Feb. 18, 1947. H. A. WHEELER 2,416,246

ANTENNA STRUCTURE

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FIG. 1

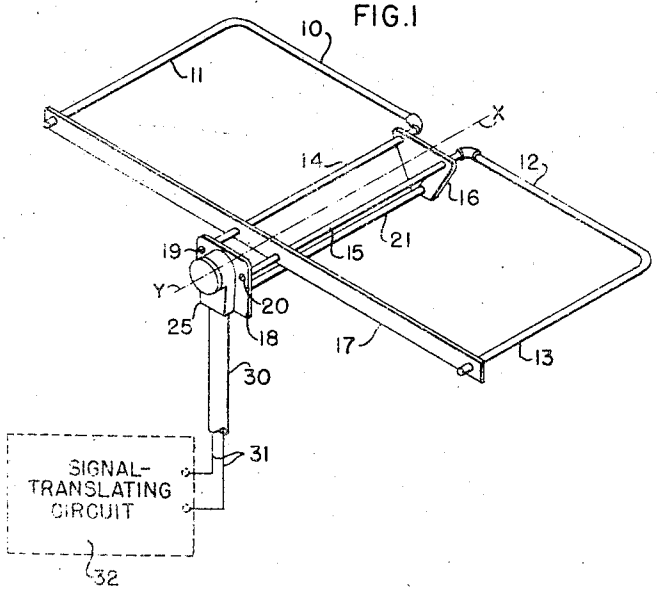


FIG. 1a

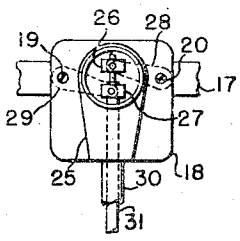


FIG. 2

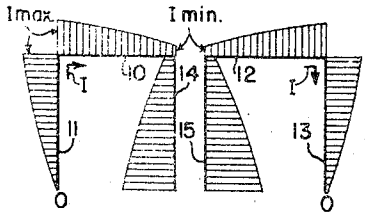


FIG. 3a

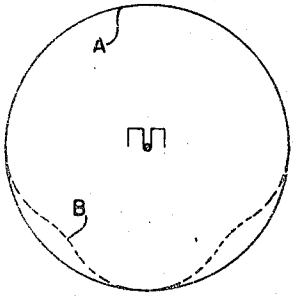


FIG. 3b

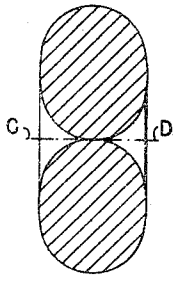


FIG. 3c

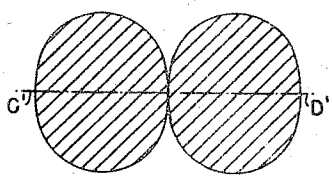
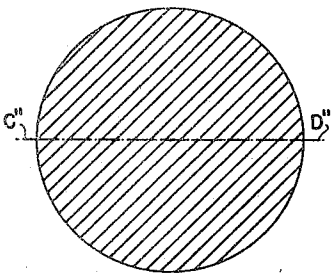


FIG. 3d



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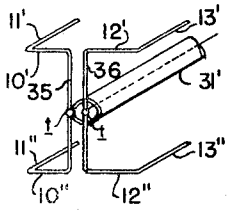


FIG. 4

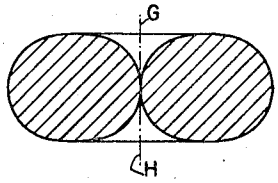


FIG. 5

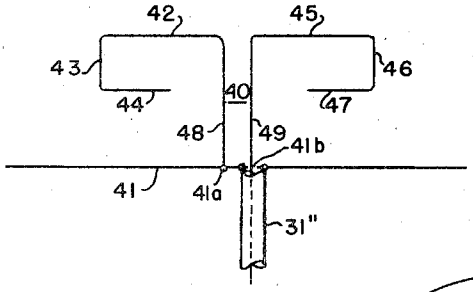
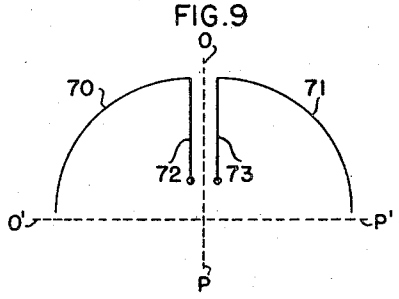


FIG. 6

FIG. 9



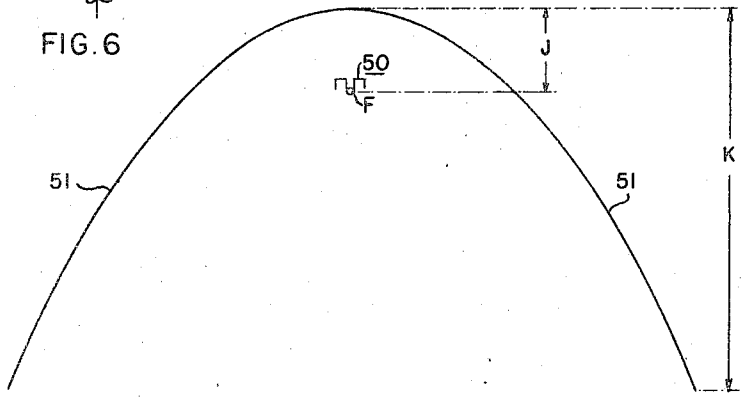


FIG. 7

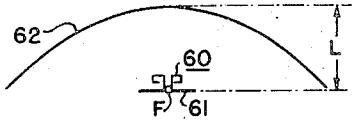


FIG. 8

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Patented Feb. 18, 1947

2,416,246

UNITED STATES PATENT OFFICE

2,416,246

ANTENNA STRUCTURE

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Application January 4, 1944, Serial No. 516,914

3 Claims. (Cl. 250—11)

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This invention relates to an antenna structure for connection to a terminal circuit having a predetermined value of impedance at a predetermined operating frequency, the antenna structure being characterized by a substantially omnidirective radiation pattern in the plane of its radiating conductors.

There are several applications wherein an antenna structure having an omnidirective radiation pattern in a particular plane is especially desirable. For example, in the translation of television signals it is most desirable that the transmitting antenna be designed for omnidirectivity in a horizontal plane. Also, in radio-ranging and direction-finding apparatus utilizing a parabolic-cylindrical reflector to cause an antenna system to have a predetermined fan-shaped characteristic polarized in a plane normal to the focal axis of the reflector, optimum reflector efficiency is obtained if the antenna structure, per se, has an omnidirective radiation pattern in the plane of polarization. In such applications the antenna structure is usually remote from the signal-translating apparatus, being coupled therewith by means of an antenna feeder cable, such as a coaxial transmission line. It is well understood that a given coaxial transmission line has a predetermined characteristic impedance at a particular operating frequency and, consequently, for maximum power transfer it is necessary that the antenna structure in the above-mentioned applications present a corresponding terminal impedance at the same frequency.

Antenna structures of the type under consideration, characterized by an omnidirective radiation pattern in a horizontal plane, have already been proposed. One prior art arrangement comprises a pair of radiating conductors having an effective electrical length of substantially one-half wave length of a predetermined operating frequency, the conductors being bent at right angles at their midpoints. The resultant L-shaped conductors are arranged in a horizontal plane with one arm of each conductor connected to one side of a transmission line which couples the antenna structure directly to a signal-translating apparatus. The portions of the two conductors which are connected to the transmission line are arranged along a common axis in the horizontal plane. While the described antenna structure is designed for omnidirective radiation in a horizontal plane, from a practical standpoint it is an undesirable arrangement. This is because the radiating conductors, which have an

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effective electrical length of one-half wave length at the operating frequency of the antenna, present a terminal impedance very much greater than the characteristic impedance of a transmission line that would be conventionally used to couple such an antenna structure to a signal-translating apparatus. For this reason, the mismatched impedances render the arrangement effectively inoperable.

In other prior art arrangements, used particularly in radio-ranging and direction-finding apparatus, a dipole antenna is positioned at the focal axis of a parabolic-cylindrical reflector with the plane of the antenna normal to the focal axis of the reflector so that the antenna system is caused to have a fan-shaped directive pattern, polarized in the plane of the antenna. Such arrangements provide normal directive gain if the reflector is shallow, that is, so long as the depth thereof does not substantially exceed its focal distance. However, if a deep reflector is used, a directive gain proportional to the increased size of the reflector is not obtained. This is due to the directive characteristics of the dipole antenna. In the first place, such an antenna has substantially no radiation from its ends so that the portions of the reflector opposite the ends of the antenna are not utilized and thus effectively comprise dead spots. Also, certain rays of energy from the antenna have opposed polarities after reflection in a deep reflector and tend to cancel, thus further reducing the directive gain of the system.

It is an object of the invention, therefore, to provide an improved omnidirective antenna structure which avoids the aforementioned limitations of prior art arrangements.

It is another object of the invention to provide an improved antenna structure for connection to a terminal circuit having a predetermined value of impedance at a predetermined operating frequency and characterized by a substantially omnidirective radiation pattern in the plane of its radiating conductors.

It is still another object of the invention to provide an improved antenna structure having a substantially omnidirective radiation pattern in the plane of its conductors and a maximum band width consistent with substantial omnidirectivity.

In accordance with a feature of the invention, an antenna structure for connection to a terminal circuit having a predetermined value of impedance at a predetermined operating frequency comprises a pair of similar coplanar radiating conductors. Each conductor has a J-shaped con-

figuration and an effective electrical length of substantially one-half wave length at the aforesaid predetermined frequency. The conductors are positioned in spaced-opposed relation with reference to a plane symmetry with an end of one adjacent to the corresponding end of the other and their relative dimensions are proportioned to cause the antenna structure to have a substantially omnidirective radiation pattern in the plane of its conductors. The conductors present between their adjacent ends a maximum impedance much greater than the aforementioned predetermined value and an impedance-transforming means is connected to the adjacent ends of the radiating conductors to transform the maximum impedance of the antenna structure at the adjacent ends to a terminal impedance substantially equal to the aforementioned predetermined value. The system further includes a plane reflector disposed normal to the plane of the antenna structure and proportioned to form virtual images of the radiating conductors so that the system effectively comprises a complete loop structure having a hemispherical directive characteristic.

In accordance with another feature of the invention, an antenna structure comprises a pair of similar coplanar radiating conductors each of which includes a section having an effective electrical length of substantially one-half wave length at a predetermined operating frequency. The conductors are positioned with an end of one adjacent to the corresponding end of the other and are shaped and disposed in such an image relation with reference to a plane of symmetry as to cause the antenna structure to have a substantially omnidirective radiation pattern in the plane of the conductors. Additionally, the conductors have a ratio of diameter to wave length at the above-mentioned predetermined operating frequency such that the antenna structure has maximum band width consistent with substantial omnidirectivity.

For a better understanding of the present invention, together with other and further objects thereof, reference is had to the following description taken in connection with the accompanying drawings, and its scope will be pointed out in the appended claims.

In the drawings, Fig. 1 is a perspective view of an antenna structure in accordance with an embodiment of the invention; Fig. 1*a* is a fragmentary view of a portion of the antenna structure of Fig. 1; Fig. 2 illustrates the current distribution along the conductors of the antenna of Fig. 1; Figs. 3*a* to 3*d*, inclusive, comprise polar-coordinate graphs illustrating the radiation characteristics of the antenna structure of Fig. 1; Fig. 4 represents a modification of the invention; Fig. 5 is a graph showing the radiation characteristics of the arrangement of Fig. 4; and Figs. 6–9, inclusive, represent additional antenna systems in accordance with the invention.

Referring now more particularly to Fig. 1, there is illustrated an antenna structure having a predetermined range of operating frequencies and designed for connection to a terminal circuit having a predetermined value of impedance at the mean frequency of the range. This antenna structure comprises a pair of similar coplanar radiating conductors each including a section having an L-shaped configuration and each having an effective electrical length of substantially one-half wave length at the mean operating frequency of the antenna structure. One such conductor

consists of conductor sections 10 and 11 of brass tubing or other suitable material arranged to define an L-shaped structure and having an effective electrical length of approximately one-half wave length at the mean operating frequency of the antenna. The other conductor comprises sections 12 and 13 having the same general arrangement and effective electrical lengths as sections 10 and 11, respectively. Conductors 10, 11 and 12, 13 are disposed within a common horizontal plane in such an image relation with reference to a plane of symmetry as to cause the antenna structure to have an approximately omnidirective radiation pattern in the plane of its conductors. The above-mentioned plane of symmetry is normal to the plane of the antenna structure, intersecting the latter as indicated by broken line X—Y.

Considering now more particularly the arrange of conductors 10, 11 and 12, 13 for the embodiment represented in Fig. 1, it will be seen that sections 10 and 12 have a colinear relationship, while sections 11 and 13 have a parallel relationship and extend in the same direction in the plane of the antenna structure. In the remaining portions of the specification and in the appended claims, this arrangement of the radiating conductors is defined as a "spaced-opposed relation with reference to a plane of symmetry." The relative proportioning of the sections of each radiating conductor required to provide an omnidirective radiation pattern in the plane of the antenna structure will be discussed more particularly hereinafter.

Due to the described effective electrical lengths of conductors 10, 11 and 12,13, the adjacent ends of sections 10 and 12 present a very high impedance which, in general, is found to be very much greater than the impedance of the terminal circuit to which the antenna is to be connected. This is especially true where the terminal circuit comprises a coaxial transmission line of the type conventionally used to couple an antenna structure to a signal-translating apparatus since such transmission lines are essentially low-impedance circuits. To facilitate connecting the antenna structure directly to such a terminal circuit with substantial impedance matching throughout the operating frequency range of the antenna and without requiring an intervening impedance-transformation network, an impedance-inverting transmission-line section is included as part of the antenna structure. As illustrated, this impedance-inverting section is provided by a pair of parallel conductors 14 and 15, also preferably of brass tubing, arranged in the plane of the radiating conductors and individually connected to the adjacent ends of conductor sections 10 and 12. The dimensions of the impedance-inverting section are proportioned to transform the impedance of the antenna structure at the above-mentioned adjacent ends to a terminal impedance at the mean operating frequency equal to the impedance of the terminal circuit to which it is desired to couple the antenna. To this end, conductors 14 and 15 are proportioned to have an effective electrical length of substantially one-quarter wave length at this mean operating frequency, a diameter corresponding to that of the radiating conductors, and a spacing such that the impedance-inverting transmission-line section has a characteristic impedance equal to $\sqrt{Z_1 Z_0}$, where Z_1 is the impedance of the terminal circuit measured at the mean operating frequency of the antenna and Z_0 is the impedance at the

adjacent ends of conductor sections 10 and 12 at this frequency. In general, the spacing of the conductors 14 and 15 will be of the order of one-twentieth wave length at the mean operating frequency of the antenna.

The radiating conductors and the conductors of the impedance-inverting section are maintained in coplanar relationship by means of a triangular-shaped aligning plate 16 apertured to receive conductors 14 and 15, the plate being positioned in close proximity to the adjacent ends of sections 10 and 12. Similarly, an aligning strip 17 is suitably apertured and positioned near the free ends of conductors 11, 13, 14, and 15, both elements 16 and 17 being formed of an insulating material such as a thermoplastic resin. The antenna structure is mechanically supported upon an insulating backing plate 18. For this purpose, tapped plugs (not shown) may be secured within the free ends of conductors 14 and 15 individually to receive mounting screws 19 and 20 which pass through backing plate 18. Also, a supporting rod 21 is interposed between the backing plate 18 and aligning plate 16, this rod preferably being of insulating material.

A junction or terminal box 25 is positioned on backing plate 18 on the opposite side thereof from the antenna structure. Within the junction box there are a pair of terminals 26 and 27 (Fig. 1*a*) adapted, respectively, to receive the inner and outer conductors of a coaxial transmission line. Terminals 26 and 27 are individually connected by means of conductive straps 28 and 29 to conductors 15 and 14, respectively, of the impedance-inverting section and thus provide means for connecting the terminal ends of the impedance-inverting section directly to a terminal circuit. Junction box 25 is apertured to receive a mast upon which the described structure is to be supported. The mast, a portion of which is indicated at 30, preferably comprises a section of steel pipe through which a coaxial transmission line 31 may be inserted, thereby to couple the antenna structure with a signal-translating circuit 32. Unit 32, shown in broken-line construction, forms no part of the present invention and may be the signal-translating circuit of a transmitting or receiving apparatus.

In considering the operation of the described antenna structure, reference is made to Fig. 2 which illustrates the current distribution along conductor sections 10–15 inclusive. The current varies along sections 11 and 13 from zero at their free ends to a maximum value at their junction with sections 10 and 12, and along the latter the current varies from this maximum value to a minimum at their adjacent ends. This current distribution results from the relative proportioning of the conductor sections mentioned which is such that the antenna structure is caused to have (1) a substantially omnidirective radiation pattern in the plane of its conductors; (2) a wide-band resonance characteristic to permit efficient operation over a prescribed band of operating frequencies; and (3) structural rigidity.

In this connection, it can be demonstrated that the antenna structure described has an omnidirective radiation characteristic if a standing wave of current is established on the conductors 10, 11 and 12, 13. However, where, as in the present case, a traveling wave of current is present on any of the conductor sections, the radiation pattern tends to depart from this symmetrical configuration. The departure from symmetry varies inversely with the magnitude of the

standing-wave ratio which, in turn, varies directly with the ratio of reactance to resistance of the radiating conductors. For the particular antenna structure under consideration, the radiation resistance has a more or less fixed value and, thus, the standing-wave ratio may be determined by selecting the radiating conductors with particular regard for their reactance characteristics. For example, small diameter conductors present a relatively high value of reactance, causing the standing-wave ratio to have a correspondingly high value so that the radiation pattern approaches the desired symmetrical configuration. On the other hand, large diameter conductors have a relatively small value of reactance but are required for wide-band resonance characteristics and for structural rigidity. Consequently, the relative dimensions, and especially the diameter of the conductor sections of each radiating conductor, are chosen with a view to establishing a compromise between the above-mentioned characteristics. Specifically, the lengths of conductor sections 11 and 13 are proportioned with reference to the lengths of sections 10 and 12 so that the effective electrical length of sections 11 and 13 is substantially equal to that of sections 10 and 12. Also, the radiating conductors are selected to have a ratio of diameter to wave length at the mean operating frequency of the antenna such that the antenna structure has maximum band width consistent with substantial omnidirectivity of the radiation characteristic. In practical embodiments of the invention, the conductors have a diameter of the order of one one-hundredth wave length at the mean operating frequency of the antenna.

In Fig. 3*a* full-line curve A represents the radiation pattern in a horizontal plane of an antenna structure designed for precise omnidirectivity. Broken-line curve B of this figure represents the radiation pattern obtained from the antenna structure of the invention when the radiating conductors are selected in the above-indicated manner to provide maximum band width consistent with the desired radiation characteristic. It will be apparent that a substantially omnidirective radiation pattern is obtained in a horizontal plane with horizontal polarization. Also, the antenna structure, if constructed from the usual materials, has structural rigidity in addition to the required band-width characteristics.

The radiation pattern in a vertical plane is represented by the curves of Figs. 3*b* and 3*c*, which are cross-sectional views of surfaces of revolution. Fig. 3*b* represents radiation from the colinear conductor sections 10 and 12 and its axis of revolution C—D is along the axis of those sections. The curve of Fig. 3*c* represents radiation from the parallel sections 11 and 13 and its axis of revolution C′—D′ is perpendicular to such sections. The radiation from sections 10 and 12 is supplemented by that from sections 11 and 13, thereby producing an approximately spherical radiation pattern, as represented by the curve of Fig. 3*d* which is a cross-sectional view of a surface of revolution, having an axis C″—D″ parallel to the colinear conductor sections 10 and 12. Thus, the described antenna structure has substantially uniform radiation properties in all directions with horizontal polarization. In discussing the radiation characteristics, no reference has been made to the effect of conductors 14 and 15 of the impedance-inverting section. The currents in these two conductors are out of phase with each other and, in view of the small

conductor spacing, they make on substantial contribution to the radiation characteristics of the arrangement.

While the invention is not to be limited to any particular dimensions and electrical parameters, the following constants represent one specific embodiment which has been found to be of particular utility:

Length of conductor sections 11, 13, 14 and 15	0.21 wave length
Distance between conductor sections 11 and 13	0.5 wave length
Spacing of conductors 14 and 15	0.045 wave length
Conductor diameters	0.011 wave length
Impedance between adjacent ends of sections 10 and 12	Approximately 1250 ohms
Characteristic impedance of impedance-inverting section comprising conductors 14 and 15	250 ohms
Terminal impedance of the antenna structure	50 ohms
Radiation resistance	Approximately 50 ohms at the junctions of sections 10, 11 and 12, 13
Characteristic impedance of the transmission line to be connected to antenna structure	50 ohms

(The wave length used in defining the dimensions of the antenna structure is that corresponding to the mean operating frequency.)

The embodiment of the invention represented schematically in Fig. 4 comprises an antenna structure including a pair of antennas vertically spaced a distance equal to approximately one-half wave length at the mean operating frequency of the arrangement. Each antenna consists of radiating conductors having the same general proportions and arrangement as the radiating conductors of the Fig. 1 embodiment, corresponding conductor sections of one antenna having like reference numerals primed and corresponding elements of the other having like reference numerals double primed. The impedance-inverting section included as a part of the antenna structure of Fig. 4 comprises a pair of parallel conductors 35 and 36 connected to the adjacent ends of each antenna. The dimensions of the impedance-inverting sections are proportioned to transform the maximum impedance at the adjacent ends of each antenna to provide at the center of the impedance-inverting section a terminal impedance having a value approximately equal to that of the terminal circuit to which the antenna structure is to be coupled. A coaxial transmission line 31' or any other terminal circuit may be connected in a conventional manner to the terminals of the antenna structure which are indicated at *t—t*.

The operation of this modification of the invention will be apparent from the description of the Fig. 1 embodiment except for the vertical radiation pattern. Due to the half wave length spacing of the individual antennas, the vertical radiation is largely suppressed as represented by the curve of Fig. 5 which is a cross-sectional view of a surface of revolution having an axis G—H parallel to the impedance-inverting section 35—36. This antenna arrangement is predominantly directive in a horizontal plane.

In one embodiment of the Fig. 4 arrangement found to have particular utility, the antennas individually present a radiation resistance of approximately 100 ohms, conductors 35 and 36 of the impedance-inverting section have a spacing of 0.057 wave length and a diameter of 0.0055 wave length, and a characteristic impedance of 360 ohms. The resulting impedance at terminals *t—t* is 50 ohms, rendering the structure suitable for connection to a 50-ohm coaxial transmission line.

In Fig. 6 there is represented schematically an antenna system in accordance with the invention including an antenna structure 40 and a plane reflector 41. The antenna structure consists of a pair of similar coplanar radiating conductors each having a J-shaped configuration and an effective electrical length of substantially one-half wave length at the operating frequency of the antenna. One such conductor includes sections 42, 43 and 44, while the other includes sections 45, 46 and 47, sections 44 and 47 having a normal relationship to sections 43 and 46, respectively, in order to clear the plane of reflector 41. The conductors are positioned in spaced-opposed relation with reference to a plane of symmetry with one end of one conductor adjacent to the corresponding end of the other, as particularly described above in discussing the conductor arrangement illustrated in Fig. 1. Further, the conductors are proportioned in the manner outlined above to cause the antenna structure to have a substantially omnidirective radiation pattern in the plane of its conductors. In determining the relative lengths of the sections of each radiating conductor to obtain substantial omnidirectivity, it must be noted that radiation from sections 44 and 47 opposes and tends to cancel that from sections 42 and 45, respectively. However, this is not serious since the integral of the current distribution along sections 44 and 47 is materially less than that along sections 42 and 45. In any event, the effect of sections 44 and 47 may be compensated by so selecting the lengths of the sections of each radiating conductor that the current maxima occur along sections 42 and 45 rather than at their junctions with sections 43 and 46.

The antenna structure also includes an impedance-inverting transmission-line section provided by a pair of parallel conductors 48 and 49 coplanar with and connected to the adjacent ends of sections 42 and 45 and extending in the same direction as parallel sections 43 and 46. The dimensions of the impedance-inverting section are proportioned to provide a predetermined impedance at the terminals of the antenna structure.

Reflector 41 consists of a disc of highly conductive material, such as copper, and is disposed normal to the plane of antenna structure 40, being positioned at the terminal end of impedance-inverting section 48—49 and on the side of antenna structure 40 opposite to its above-mentioned adjacent ends. Reflector 41 has a diameter of one to four times the wave length at the mean operating frequency of the antenna system and is proportioned to form virtual images of the radiating conductors 42, 43, 44 and 45, 46, 47 so that the antenna system effectively comprises a complete loop structure. Additionally, the reflector serves as a ground plane for the antenna system and includes provisions for con-

necting a terminal circuit thereto. Specifically, conductor 48 of the impedance-inverting section is electrically and mechanically coupled with the reflector, as indicated by connection 41a, and the grounded conductor of a coaxial transmission line 31'' is likewise connected to the reflector, as represented. An aperture 41b is provided at the center of the reflector and the inner or central conductor of coaxial line 31'' projects therethrough for connection with conductor 49 of the impedance-inverting section. Suitable means (not shown) are provided for insulating the inner conductor of transmission line 31'' from the reflector.

Neglecting for a moment the effect of reflector 41, antenna structure 40 will be seen to have a substantially omnidirective radiation pattern throughout a sphere. The reflector 41, by reversing the direction of propagation of signal energy incident thereon, causes the antenna system to have a hemispherical radiation pattern with horizontal polarization.

In one embodiment of this arrangement the conductor sections have the following dimensions:

Length of conductor sections 42 and 45	0.24 wave length
Length of conductor sections 43 and 46	0.11 wave length
Length of conductor sections 44 and 47	0.13 wave length
Length of conductors 48 and 49	0.26 wave length
Spacing of conductors 48 and 49	0.053 wave length
Diameter of all conductor sections	0.011 wave length

(The wave length referred to is at the mean operating frequency of the antenna system.)

In Fig. 7 there is represented a plan view of another directional antenna system in accordance with the invention. This system includes an antenna structure 50 preferably having the same general construction and arrangement as that of Fig. 4, although a structure of the type shown in Fig. 1 or an array of such structures may be used if desired. The antenna system also includes a reflector 51 having the form of a parabolic cylinder. The focal axis of the reflector which has a point projection in the plane of illustration is represented at F. The reflector has a focal distance J which is large with reference to the overall dimensions of antenna structure 50 and, preferably, is equal to an integral multiple of half wave lengths at the mean operating frequency of the system. Reflector 51 is a deep reflector having a depth, indicated by dimension line K, which is substantially greater than its focal distance J. Further, the reflector is disposed with the focal axis thereof normal to the plane of antenna structure 50 and is so positioned that antenna structure 50 is located substantially at its focal axis F. The described system has a fan-shaped radiation pattern, determined by the dimensions of reflector 51, polarized in a plane normal to the focal axis of the reflector. For the particular embodiment represented, the polarization is horizontal and, due to the omnidirectional radiation characteristics of antenna structure 50 in a horizontal plane, a maximum directive gain is obtained.

A further directive antenna system is represented in plan view in Fig. 8 comprising an antenna structure 60 having a plane reflector 61 positioned on one side thereof, proportioned and arranged as described in connection with the embodiment of Fig. 6. The system also includes a parabolic-cylindrical reflector 62 positioned on the opposite side of antenna structure 60 and having the same general construction and arrangement as reflector 51 in the embodiment of Fig. 7. However, reflector 62 is shallow having a depth L equal to its focal distance. This antenna system is also characterized by a horizontally polarized, fan-shaped radiation pattern and has a maximum directive gain due to the hemispherical radiation pattern of antenna structure 60 caused by plane reflector 61.

While in each of the described antenna structures the radiating conductors include a section having an L-shaped configuration, it is to be understood that this is not a necessary limitation of the invention. If desired, the radiating conductors may have a curvilinear configuration, as illustrated in Fig. 9. In this embodiment of the invention the radiating conductors 70 and 71 have an effective electrical length of substantially one-half wave length at the operating frequency of the antenna and are positioned with an end of one conductor adjacent to the corresponding end of the other. Further, the conductors are shaped and disposed in such an image relation with reference to a plane of symmetry as to cause the antenna structure to have a substantially omnidirective radiation pattern in the plane of the conductors. In this connection, it will be apparent that conductors 70 and 71 have predetermined projected lengths along a pair of mutually perpendicular axes O—P and O'—P' in the plane of the conductors. The dimensions of the conductors should be proportioned to provide a current distribution such that the integral of the current distribution along the projected lengths of the conductors on one axis is equal to the integral of the current distribution along the projected lengths of the conductors on the other axis. This general criterion may be utilized in constructing any antenna structure in accordance with the invention, wherein the radiating conductors may have any of a wide variety of forms.

An impedance-inverting transmission-line section comprising a pair of conductors, such as 72 and 73, connected to the adjacent ends of the radiating conductors is included as part of the antenna structure in any case and proportioned to provide a predetermined terminal impedance for the structure in the manner described above. While the impedance-inverting section of each arrangement has been described as a pair of parallel conductors, it will be understood that other structural arrangements may be employed. For example, a tapered impedance-matching transmission line may be utilized. Furthermore, the impedance-inverting section need not necessarily be proportioned to provide an exact impedance match between the antenna structure and the terminal circuit to which it is to be connected, although this condition is required for maximum power transfer. In practical embodiments of the invention a certain latitude is permissible, being limited by that amount of mismatch between the antenna structure and its terminal circuit which results in a loss of energy due to the mismatch in excess of the tolerable loss. Accordingly, the definition "the dimensions of the impedance-inverting section being proportioned to transform the impedance of the antenna structure to a terminal impedance substantially equal to that of the terminal circuit," as used in the specification and

appended claims, is intended to include not only the condition of exact impedance matching but also the conditions of mismatching within the limits given above.

For convenience of illustration, the aligning members and terminal box have been omitted from all figures of the drawings except Fig. 1. However, it will be understood that these elements will be provided in preferred embodiments of the invention.

While there have been described what are at present considered to be the preferred embodiments of this invention, it will be obvious to those skilled in the art that various changes and modifications may be made therein without departing from the invention, and it is, therefore, aimed in the appended claims to cover all such changes and modifications as fall within the true spirit and scope of the invention.

What is claimed is:

1. In an antenna system, an antenna structure for connection to a terminal circuit having a predetermined value of impedance at a predetermined operating frequency comprising, a pair of similar coplanar radiating conductors each having a J-shaped configuration and an effective electrical length of substantially one-half wave length at said frequency, said conductors being positioned in spaced-opposed relation with reference to a plane of symmetry with one end of one conductor adjacent to the corresponding end of the other and the relative dimensions of said conductors being proportioned to cause the antenna structure to have a substantially omnidirective radiation pattern in the plane of said conductors, said conductors presenting between said adjacent ends a maximum impedance much greater than said predetermined value, an impedance-transforming means connected to said adjacent ends for transforming said maximum impedance to said antenna structure at said adjacent ends to a terminal impedance at the other end of said transforming means equal to said predetermined value, and a plane reflector disposed normal to the plane of said antenna structure and proportioned to form virtual images of said radiating conductors so that said antenna system effectively comprises a complete loop structure having a hemispherical directive characteristic.

2. In an antenna system, an antenna structure for connection to a terminal circuit having a predetermined value of impedance at a predetermined operating frequency comprising, a pair of similar coplanar radiating conductors each having a J-shaped configuration and an effective electrical length of substantially one-half wave length at said frequency, said conductors being positioned in spaced-opposed relation with reference to a plane of symmetry with one end of one conductor adjacent to the corresponding end of the other and the relative dimensions of said conductors being proportioned to cause the antenna structure to have a substantially omnidirective radiation pattern in the plane of said conductors, said conductors presenting between said adjacent ends a maximum impedance much greater than said predetermined value, an impedance-inverting transmission-line section included as a part of said antenna structure comprising a pair of parallel conductors connected at one end to said adjacent ends of said radiating conductors, having a diameter and length approximately equal to that of the longest element of said radiating conductors and a spacing selected to transform said maximum impedance of said antenna structure at said adjacent ends to a terminal impedance at the other end of said section substantially equal to said predetermined value, and a plane reflector disposed normal to the plane of said antenna structure and proportioned to form virtual images of said radiating conductors so that said antenna system effectively comprises a complete loop structure having a hemispherical directive characteristic.

3. In an antenna system, an antenna structure for connection to a terminal circuit having a predetermined value of impedance at a predetermined operating frequency comprising, a pair of similar coplanar radiating conductors each having a J-shaped configuration and an effective electrical length of substantially one-half wave length at said frequency, said conductors being positioned in spaced-opposed relation with reference to a plane of symmetry with one end of one conductor adjacent to the corresponding end of the other and the relative dimensions of said conductors being proportioned to cause the antenna structure to have a substantially omnidirective radiation pattern in the plane of said conductors, said conductors presenting between said adjacent ends a maximum impedance much greater than said predetermined value, an impedance-inverting transmission-line section included as a part of said antenna structure comprising a pair of conductors connected to said adjacent ends and disposed in the plane of said radiating conductors in parallel relation with and extending in the same direction as one element of each of said J-shaped sections, the dimensions of said impedance-inverting section being proportioned to transform said maximum impedance of said antenna structure at said adjacent ends to a terminal impedance substantially equal to said predetermined value, and a plane reflector disposed normal to the plane of said antenna structure adjacent to the terminal end of said impedance-inverting section, said reflector including provisions for connecting said terminal circuit to said antenna structure and being proportioned to form virtual images of said radiating conductors so that said antenna system effectively comprises a complete loop structure having a hemispherical directive characteristic.

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