March 5, 1968

H. W. KLINE

3,372,395

VLF ANTENNA

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2 Sheets-Sheet 1

Fig. 3.

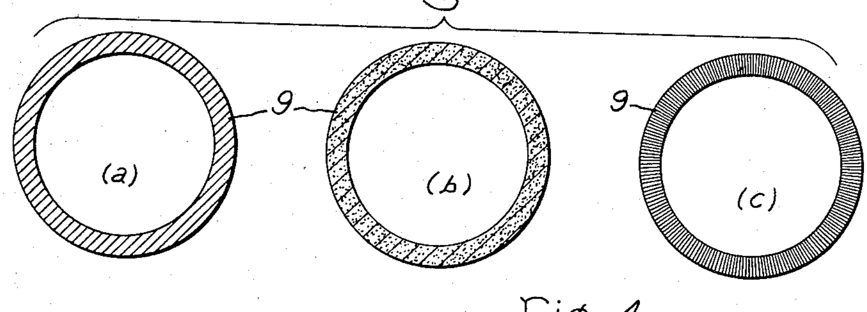

Fig. 4.

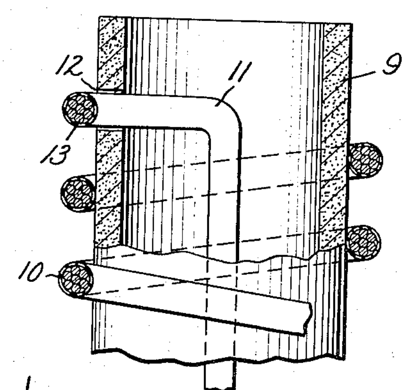

Fig. 2.

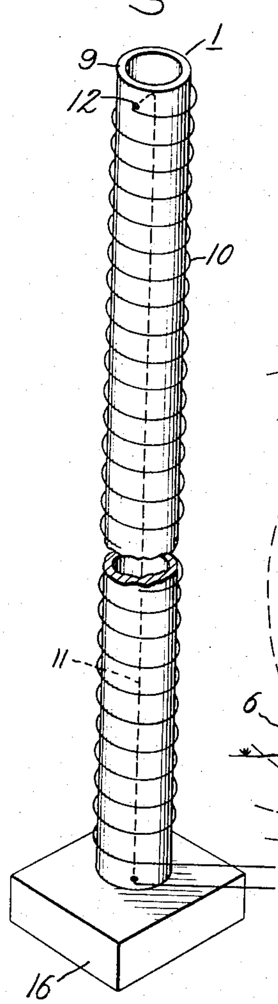

Fig. 1.

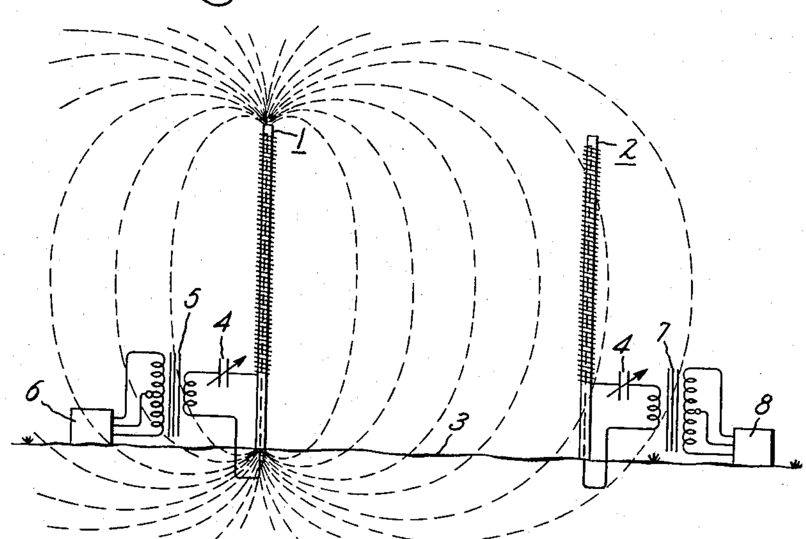

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Fig. 5

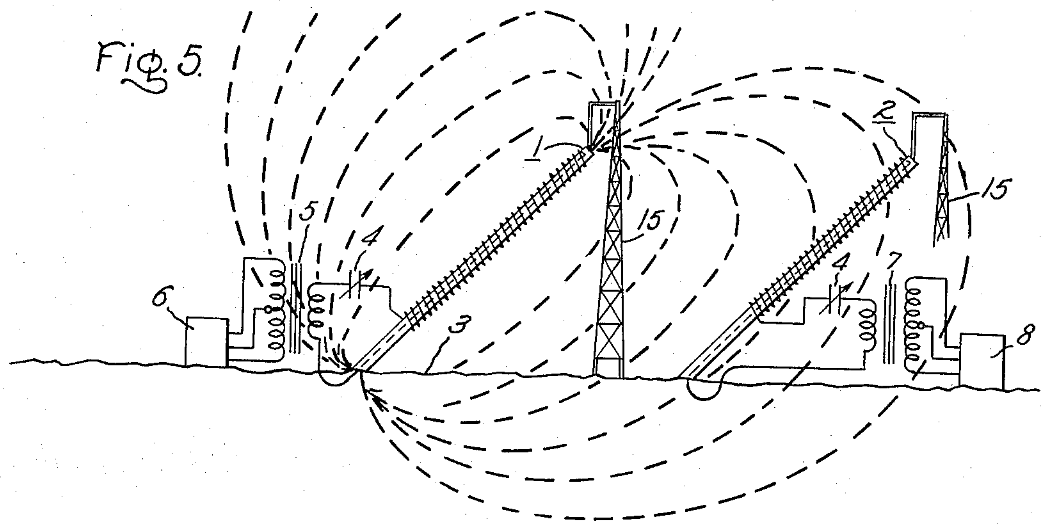


Fig. 6

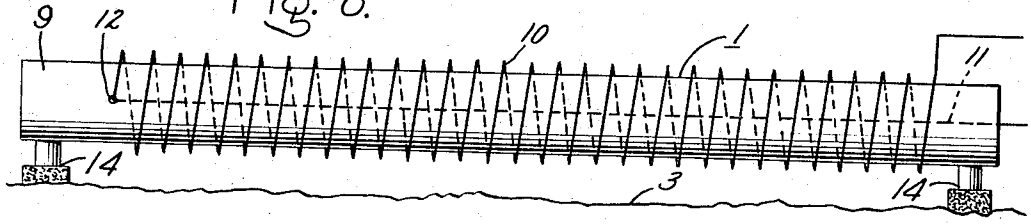
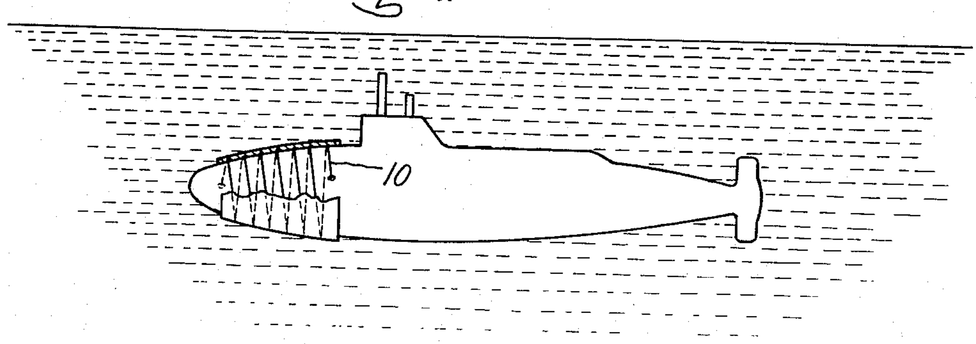


Fig. 7



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VLF ANTENNA

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2 Claims. (Cl. 343—787)

My invention relates to an antenna operable in the very low frequency range of the electromagnetic energy spectrum, and in particular, to an inductive-type antenna which is substantially shorter in length than conventional straight-wire antennae operable in the very low frequency range.

Radio communication is conducted in a number of frequency ranges or bands of the electromagnetic energy spectrum. The lowest of the frequency ranges, commonly designated very low frequency (VLF) extends to an upper limit of 30 kilocycles per second. Radio communication in the VLF region possesses several favorable characteristics. Thus, the propagation of ground waves is subject to less attenuation, the atmospheric absorption is much less, and the propagation of sky waves is less affected by ionospheric conditions than at the higher frequencies. These characteristics make the VLF region especially favorable for communication and navigational aids to widely dispersed seagoing ships and aircraft. Another favorable propagation characteristic of the VLF range is the ability of the radio waves to penetrate sea water and thereby permit communication with submerged submarines.

A disadvantage of communication at VLF frequencies is the practical difficulty associated with the construction of antennae having dimensions appreciable with respect to the wavelength of the radiated electromagnetic energy. Thus, simple vertical radiators, which may be considered as being long, vertical, straight-wire electrical conductors are not generally utilized at VLF frequencies due to their extremely long length. The conventional VLF antenna design comprises a plurality of relatively short vertical towers of sturdy construction between which are strung a plurality of relatively long, horizontally disposed, straight-wire electrical conductors insulated from ground. Such antenna is commonly described as a flat top or top-loaded vertical antenna and has a high capacitive reactance and may be referred to as a capacitive-type antenna. Ground areas as large as three thousand acres are employed to contain the conventional or capacitive-type VLF antenna installations. The large ground area is required for the horizontally disposed straight-wire conductors which pass radially outward from the vertical towers, or in parallel therebetween, for distances up to thousands of feet. The large ground area is further required for extensive underground counterpoise networks of conductors used to reduce the ground resistance and thereby improve the operating characteristics of the capacitive-type antenna.

Therefore, an object of my invention is to provide a VLF antenna which employs an electrical conductor wound on a core in inductive relationship as distinguished from the straight-wire conductors of the capacitive-type VLF antenna.

Another object of my invention is to provide a VLF antenna of the inductive type which occupies a relatively small ground area and is of simplified construction as compared to the capacitive-type VLF antenna.

The horizontal conductors of the capacitive-type antenna, in general, increase the effective height of the antenna and thereby increase the antenna's efficiency in propagating and receiving radiated energy at a desired VLF frequency. Although the horizontal conductors increase the capacitance of the antenna, the capacitive reactance remains high due to the low frequency in the VLF

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range. The high capacitive reactance necessitates the use of voltages as high as 250,000 volts to obtain the required antenna current which generates the propagated VLF electromagnetic waves. The high voltage employed with the capacitive-type antenna requires the use of elaborate electrical insulators. The insulators and horizontal conductors are especially susceptible to damage from weather conditions such as ice, sleet, and wind. For weather protection purposes, the capacitive-type antenna is equipped with sleet melting systems. Corona discharge at the high voltage levels employed with the capacitive-type antenna is another phenomenon which requires important design considerations in the construction of a VLF antenna.

A further object of my invention is to provide an inductive-type VLF antenna which is less vulnerable to weather conditions and corona discharge than is the capacitive-type VLF antenna.

A conventional antenna system employs antenna structures disposed in either a vertical or horizontal position and thereby attains vertical or horizontal polarization of the radiated electromagnetic waves. Radio communication systems which operate on the same or adjacent frequency channels may cause interference and thereby reduce the effectiveness of such communication. Adjacent channel interference is conventionally avoided by limiting the maximum radiated power, providing directivity for the radiated electromagnetic waves, and providing polarization of the radiated waves at 90 degree angles to the polarization of the waves radiated by the adjacent and possibly interfering radio channel. Thus, as an example, an antenna producing horizontally polarized radio waves is employed in regions where vertically polarized radio waves of similar frequency exist. With an increasing number of radio channels constantly coming into existence, the problem of adjacent channel interference becomes formidable since the number of different frequency channels within the VLF range is limited.

A still further object of my invention is to provide an inductive-type VLF antenna system wherein the transmitting and receiving antennae are oriented at an angle lying between the horizontal and vertical positions and thereby reduce adjacent channel interference.

Underwater communication, such as from surface ship to submarine, or submarine to submarine, is conventionally conducted at the VLF frequencies and employs a straightwire type antenna which in the case of a submarine is strung from the front end thereof to the conning tower and thence to the back end.

Another object of my invention is to provide an inductive-type VLF antenna which comprises an electrical conductor wound coaxially around a portion of the hull of a seagoing vessel.

In accordance with my invention in meeting the objects enumerated above, I provide an antenna system wherein the transmitting and receiving antennae are of similar construction. Each antenna in a particular antenna system is oriented in an identical position with respect to the ground plane and thus may be positioned in the vertical, horizontal, or at any angle between the vertical and horizontal. The antenna comprises a cylindrical magnetic core which is relatively short with respect to the wavelength of the particular VLF frequency of electromagnetic radiation. An electrical conductor, insulated from the core, is wound coaxially around the core along its length in inductive relationship to provide a relatively high Q inductive circuit. The Q_h factor (a figure of merit) of my antenna, wherein h is the effective height of the antenna, is comparable to the Q_h factor of the relatively large area capacitive-type antennae conventionally employed for radio communication in the VLF region of the electromagnetic energy spectrum. An inductive-type VLF antenna for underwater communication is produced by winding an electrical conductor coaxially around a portion of a seagoing vessel such as a submarine and insulating the conductor from the submarine hull and from the sea water.

The features of my invention which I desire to protect herein are pointed out with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation, together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawings, wherein:

FIGURE 1 is a diagrammatic view of horizontally polarized inductive-type VLF antenna system constructed in accordance with my invention;

FIGURE 2 is a perspective view, partly in section, illustrating one of the antennae of FIGURE 1 in greater detail;

FIGURE 3 illustrates the antenna core taken in cross section and indicates three types of material which may be employed in its construction;

FIGURE 4 is a detail view of the top portion of the antenna shown in FIGURE 2;

FIGURE 5 illustrates a second embodiment of my antenna system wherein the transmitting and receiving antennae are each positioned at an angle of approximately 45 degrees with respect to the ground plane;

FIGURE 6 illustrates a third embodiment of my antenna wherein the antenna is positioned horizontally with respect to the ground plane; and

FIGURE 7 is a diagrammatic view of my inductive-type VLF antenna as employed for submarine radio communication.

In FIGURE 1 there is shown, in diagrammatic view, my inductive-type VLF antenna system having the individual antennae **1**, **2**, disposed in a vertical position with respect to the ground plane **3** to thereby obtain radio communication in the VLF region of the electromagnetic energy spectrum by means of horizontally polarized radio (electromagnetic) waves. The magnetic field component of the electromagnetic waves is shown being radiated from antenna **1** in a 360 degree radial pattern and received by antenna **2**. The radiating characteristics of the antenna thus provide omnidirectional propagation in the horizontal plane perturbed by the surrounding terrain and nearby structures, As a particular example of the electrical characteristics of my antenna, for operation at 20 kilocycles per second, a Q of 200 and total resistance of the resonant circuit of 0.4 ohm, an antenna inductance of 633 microhenries is employed. Each antenna is series tuned, by means of variable capacitor **4**, to produce a series resonant circuit which is resonant at the desired VLF carrier frequency. Transformer **5** is employed to match the impedance of antenna **1** to the output of VLF radio transmitter **6**. In like manner, transformer **7** is employed to match the impedance of antenna **2** to the input of a VLF radio receiver **8**. Antennae **1** and **2** are spaced apart at distances which may be as great as thousands of miles. The electrical power being supplied to antenna **1** from radio transmitter **6**, the sensitivity of radio receiver **8**, and the Q_h factor of antennae **1** and **2** are determined primarily by the distance between antennae **1** and **2**, that is, the desired range of propagation of the radio waves. The factor Q determines the bandwidth of the antenna, that is, the frequency width of the communication channel within which the intelligence is transmitted. The Q of a series resonant circuit is directly proportional to the resonant frequency of the circuit and inversely proportional to the frequency difference between half-power points (the bandwidth). For an inductive-type antenna, Q is also directly proportional to the inductive reactance and inversely proportional to the resistance of the inductive circuit. The factor h is generally known as the "effective height" of the antenna. The factor Q_h is a figure of merit for an antenna and may thus be viewed

as a function of the efficiency of the antenna, that is, the larger the Q_h factor, the greater is the energy radiated by the antenna within the desired bandwidth for a fixed amount of radio frequency electrical energy supplied to the antenna. Conversely, the larger the Q_h factor, the greater is the signal produced in a receiving antenna for a fixed amount of propagated energy. The Q_h factor thus indicates that the effective height h of an inductive-type antenna may be made relatively small provided that the Q is made sufficiently large (within limits dictated by the desired bandwidth). The vertical position of the antennae in FIGURE 1 has the advantage of occupying minimum ground area.

FIGURE 2 illustrates the construction of antenna **1** or **2** in greater detail. In particular, the antenna is comprised of a generally cylindrical shaped core **9** which is preferably hollow and circular in cross section. As herein employed, "cylindrical" is defined as the surface traced by any straight line moving parallel to a fixed straight line and thus is not limited to a circular cross section. The length of core **9** may be up to several hundred feet. The outside diameter of core **9** is between 1 and 10 feet and the thickness of the cylindrical wall is between 1 and 6 inches, the outside diameter and wall thickness in general increasing with the longer length cores. Core **9** is constructed from a suitable magnetic material which preferably has high permeability and low resistivity and may comprise an iron casting, illustrated in cross section in FIGURE 3*a*, or a molded ferromagnetic material such as ferrite, illustrated in FIGURE 3*b*. Core **9** is preferably constructde from a single piece of magnetic material to thereby obtain the most desirable magnetic properties, but, may be constructed of several cylindrical sections in contiguous relationship forming the desired long core. Alternatively, as illustrated in FIGURE 3*c*, the core may be constructed from strips of magnetic materials such as Alexanderson iron to reduce eddy current effect which may be produced therein.

An electrical conductor **10** is wound coaxially around core **9** and along the length thereof in inductive relationship. The manner in which conductor **10** is wound around core **9** is illustrated in FIGURES 2 and 4 wherein a first part **11** of conductor **10** passes along substantially the full length of core **9** on the inside thereof, and thence passes to the outer surface of core **9** by means of aperture **12**. Conductor **10** is electrically insulated from core **9** and may comprise a single high current conductor, but more generally, comprises a plurality or bundle of electrical conductors **13** as illustrated in FIGURE 4. As one example, electrical conductor **10** may comprise high current Litzendraht wire. The core and conductor may both be ungrounded or one end of the core and/or the conductor may be grounded as desired. Antennae **1** and **2** may be made self-supporting by being mounted in a suitable base **16** for the shorter lengths of core such as approximately 100 feet, or may be further supported from the upper end as illustrated in FIGURE 5. The relatively simple construction of my antenna renders it relatively immune to damage from weather conditions such as sleet, rain, and snow. For more positive protection from weather conditions, the top of the antenna or the whole length thereof may be sealed with a suitable material such as a glass compound.

FIGURE 5 illustrates a second embodiment of my antenna system wherein antennae **1** and **2** are each disposed at an angle of approximately 45 degrees with respect to the ground plane **3**. Such arrangement permits maximum flux interlinkage between the antennae while reducing flux interlinkage of any horizontally or vertically polarized electromagnetic waves which may be present. Thus, adjacent channel interference, occasioned by a horizontally or vertically polarized radio wave having a similar frequency and being of substantial amplitude in the vicinity of a receiving antenna **2**, is considerably reduced. The angularly disposed antennae are supported from suitable towers **15** which are electrically insulated therefrom. The angular position of the antennae, also provides directivity of the propagated radio waves since the waves which penetrate the ground to a maximum degree are more attenuated than the waves which penetrate to a lesser degree.

FIGURE 6 illustrates a third embodiment of my antenna configuration wherein the antenna **1** is disposed in a horizontal position relative to the ground plane **3** and is supported from ground by means of base members **14**. Such antenna radiates and receives vertically polarized electromagnetic waves. The horizontal antenna may also conveniently be placed underground and function satisfactorily at moderate depths.

An inductive-type VLF antenna may also be provided for underwater radio communication as illustrated in FIGURE 7. The antenna comprises an electrical conductor **10** which is wound coaxially around a portion of a seagoing vessel in inductive relationship. As one example, FIGURE 7 illustrates conductor **10** wound along a portion of the hull of a submarine. It would be appreciated that such conductor winding may also be employed on a surface vessel or aircraft having at least a portion of its structure comprised of a magnetic material. Since the permeability of the metal comprising the hull of the seagoing vessel is considerably less than the permeability of ferrites and the like, the Q_h factor is smaller but sufficient for underwater radio communication. The Q_h factor may be increased by coating the outer surface of the vessel in the area of the conductor winding with a higher permeability material. Electrical conductor **10** is electrically insulated from the vessel's hull and is further insulated from the salt water environment to prevent deterioration of the conductor. The salt water insulation is conveniently applied over the conductor winding in a manner whereby the conductor is virtually imbedded on the surface of the vessel's hull and produces a smooth surface. The inductive-type VLF antenna in accordance with my invention thus has the advantage that the smooth surface presented to the sea water maintains a desired streamline flow about the submarine as distinguished from the turbulence produced by conventional submarine radio antennae. The use of an inductive winding around the hull of a seagoing vessel may be extended to structures having hollow cross sections such as water tanks and buildings of the skyscraper type which are, in general, constructed of a ferrous metal. The magnetic flux developed within the core (vessel's hull, metal building) by the current flowing in the electrical conductor has relatively no effect within the volume enclosed by the core since the flux remains concentrated within such core.

From the foregoing description, it can be appreciated that my invention makes available an improved VLF antenna of relatively short length and simple construction as compared to conventional straight-wire VLF antennae. The shorter length is attained by employing an inductive-type antenna wherein an electrical conductor is wound coaxially around a magnetic core to produce a relatively high Q inductive circuit. My antenna may be installed above ground at any desired angle with respect to the ground plane, underground, or on seagoing vessels. The underground counterpoise system of electrical conductors conventionally required with top loaded capacitive-type VLF antennae is eliminated with my simplified inductive-type antenna. Further, my inductive-type antenna, being an electrical current device, does not require the usual high voltages necessary for efficient radiation from capacitive-type antennae and therefore does not have the resultant insulator and carbon discharge problems generally associated with high voltage. The simplified structure of the inductive-type antenna reduces, and may completely eliminate, the need for elaborate sleet melting systems commonly utilized with top loaded capacitive-type

antenna. The Q_h factor of the inductive-type antenna is constant regardless of weather conditions as distinguished from the capacitive-type wherein the Q may vary considerably with weather conditions due to variations in insulation leakage with rain, snow, and sleet. The dielectric constant of the moist air between the top loaded capacitive-type antenna and the underground counterpoise may also vary with weather conditions. Considerable power loss is incurred during the periods wherein the Q has varied and these conditions are relatively uncontrollable in the capacitive-type antenna. Further, the use of loading coils to increase the effective height of conventional VLF antenna, and the resultant power loss therein, is also eliminated with my inductive-type VLF antenna.

Having described an improved inductive-type VLF antenna for radio communication purposes, it is believed obvious that modifications and variations of my invention are possible in the light of the above teachings. For example, a plurality of spaced-apart transmitting antennae of the VLF inductive-type herein disclosed may be fed from a centrally located transmitter to obtain desired radiating patterns. It is, therefore, to be understood that changes may be made in the particular embodiment of my invention described which are within the full intended scope of the invention as defined by the following claims.

What I claim as new and desire to secure by Letters Patent of the United States is:

1. An inductive-type antenna system for the transmission and reception of electromagnetic radiation in the very low frequency (VLF) range and including at least two relatively widely spaced-apart antennae, each antenna comprising

a magnetic core being hollow cylindrical in cross section and comprised of a relatively high permeability material, said core being disposed at an angle of approximately 45 degrees relative to the ground plane to thereby reduce interference developed by vertical and horizontal antennae systems operating at a similar frequency as said inductive-type antenna system, and

a first part of an electrical conductor wound coaxially around said core along substantially the total length thereof and electrically insulated therefrom to produce a relatively high Q inductive circuit, a second part of said conductor passing along substantially the total length of said core on the inside thereof, said core being of length *h* substantially shorter than conventional half wavelength straight-wire antennae operable in the very low frequency range up to 30 kilocycles per second of the electromagnetic energy spectrum and the magnitude of the product Q_h of said inductive-type antenna being in the order of the Q_h product of said straight-wire antennae.

2. The antenna set forth in claim **1** and further comprising a vertical tower associated with each antenna and electrically insulated therefrom for supporting each said core at the angle of approximately 45 degrees relative to the ground plane.

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