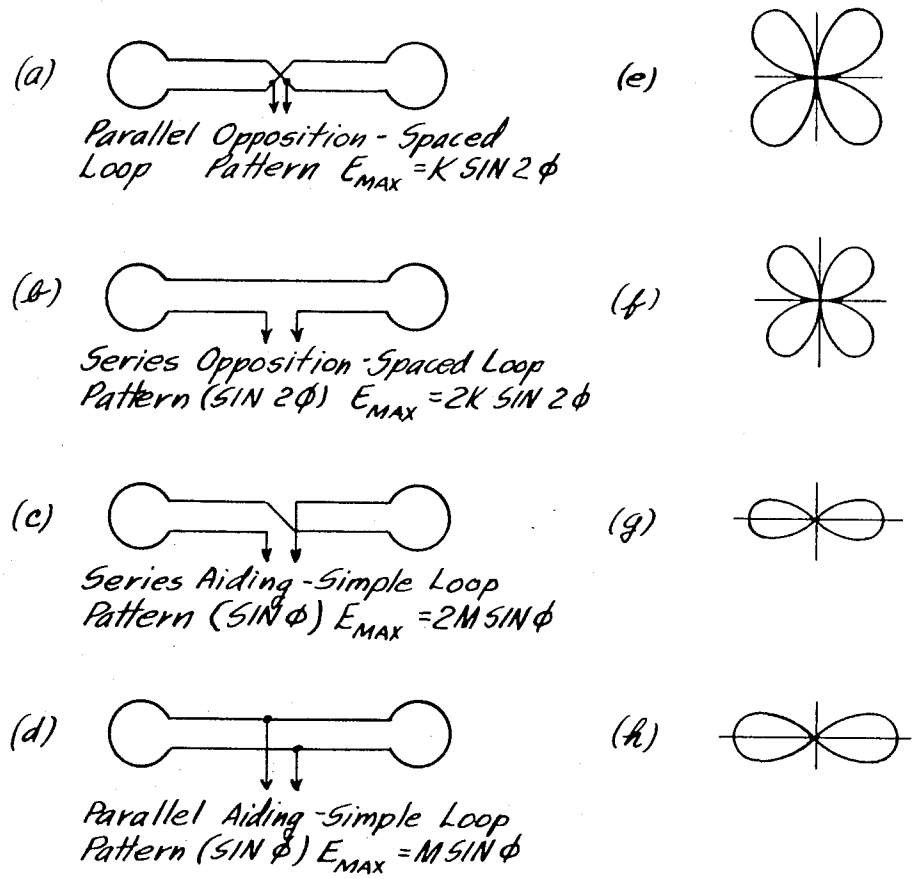
Fig. 5



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Fig. 6



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Fig. 8

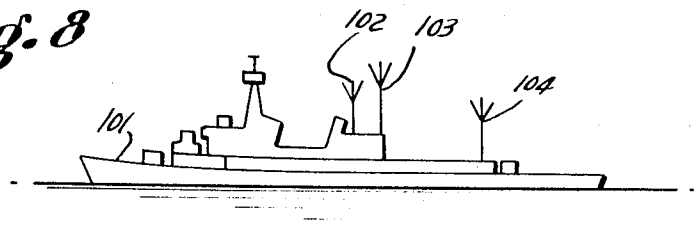
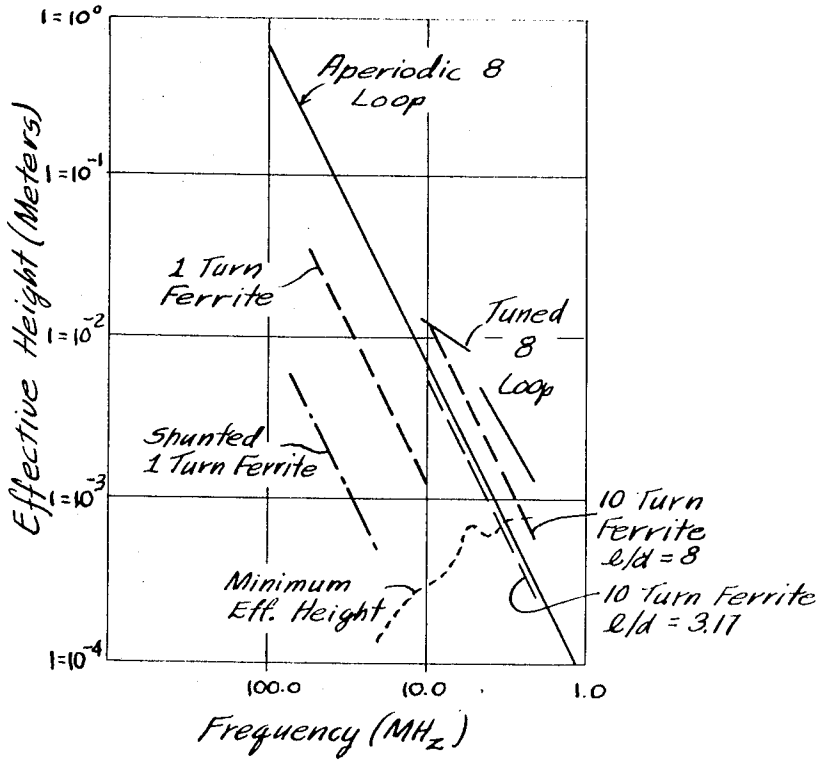


Fig. 9



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FERRITE CORE CROSSED SPACED LOOP ANTENNA

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

FIELD OF INVENTION

The present invention relates, in general, to radio antennas and, in particular, is a crossed ferrite core spaced loop antenna with ferrite core simple-loop sensing. In even greater particularity, the invention is a unique combination of ferrite-cored, tiered, loop antennas which are structurally arranged to have improved broadband sensing and direction finding performance characteristics for a given size, thereby facilitating its being used aboard ship or in other places where, for one reason or another, space limitations must be considered.

BACKGROUND OF THE INVENTION

High-frequency shipboard radio direction finders, for example, are used to a considerable extent against submarine or coastal inshore transmitters, and the usual performance required thereof is that of determination of the azimuth angle of the signal arriving therefrom. Of course, in addition, direction finding receivers and the antennas associated therewith may also be combined with other devices, such as passive countermeasure devices, and for other purposes, such as, for instance, net controlled position location, signal recording, signal analysis, and the like.

Because of their size limitations, shipboard high-frequency direction finders must employ a relatively small aperture direction finding (DF) antenna which determines the normal to the incoming wavefronts incident thereon; that is, the apparent direction of the received signal propagation in the vicinity of the antenna. For the idealized case of plane wave incidence, the small aperture direction finder achieves bearing accuracies equivalent to that of a wide aperture system; however, the plane wave is seldom, if ever, achieved in actual practice aboard ship, because of the adverse affects of masts, yardarms, bridge structure, and other antennas. Such structures passively reradiate incident energy which, in turn, produces coherent perturbations to the incident wave front, so that the wave front normal to the resultant field does not correspond to the direction of propagation to a distant target. This reradiation error is the most significant cause of bearing aberrations or errors in shipboard direction finder antennas.

In addition to the requirement for operation in the reradiation environment, the direction finder must also function against target emitters which utilize deceptive techniques to make an accurate interpretation of the bearing display extremely difficult.

Finally, since small aperture direction finding antennas typically produce bearing ambiguities—that is, more than one bearing to the target, only one of which is correct—still another major requirement of the operational direction finder is to resolve such bearing ambiguities in the shipboard environment, in order to produce an unambiguous azimuth to the target emitter.

Hence, it may readily be seen that such a background of operational conditions requires a sophisticated method and means for avoiding or overcoming the adversities presented thereby, and, thus, antennas having physical and operational characteristics which constitute improvements over the prior art are of considerable value and are needed if accurate direction finders are to be employed for all practical purposes.

DESCRIPTION OF THE PRIOR ART

In the past, air core antennas, in general, and eight-loop crossed spaced air core antennas, in particular, have been developed and used in the aforementioned environments; and for many practical purposes have been eminently satisfactory,

too. However, in most cases during the use thereof, it becomes obvious that they have a great deal to be desired because of their deleterious size, weight, and vibration characteristics. For example, the typical air core eight-loop shipboard antenna utilizes aluminum alloy tubing for the construction of the elements thereof, and such tubing forms the electrostatic shield about a suspended insulated inner conductor. Each element is attached to a center hub which forms the main antenna support and ordinarily contains the associated electronic circuitry, as well. The hub also provides the interface to the support mast for single point mounting. Although comparatively light in weight in most installations, they are usually quite large in size for any given design frequency range. But because they require substantially uncluttered, large installation spaces for accurate operation, their excessively large size constitutes a severe handicap from the performance standpoint, as well as from the standpoint of just obtaining a physical location within which they will fit without disturbing other nonassociated but necessary shipboard equipment. Moreover, due to their geometrical configurations, they sometimes become awkward and difficult to handle or maintain in their mounted positions. But most of all, as previously mentioned, due to their large size, they are extremely susceptible to errors effected by reradiated signals from local ambient structures.

SUMMARY OF THE INVENTION

The instant invention overcomes most of the disadvantages and difficulties of the air core antennas of the prior art, in that the incorporation of ferrite cores therein in conjunction with the other unique structural elements associated therewith causes a new and very useful combination of elements to be effected, which, in turn, considerably reduces the size, considerably simplifies the geometrical configuration, and vastly increases the sensitivity compared to equivalent size air core antennas. Hence, both conceptually and actually, the subject ferrite core crossed spaced loop antenna offers considerable merit in shipboard and other relatively confining situations. Furthermore, due to its compactness, it is more easily and economically manufactured, installed, maintained, stored, and operated. In addition, because the inductance of the subject ferrite core spaced loop antenna is greater than that of a comparable air core antenna of identical height, arrays thereof have greater sensitivity at lower frequencies. Also, through appropriate construction and alignment techniques and using the aperiodic mode, it may be used over extremely large bandwidths, depending on the desired sensitivity.

It is, therefore, an object of this invention to provide an improved crossed spaced loop antenna.

Another object of this invention is to provide an improved direction finding antenna.

Still another object of this invention is to provide an improved ferrite core antenna.

A further object of this invention is to provide a compact radio direction finding antenna having reduced reradiation errors which occur as a result of being in too close proximity with the secondary fields reradiated from ambient ship superstucture and other onboard apparatus.

A further object of this invention is to provide a crossed spaced loop antenna that is smaller in size than a comparable air core antenna of equivalent inductance and signal bearing sensitivity.

Still another object of this invention is to provide an improved crossed spaced loop antenna array having improved bandwidth performance characteristics for any given size, when compared to a comparable air core crossed spaced antenna array.

Another object of this invention is to provide a radio antenna array having tiered upper and lower sense and direction finding ferrite core simple loop antennas spaced at 90° and 45°, respectively.

Another object of this invention is to provide a unique ferrite core antenna having improved vibration characteristics,

thereby being less affected by shaft, propeller, and ship motion vibration at various sea states, ship speeds, and wave encounter angles.

Another object of this invention is to provide a ferrite core crossed spaced loop antenna having improved corrosion characteristics, while maintaining critical low electrical resistance joints at the various and sundry interfaces thereof.

Another object of this invention is to provide a ferrite core crossed spaced loop antenna that is easily and economically manufactured, installed, maintained, and operated.

Other objects and many of the attendant advantages will be readily appreciated as the subject invention becomes better understood by reference to the following detailed description, when considered in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWING

FIG. 1 is a pictorial view of a preferred embodiment of the subject invention which illustrates an array of ferrite core loop antennas arranged in a four loop upper sense tier and an eight loop lower direction finding tier;

FIG. 2 is an enlarged view of the ferrite core spaced loop antennas sensors incorporated in the antenna array of FIG. 1;

FIG. 3 is a perspective view of the electrostatic shield portion of the ferrite core loop sensors of the antenna constituting this invention;

FIG. 4 is a top schematic view with parts broken away of the electrostatic shield and antenna loop combination incorporated in the invention;

FIG. 5 is a cross-sectional view of the device of FIG. 4 taken at 5—5 thereof;

FIG. 6 schematically depicts various and sundry loop arrangements, their possible electrical crossover connections, and idealized representations of the response or radiation patterns obtainable from or produced thereby, respectively, and which may optionally be incorporated in the subject invention;

FIG. 7 schematically illustrates an equivalent spaced loop antenna circuit;

FIG. 8 is a schematic pictorial view of various appropriate shipboard locations for the subject antenna; and

FIG. 9 is a graphical representation of the performance curves of various ferrite core spaced antenna, including that of the instant invention, wherein operational frequency is plotted against effective antenna height.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to FIG. 1, there is shown a combination four loop sense and eight loop direction finding antennas as having a pipe 11 which has a substantially vertical longitudinal axis at the center of the passageway thereof and which preferably acts as the main support member for the remainder of the antenna. Although not shown in detail, pipe 11 may be attached to any suitable support structure, such as that of a ship or other vehicle, by any appropriate, conventional attachment means, such as, for example, by a flange 12, which is bolted thereto by a plurality of screws or bolts 13. Of course, said attachment means may also include a plurality thereof and, additionally, may be located at one or more positions along pipe 11, in order to securely position it in the proper location and at the proper attitude. Obviously, it would be well within the purview of one skilled in the art having the benefit of the teachings presented herewith to employ whatever support means for pipe 11 as is deemed desirable for any given operational circumstances. Moreover, if so desired, said artisan could also incorporate any suitable adjustable or rotatable attitude determining attachment means for such purpose, too.

Attached to a flange at the upper end of pipe 11, as by bolts or the like, is a hub 14 having eight holes spaced at 45° intervals therearound, and attached to said hub 14, respectively, in line with said holes, is a lower tier of eight hollow, cantilever, tapered-wall, arms 15 through 22 which radially extend therefrom. Said arms are preferably attached by a like plurality of flanges 23 and a plurality of bolts 24, as is exemplarily depicted with respect to arm 21.

At the outer end of said arms 15 through 22, a like number of ferrite core electromagnetic energy sensor loop antenna assemblies 25 through 32 are respectively mechanically connected thereto, as by a clamp type arrangement—encapsulation, or any other appropriate, conventional connection means. Spaced loop antennas 25 through 32 are all alike and will be described in detail subsequently in conjunction with FIGS. 2 through 6. Suffice to say at this time, that, basically, they each include N turns of wire wound around a rectangular cross section bar of ferrite material, which, in turn, is held to said arms by means of complementary configured saddle or cradlelike assemblies bolted, encapsulated, or otherwise attached thereto.

Another pipe 33 is mounted on the top of hub 14 by a flanged portion 34 and a plurality of bolts 35, or the like. The longitudinal axis of pipe 33 is aligned with the longitudinal axis of pipe 11 and effectively acts as an extension thereof.

Connected to the upper end of pipe 33 is another hub 36, with the connecting means being by flange and bolts like the connections between the lower end of pipe 33 and the upper side of hub 14, although in the view of FIG. 1 it cannot be seen.

Hub 36 is preferably similar in some respects to hub 14, but only predetermined diametrically opposed holes (spaced 90° therearound) are used for antenna purposes, with the remaining holes thereof covered by plates 37 and a plurality of bolts 38.

Like the arms in the lower direction finding tier of the antenna, a plurality of hollow cantilever, tapered-wall, arms 39 through 42 are respectively connected to hub 36 by means of a like number of inner flanges, exemplarily illustrated by flange 43 and bolts 44 in conjunction with arm 42. As may readily be seen, the upper sense tier of the subject antenna has only four arms connected to hub 36, with arms 39 and 41 aligned parallel with arms 15 and 19 of the lower tier, and with arms 40 and 42 aligned parallel with arms 17 and 21 of said lower tier.

At the outer ends of arms 39 through 42, a like plurality of three-turn loop electromagnetic energy sensor antenna assemblies 45 through 48, which are identical to the aforesaid ten-turn loop electromagnetic energy sensor antenna assemblies 25 through 32, are mounted by clamping, or any other suitable mounting means.

Still another pipe 49 is optionally mounted on top of hub 36 by a flanged portion 50 and a plurality of bolts 51, or the like. Of course, the longitudinal axis of pipe 49 is in coalignment with the longitudinal axes of pipes 11 and 33 and, thus, effectively constitutes an extension thereof. Obviously, pipe 49 may, likewise, be used as both support means and an attachment means for other shipboard elements not related to the subject DF antenna, if so desired, although no specific shipboard or other mounting means is shown connected thereto.

Although other appropriate and compatible materials may be used to make the various components of the invention, the aforesaid hubs and support arms are preferably manufactured of aluminum alloy and are cadmium plated for maximum corrosion resistance to sea water and other adverse environmental conditions or elements.

Electrical leads, effectively connected to the loop antenna assemblies of the sense and direction finder tiers, respectively, ordinarily extend through any of the aforesaid arms and pipes 11 and 33 are coupled to the inputs of a radio frequency processor and receiver 51. Of course, the receiver (portion of 51) is of any predetermined type of receiving means that performs signal processing functions in such manner as to optimize the response of the subject antenna for any given operational circumstances. Obviously, it would be well within the purview of one skilled in the art having the benefit of the teachings presented herewith to select whatever receiver,

phase shifter, data processing and/or computer systems that would accomplish said optimization. Likewise, a suitable readout 52 is preferably selected and connected to the output of receiver 51, the combination of which forms a utilization apparatus 53.

At the option of the artisan, depending on operational circumstances, and for reasons to be discussed in greater detail subsequently, the entire antenna or any portion thereof may be encapsulated in a potting compound 54. Such potting is depicted exemplarily in FIG. 1 by means of the dashed line 54 around the ferrite loop element 47, but, of course, any preferred geometrical configuration may be used therefor.

Perhaps at this time it should be noted that the mechanical connection means used to properly mount and interconnect the aforesaid various structural elements of the instant invention to effect the preferred geometrical configuration depicted in FIG. 1 (and the concomitant drawing figures, as well) are well known and conventional, per se; thus, it is the unique assemblies and subassemblies produced thereby which causes the invention to be effected and enables it to uniquely perform new and/or improved antenna functions, especially with respect to comparable prior art air core antennas.

Referring now to FIGS. 2 through 5, where, to the extent practicable, like elements are identified by like reference numerals, there is shown various and sundry views of the assemblies that are incorporated in the subject invention, along with some of the specific details thereof.

FIG. 2, in particular, illustrates a ferrite core loop antenna assembly 61 that is similar to the ferrite loop antenna assemblies 25 through 32 and 45 through 48 mentioned above during the description of FIG. 1, as well as an end portion of an arm 62 that is similar to the aforesaid radially extending arms 15 through 22 and 39 through 42. Hence, it may readily be seen that FIG. 2 portrays in greater clarity and detail the outer receiving ends of the booms of the subject antenna and FIGS. 3 through 5 depict additional details thereof.

Antenna assembly 61 includes a pair of saddles 63 and 64, each of which are preferably made of NEMA Grade G–10 or G–11 shock resistant fiberglass. Disposed within and extending between said saddles 63 and 64 is a ferrite bar 65, which is a continuous ferromagnetic material preferably made of Q–1 grade ferrite, manufactured by Indiana General Corporation, but may be constructed of any suitable ferrite composition. A pair of covers 66 and 67 secure ferrite bar 65 firmly within the aforesaid saddles 63 and 64, and they are attached thereto by means of a plurality of bolts or screws 68 and 69, respectively. Although in this particular embodiment covers 66 and 67 are respectively attached to saddles 63 and 64 by the aforesaid bolts 68 and 69, as an alternate means for accomplishing such securing operation, a plurality of studs may be extended down through holes within said saddles, and, perhaps, even screw into threaded holes within arm 62 for the mounting thereof on said arm 62. Of course, in such case, nuts would be screwed on the upper threaded ends of said stud, in order to make a firm fast geometrical configuration of the saddle assemblies and the ferrite bar secured thereby.

In the subject preferred embodiment, however, saddles 63 and 64 are preferably secured to the aforesaid boom arm 62 by means of bolts extending through the L-shaped base of the saddles 63 and 64 into the aluminum arm 62, any suitable adhesive 70 and 71, such as, an epoxy resin, or the like.

Referring now to FIGS. 2 through 5 there is shown an electrostatic shield 72 which is mounted around the aforesaid ferrite bar 65. Said electrostatic shield 72 is preferably an open-ended boxlike construction of copper clad fiberglass boards 74 which are framed within copper-clad frame members 75 which are soldered to each other and to the copper cladding of the aforesaid copper clad fiber glass boards 74, in order to effect a rigidly constructed assembly thereof. The lower surface of electrostatic shield 72 has a pair of holes 76 and 77 cut therein of such dimension which will facilitate the extension of a pair of lead wires 78 and 79 therethrough. The electrostatic shield 75 is electrically connected to the upper surface of arm 72 through a monel gasket 81 and using silver-loaded epoxy.

As may be seen more readily in FIGS. 2 and 3, at the top surface of electrostatic shield 72 is a gap 82 which extends around the copper clad portions of both of the fiberglass wall boards 74 of the top walls thereof. Likewise, it may readily be seen that said fiberglass boards 74 are actually disposed in a parallel plane configuration within which a 10 or other multiturn loop coil of wire 83 is sandwiched in such manner as to be wound around that portion of the aforesaid ferrite bar 65 which is substantially the center section thereof. Of course, the electrical leads from coil 83 are those which were previously mentioned as electrical leads 78 and 79 which extended through holes 76 and 77, and they are, in turn, respectively connected to a pair of connected leads 84 and 85 which are held in place by mountings 86 and 87 attached to wall board 88 secured within arm 62. Of course said electrical leads 84 and 85 are those which extend through the passageway of arm 62 and into any of the aforementioned pipes 11 and 33, of FIG. 1 for interconnection to other ferrite core spaced loop electromagnetic sensors or to the aforementioned utilization apparatus 53, as necessary to effect the desired antenna operation during any given circumstances.

As indicated in FIG. 2, the section of arm 62 which incorporates the interconnections of lead wires 78 and 79 with electrical leads 84 and 85 is made lower end by the removal of a cover plate 89 which, during normal operation, is held in place by a plurality of screws 91 which extended therethrough into threaded holes located in said boom arm 62 (see FIG. 1).

As previously mentioned, electrostatic shield 72 can be soldered to the top surface of gasket 81 by means of solder 93. However, for structural integrity, the electrostatic shield 72 should be encapsulated with arm 62 in a suitable configuration, as schematically illustrated by dotted lines 54.

At this time, it might be well to give some consideration to possible construction features used to optimize the construction of the subject antenna, so that it will be strong and durable during installation aboard ship or at any other place where the ambient environment would be hostile. For example, the usual ship installation is at an aft mast site and, therefore, the subject antenna would ordinarily be subjected to exhaust stack gases, as well as oxygen-rich sea water splashing. As a result of such hostile environment, materials for the fabrication of the antenna were used which will minimize corrosion and still maintain the critical low electrical resistance at the various interfaces. For example, aluminum alloys were chosen because of their lower resultant weight of structure and certain aluminum alloys because of their commercial availability in the required forms and configurations. In order to reduce the effects of corrosion, various and sundry coatings were employed as necessary. For instance, the items fabricated of aluminum alloys may be cadmium plated. Furthermore, monel gasketing was used as warranted between the various plated aluminum pieces of the entire structure. Combined monel gasket material with silicone environmental gasket material were incorporated as warranted to provide radio frequency and environmental seals for the larger surface interfaces and sheets of monel impregnated with silicone rubber were employed to provide seals at other metal to metal interfaces, because the monel has been found to provide a low electrical resistance path therebetween. An adhesive sealant is preferably used around the mechanical joints, so as to protect those areas from aqueous environments, and if so desired, the entire structure may be painted with a high quality epoxy paint.

During construction, the antenna assembly or any portion thereof may optionally be encapsulated with any suitable potting compound such as for example, a high grade polyurethane similar to that manufactured as PR–1547 by the Products Research Company. This compound can be readily used on the antenna portions to be encapsulated because it has been especially formulated for electrical cables and connectors where resistance to cold flow, high tensile strength, exposure over broad temperature ranges, and high electrical insulation resistance are required.

As may be seen from the schematic portrayal of spaced loop antennas in FIG. 6, there are several connection possibilities which may be employed to achieve several radiation and resistance patterns. They are: parallel opposition-spaced loop pattern; series opposition-spaced loop pattern; series aiding-simple loop pattern; and parallel aiding-simple loop pattern. Of course, although those shown are perhaps somewhat typical, other designs are obviously available for selection by the artisan. Furthermore, although the electrical leads are not shown as being interconnected in a certain way—that is, for summing or other interaction effects—they may be connected in any electrical manner which facilitates the use of the subject invention during any particular operational circumstances. In addition they may be individually led out of the end pipe or pipes of the antenna and connected to a suitable receiver or data processor which, in turn, effects any resolving, tuning, summing, combining, interconnecting, and the like, in such manner that any desired combinations or permutations thereof will be effected for any appropriate operational frequency. Since so doing would be obvious to the artisan having the benefit of the teachings presented herewith, and in order to keep this disclosure as simple as possible, further elaborations thereon have been omitted, with the understanding that those which are shown and discussed are not intended to be by way of limitation. However, to facilitate understanding the coil connections that may be used in this invention, the schematic diagrams thereof disclosed in FIG. 6A, B, C, and D and their respective radiation or response patterns of FIG. 6E, F, G, and H are herewith mentioned.

FIG. 7, as may readily be seen from inspection thereof, is an equivalent spaced loop antenna circuit that is disclosed herewith because it facilitates the understanding of the theory and operation of the subject invention, the details of which will be discussed subsequently.

Referring now to FIG. 8, there is shown a ship **101** and a plurality of typical locations **102** through **104** where the antenna of the subject invention may be mounted to an advantage. Although ship **101** is illustrated herewith as being a representative mounting platform or support means therefor, it should be understood that numerous other mounting means may be substituted therefor, if so desired, inasmuch as it would be well within the purview of one skilled in the art having the benefit of the teachings presented herewith to so do.

FIG. 9, like FIGS. 7 and 8, is presented herewith to disclose pertinent operational characteristics of the invention, as well as facilitate comparing the effective heights of various and sundry antennas, including the instant invention, for representative operational frequency ranges. The graph thereof will, therefore, be mentioned again during the discussion of the operation of the antenna constituting this invention given below.

THEORY OF CONSTRUCTION AND OPERATION

The design of spaced loop antennas for shipboard applications or other applications wherein the immediate ambient environment is cluttered with other extraneous structure is predicated on producing a tactically useful equipment which will meet the required sensitivity and directivity over a specified bandwidth. Also, under such circumstances, it becomes necessary to take the effective height of such antennas into consideration and, accordingly, it has been found that the effective height for a coaxially spaced loop antenna may be obtained from

$$h_e=2\pi^2 A r_d N \mu_r/\lambda^2 \qquad (1)$$

where

h_e is the effective height of the antenna,
A is the cross-sectional area of the loop element,
r_d is one-half the diametrical distance between element loops,
N is the number of turns of the antenna coil,
λ is the frequency of interest, and
μ_r is the permeability of the core medium.

The voltage developed across the open-circuited antenna terminals is given by

$$V_A=h_e E_i \text{ volts} \qquad (2)$$

where

h_e is again the effective height of the antenna,
E_i is the incidence field strength in volts/meter, and
V_A is the open circuit voltage.

Therefore, an approximate method of predicting antenna sensitivity is to calculate the effective height from the proposed physical dimensions of the antenna and calculate the antenna terminal voltage for the specified field strength. However, a complete calculation of antenna sensitivity must also include an estimate of the signal-to-noise ratio developed across the receiver input impedance. Primary sources of such noise which emanates from the antenna itself are antenna radiation resistance, loss resistance, the antenna coupling network, and the first amplifier stage connected to the antenna output terminals.

A theoretical analysis of the minimum observable field strength for a given spaced loop antenna has been determined, and a spaced loop antenna equivalent circuit useful for such noise analysis is shown in FIG. 7.

The antenna noise developed at terminals x—x of said equivalent circuit is given by

$$e_o=2\sqrt{kB}\,[n_a^2 T_r R_r+n_s^2 T_s R_s]^{1/2} \qquad (3)$$

where

k is Boltzman's constant,
e_o is the antenna noise,
B is the bandwidth of the measurement device,
T_s is the temperature of the coupling network resistance,
R_s is the effective component of the impedance Z_s which includes the coupling network impedance and the loss resistance in the antenna,
T_r is the antenna equivalent temperature,
R_r is the radiation resistance of the antenna,
n_s is the voltage transfer ratio from the impedance Z_s to terminals x—x, and
n_a is the voltage transfer ratio from the antenna to terminals X—x.

Amplifier noise may be taken into account by adding the voltage produced by the equivalent noise resistance of the amplifier. The noise voltage at the amplifier output y—y is, therefore, the noise voltage of the antenna multiplied by the amplifier gain plus the internally generated amplifier noise. Thus,

$$e_o'=2\sqrt{kB}\,g^2 n_a^2 T_r R_r+g^2 n_s^2 T_s R_{ss}+TR_v]^{1/2} \qquad (4)$$

where

e_o' is the total noise at amplifier output,
R_v is the equivalent noise resistance of the amplifier,
g is the amplifier gain, and
T is the amplifier temperature.

At the terminals y—y

$$V_N=gh^e E_m \qquad (5)$$

where

V_N is the noise voltage of the antenna,
g is the amplifier gain, and
E_m is the minimum observed incident field strength.

Then we have

$$gh_e E_m=2\sqrt{kB}\;\;[g^2 n_a^2 T_r R_r+g^2 n_s^2 T_s R_s+TR_v]^{1/2} \qquad (6)$$

and solving for E_m

$$E_{(\min)}=\frac{\lambda^2\sqrt{kB}[g^2 n_a^2 T_r R_r+g^2 n_s^2 T_s R_s+TR_v]^{1/2}}{\pi^2 g A r_{dr} \mu n_s N} \qquad (7)$$

For two spaced loops oriented at 90° relative to each other and electrically connected in parallel, the radiation resistance is one-half that of a single spaced loop and is

$$R_r=1.23\times 10^5\frac{Ar_d^2}{\lambda^3} \qquad (8)$$

where

R_r is the radiation resistance in ohms.

Substituting this into equation (7), the incident field strength required for a unity signal strength at the preamplifier output terminals is

$$E=\frac{16}{\lambda\mu_r N}\sqrt{\frac{kB}{2}}\left[T_r+\frac{(g^2T_sR_s+T_vR_v)^6}{1.23\times10^5g^2(Ar_d)^2}\right]^{1/2} \quad (9)$$

where

E is the incidence field strength in volts per meter,

g is the nominal voltage gain of the amplifier, and

$n_n=n_s$ 32 unity.

From this equation, it may be seen that changing the permeability of the core medium to ferrite has a considerable effect on incident field strength response of an antenna and thus, on the antenna constituting this invention.

For a tuned spaced loop antenna the sensitivity is simply a modified version of equation (9), with the antenna noise voltages multiplied by the Q of the terminating resistance network associated therewith.

The bandwidth of the aperiodic crossed spaced loop antenna is limited by the required sensitivity at the lowest design frequency and, to some extent, by the impedance characteristics of the antenna at the upper frequency of interest. The spaced loop antenna design should be such that for a given incident field strength at the lowest frequency of interest the antenna effective height and the sensitivity will be sufficient to produce the minimum signal-to-noise ratio required to drive the appropriate direction finder receiver, data processor, or other utilization apparatus.

Since the effective height of the aperiodic crossed spaced loop antenna increases as a function of frequency squared, sensitivity does not become a factor in the upper frequency limitation but, rather, the antenna pattern quality becomes a significant factor to consider at the various resonant frequencies. For the crossed spaced loop antenna, the antiresonance (parallel resonance) can occur at slightly different frequencies for the two crossed spaced loop elements because of imperfections in their construction geometry. Antenna reactance changes very rapidly with frequency at the antiresonant points and, therefore, two crossed spaced loops having slightly different antiresonant points can quite easily have large differences in impedances in a predetermined frequency region. If the differences in impedance are sufficient, the combined patterns will be deteriorated, and large bearing errors and/or blurring will occur. This is illustrated when effective heights of the spaced loop increase sharply about the parallel resonance region. If the individual spaced loop elements of a crossed spaced loop have effective heights which do not track identically, the antenna terminal voltages will be unequal and probably out of phase in this frequency region, thereby causing pattern distortions to result.

The parallel resonance does not produce serious problems for aperiodic crossed spaced loops using conventional bipolar transistor preamplifiers as antenna terminations. These preamplifers have a relatively low input impedance and result in a low Q antiresonance within the antenna.

The antenna resonance or series resonance which forms a low antenna input impedance also can be detrimental to crossed spaced loop performance. Again, it is the slight asymmetry between the two crossed spaced loops that results in unequal antenna currents and antenna interaction at the resonance frequency region.

The series resonance is relatively independent of antenna resistive loading, and low Q techniques are not effective in reducing the pattern deterioration that may occur in this frequency region. However, it has been determined by experimentation with the eight-loop crossed space loop antenna that by actively utilizing only spaced loop elements crossed at 45° eliminates much of the pattern distortion normally present in the series resonance frequency region. Symmetry, however, must be retained, and the unused antenna elements must be electrically loaded to simulate active antennas.

Therefore, the impedance characteristics of the crossed spaced loop antenna do not limit the upper limits of the antenna bandwidth but place stringent requirements on the antenna construction, particularly from the symmetry and uniformity standpoints. The upper frequency of the crossed spaced loop antenna is ultimately limited by the spacing between the two simple loops thereof. A spacing of 1 wavelength, where said wavelength is that of the maximum desired frequency, is a nominal maximum to limit the spacing errors. The spacing between the simple loop vertical elements is normally limited to a maximum of wavelength of the operative signal divided by ten. As the frequency is increased and the wavelength divided by 10 spacing requirements is exceeded, the simple loop pattern deteriorates to produce a distorted crossed spaced loop pattern. The final design, therefore—and this is exceedingly important—is a compromise between sensitivity, bandwidth, and physical size for any specific core medium utilized. Hence, it may readily be seen that the size characteristics of the antenna constituting this invention are considerably improved through the relative miniaturization thereof compared to that of the prior art air core antennas because suitable ferrite cores are used in compatible combinations therein.

The use of ferrite cores for crossed spaced loop antennas conceptually offers considerable merit in shipboard direction finder applications. As indicated above, the ferrite core antenna is considerably more compact and usually has less critical construction requirements compared to an air core antenna of the same effective height. An extensive theoretical analysis of the application of ferrite cores to spaced and simple loop antennas has been made, and the results of such analysis illustrated the effect of the physical parameters of the ferrite core and the other antenna elements combined therewith on the effective height and the inductance of the antenna. For a ferrite core spaced loop and an air core spaced loop of equivalent effective heights, it has been found that the inductance of the ferrite antenna will be considerably larger than that of the air core antenna. Such increased inductance results in lower resonant frequencies compared to those of an air core antenna with an equivalent effective height. Through appropriate construction and alignment techniques, a ferrite core crossed spaced loop antenna has been assembled, as shown in FIG. 1. Because of the basic properties of ferromagnetic materials, in particular Q–1, it has been determined that ferrite core crossed spaced loops also may be used over extremely large bandwidths, depending on the sensitivity requirements.

In view of the foregoing, it may readily be seen that the crossed spaced loop antenna constituting this invention provides unambiguous bearing on vertically polarized radio waves in the high frequency and very high frequency ranges. Limiting the antenna to vertically polarized signals is not considered a serious deficiency for tactical direction finding intercept applications to targets at sea. Wideband direction finding intercept capability within, for example, the 2 MHz to 100 MHz range can be accomplished utilizing a combination of crossed spaced loops and crossed simple loops in the tiered configuration shown in FIG. 1. The capability of switching the crossed spaced loop antenna from a spaced loop pattern to a simple loop pattern, of course, provides additional versatility thereto. Hence, it may readily be seen that the size, weight, and geometrical configuration of the subject ferrite core crossed spaced loop antenna allows a mast top or through mast shipboard mounting, as well as mountings at other various and sundry locations which would be physically advantageous.

MODE OF OPERATION

The operation of the invention will now be discussed briefly in conjunction with all of the figures of the drawing, but especially with respect to the embodiment thereof depicted in FIGS. **1**, **8**, and **9**.

The antenna of FIG. **1** may be mounted at any place where it is desired to determine the direction of travel of electromagnetic energy present thereat. However, it is particularly useful for mounting on ships, and, thus, a few representative mounting places therefor are shown in FIG. **8**, so that it may be seen how it may be disposed relative to any superstructure or other apparatus without being unduly adversely affected thereby.

FIG. **8** very simply shows a typical ship **101** which may have the antenna of the subject invention installed thereon to an ad-

vantage. For example, locations **102**, **103**, and **104** may be used for such purpose, but, obviously, others may be used, as well.

Of course, it should be understood that the invention will work any place where it is not sufficiently crowded by ambient apparatus to be adversely affected by energy reflections therefrom. Obviously, because of its relatively small size, compared to comparable prior art air core antennas, the deleterious operational effects due to the confinement thereof by other apparatus in its immediate environment is minimized, thereby optimizing the performance thereof for any given situation. Such optimization is typically illustrated in FIG. **9** for a 10-turn ferrite core spaced loop antenna.

The antenna constituting this invention functions to receive electromagnetic energy in a manner similar to that of any antenna, but it does it in a unique way. The upper tier senses the incoming energy from the field strength standpoint and the lower tier senses the incoming energy from a direction standpoint, and output signals are produced thereby, respectively, which are proportional thereto. Because of the unique construction which incorporates, among other things, ferrite cores, the intercepted or incoming energy is sensed with greater sensitivity by both tiers than would otherwise be possible with air core antennas of the prior art. Hence, very weak incoming signals will be sensed thereby which may be further processed by any suitable electronic equipment—such as receiver **51** and readout **52** of utilization apparatus **53**—to provide useful indications of the incoming direction thereof.

Because the subject invention is primarily an antenna that may be included as an important and unique component of an overall receiver system—such as is portrayed in FIG. **1**—only the antenna portion thereof is disclosed in detail herewith. Thus, when considered as a system, it will be left to the artisan to select the proper processing, receiving, or the like, apparatus to be combined therewith, inasmuch as so doing could readily be done thereby, if he had the teachings presented therewith.

Obviously, other embodiments and modifications of the subject invention will readily come to the mind of one skilled in the art having the benefit of the teachings presented in the foregoing description and the drawings. It is, therefore, to be understood that this invention is not to be limited thereto and that said modifications and embodiments are intended to be included within the scope of the appended claims.

What is claimed is:

1. An antenna, comprising in combination:

a pipe means, having a longitudinal axis, adapted for being mounted at a predetermined attitude on a predetermined support structure;

a first plurality of hollow arm means connected to said pipe means in such manner as to radially extend therefrom at uniform angular intervals therearound in a first plahe that is normal to the longitudinal axis thereof;

a first plurality of ferrite core loop energy sensors respectively connected to said first plurality of hollow arm means at a predetermined distance from said pipe means;

a second plurality of hollow arm means connected to said pipe means in such manner as to radially extend therefrom at uniform angular intervals therearound in a second plane that is normal to the longitudinal axis thereof and disposed at a predetermined distance from the aforesaid first plane;

a second plurality of ferrite core loop energy sensors respectively connected to said second plurality of hollow arm means at a predetermined distance from said pipe means;

electrical leads respectively connected to each of said ferrite core loop energy sensors adapted for being connected in predetermined manners to each other as required to obtain spaced loop and simple loop modes and to a predetermined utilization apparatus to, in turn, cause predetermined operational characteristics to be effected by said antenna.

2. The invention of claim **1** further characterized by means for encapsulating at least portions of said antenna, so as to effect protection thereof from an ambient environment that is hostile thereto.

3. The device of claim **1** wherein said pipe means and said first and second pluralities of hollow arm means are respectively constructed of a material that acts as electromagnetic shielding between the outside ambient environmental medium in which they are disposed and the inside passageways thereof.

4. The device of claim **1** wherein said utilization apparatus comprises:

a receiver; and

a readout connected to the output of said receiver.

5. The device of claim **1** wherein each of said first and second pluralities of ferrite core loop energy sensors comprises:

a ferrite bar having a longitudinal axis;

a coil of wire having a predetermined number of turns wound around said ferrite bar along a predetermined center section thereof;

a first U-shaped saddle disposed around one end of said ferrite bar for the support thereof;

a first cover releasably attached to said first U-shaped saddle for the securing of said ferrite bar therein;

a second U-shaped saddle disposed around the other end of said ferrite bar for the support thereof;

a second cover releasably attached to said second U-shaped saddle for the securing of said ferrite bar therein;

an electrostatic shield, having a plurality of electromagnetic energy insulating walls, effectively disposed around said coil of wire and the predetermined center section of the ferrite bar around which it is wound;

a slot located in and extending through one of the walls of said electrostatic shield in parallel with the longitudinal axis of said ferrite bar; and

means connected to said first and second U-shaped saddles for the attachment thereof to the aforesaid hollow arm means.

6. The device of claim **5** wherein said first and second U-shaped saddles are constructed of shock resistant fiberglass.

7. The device of claim **5** wherein said first and second covers are compression covers constructed of shock resistant fiberglass.

8. The device of claim **5** wherein said coil of wire is configured to have predetermined inductance characteristics.

9. The device of claim **5** wherein said coil of wire is multiturn.

10. The device of claim **5** wherein said electrostatic shield comprises:

a plurality of walls surrounding said ferrite bar, each of which has a pair of fiberglass plates disposed in such manner as to have the aforesaid coil of wire sandwiched therebetween;

at least one metallic plate bonded to those sides of each of said fiberglass plates that are not adjacent to the wire of said coil of wire;

means connected to each of said metal sheets for the electrical connection thereof and for holding of the aforesaid walls in a predetermined geometrical configuration;

means connected to one wall of said plurality of walls for the securing thereof to one of the arm means of the aforesaid plurality of hollow arm means;

a pair of apertures located in said one wall of said plurality of walls; and

a pair of electrical conductors respectively extending through said pair of apertures and connected to the terminals of the aforesaid coil of wire.

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