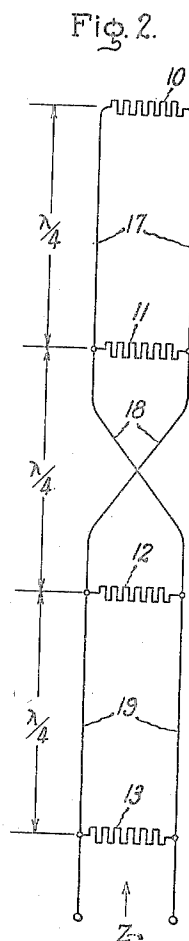
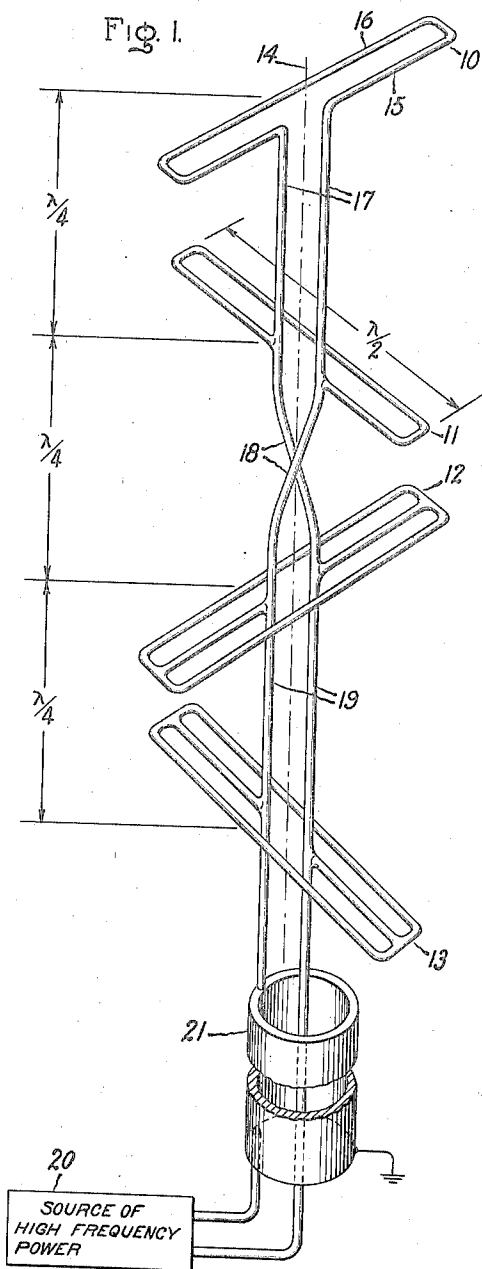


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ANTENNA SYSTEM

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ANTENNA SYSTEM

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My invention relates to an antenna system, and particularly to a high frequency directive antenna system suitable for operation on horizontally polarized waves.

Antenna arrays have heretofore been proposed which comprise a plurality of horizontal half-wave antenna elements oriented in a particular manner to produce a field strength pattern of desired configuration. One form of array which is particularly suited for high frequency broadcast service comprises several pairs of horizontal dipoles centrally supported on a common mast, the dipoles of each pair being placed at right angles to each other and energized in phase quadrature. If such an array is to radiate energy fairly uniformly in all horizontal directions, as is generally desirable for broadcast service, the magnitudes and phase relationships of the currents in the various radiators must be carefully adjusted. Ordinarily this necessitates the use of several transmission lines for feeding the antenna elements, together with phase adjusting circuits. Impedance matching elements must also generally be employed between the transmission lines and the radiators if the system is to function with maximum efficiency. In accordance with my invention a simple and efficient antenna system is provided, suitable for such service, which requires a minimum of component parts and which is very easily adjusted.

It is therefore an object of my invention to provide an improved high frequency directive antenna system.

Another object of my invention is to provide an improved directive antenna system having a plurality of half-wave antenna elements symmetrically disposed along a common axis and fed from a common transmission line.

A further object of my invention is to provide an improved system of this general type in which the antenna elements are alternately disposed at right angles to each other and fed in phase quadrature directly from a single transmission line without the necessity for additional phase adjusting circuits.

Still another object of my invention is to provide an improved system of this general type in which all the feeding point impedances of the antenna elements may be correctly matched directly to sections of a single transmission line feeding these elements without the use of additional impedance matching circuits.

The features of my invention which I believe to be novel are set forth with particularity in the appended claims. My invention itself, however,

together with further objects and advantages thereof, may best be understood by reference to the following description taken in connection with the accompanying drawing, in which Fig. 1 is a perspective view, partly schematic, of an antenna array embodying my invention, and Fig. 2 is an equivalent circuit diagram of the antenna array of Fig. 1 which will be referred to in considering the impedance relationships between the various elements of the array.

In the antenna array illustrated in Fig. 1 four linear half-wave antennae 10, 11, 12 and 13 constitute the active antenna elements of the system. They are positioned horizontally and symmetrically disposed one above the other with their centers effectively lying on a common vertical axis 14. The antenna elements are spaced apart vertically from each other by a distance which corresponds substantially to one quarter of a wave length at the operating frequency of the system. The antenna elements 10 and 12 are therefore spaced apart by substantially a half wave length, and they also are positioned in a common vertical plane passing through the axis 14. The antenna elements 11 and 13 are likewise spaced apart by substantially a half wave length, and they are positioned in a second vertical plane which intersects the first along the axis 14 and which is mutually perpendicular thereto.

The antenna elements 10—13 are generally of the type which has been termed the folded dipole. Briefly, the antenna 10 comprises two ordinary half-wave dipoles 15 and 16 which are closely spaced from each other in terms of the operating wave length and connected together at their ends. The dipole 15 is opened at its center for connection to a feed line. The antenna 11 is of substantially the same construction. The antennae 12 and 13 are folded dipoles of a slightly different type, each comprising three closely spaced half-wave dipoles connected together at their ends, the center dipole being opened for the feed connection.

The electrical characteristics of the folded dipole are familiar to those skilled in the art and will be discussed in somewhat greater detail at a subsequent point. It may be stated here that the radiation characteristics of a folded dipole do not differ substantially from the characteristics of the simple half-wave dipole. The current distribution is approximately sinusoidal and the radiation pattern is essentially the same as the pattern produced by the simple dipole. The precise design and construction of the half-wave

elements 10—13 are familiar to those skilled in the art and form no part of my invention.

Extending along the axis 14 and connected to each of the antenna elements 10—13 is a two-conductor transmission line having three quarter-wave sections, 17, 18 and 19. The lower end of this transmission line, i. e., where it joins the antenna element 13, is connected in any suitable manner to a source of high frequency power. Such a power source is indicated schematically by the block 20 and may comprise high frequency radio or television transmitting apparatus. The means for connecting the source 20 to the antenna array is illustrated as a coaxial cable 21. Of course, an open-wire transmission line may be employed, if desired.

The power source 20 supplies current to the antenna system at the operating frequency of the array. In an amplitude modulation system this frequency will of course be the carrier frequency, whereas in a phase or frequency modulation system it will be the mean carrier frequency.

In the antenna system illustrated in Fig. 1 it is desired to have the pairs of antennae 10, 12 and 11, 13 in the respective vertical planes energized cophasally. Furthermore, the currents in the antennae 10, 12 are to be in phase quadrature to the currents in the antennae 11, 13. The transmission line 17—19 has a progressive phase shift in the current distribution of 90 degrees for each quarter-wave interval along its length. Therefore, the proper phase relations among the antenna currents are easily established by connecting the antenna elements to quarter-wave points along the line. Since the antennae in each plane are to be energized cophasally, the transmission line must be effectively transposed once in each half-wave interval between the dipoles in each plane. In a practical construction, the simplest way to obtain this necessary transposition is to employ a helical transmission line which spirals smoothly along the axis of the antenna array, making one-half revolution in each half wave length. This avoids the necessity for abrupt crossovers between the conductors and simplifies the physical construction of insulators and supporting structure.

The antenna system of Fig. 1 is supported in any suitable manner, not shown. A single central mast extending along the axis of the system will generally be found preferable for supporting the entire array.

The impedance of the ordinary half-wave dipole is generally too low to be matched directly to a transmission line. However, as is known to the art, the folded dipole performs the dual function of a radiator and an impedance matching transformer. The quotient of the total power radiated divided by the square of the total current at the center, i. e., the radiation resistance, is about 73 ohms as in the case of a simple half-wave dipole. However, the feeding point impedance presented to the transmission line depends primarily upon the number of sections connected together and their physical dimensions. In the case of a folded dipole having two sections of equal diameter the feeding point impedance is approximately four times 73 ohms or 292 ohms. The three-section antenna element has a transformation ratio of substantially 9 to 1 when the conductors are of equal diameter. Furthermore, the transformation ratio may be varied over considerable limits by

the use of conductors of unequal diameters for the radiating elements. Thus, the folded dipoles provide means for increasing the feeding point impedances of the elements to values suitable for direct connection to a transmission line of reasonable physical dimensions.

In the antenna system constructed in accordance with my invention it is possible to match the feeding point impedances of all the antenna elements directly to the characteristic impedances of the quarter-wave sections of the transmission line 17—19. If this is done the power input of the system will be equally divided among all the radiating elements and the radiation pattern of the system will be symmetrical. A better understanding of this feature of my invention may now be had by considering Fig. 2 of the drawing in conjunction with the following description.

Since the antennae 10—13 are substantially resistive at their resonant frequency, the system of Fig. 1 can be represented by the equivalent circuit of Fig. 2 wherein the resistors 10—13 represent the antennae and have values equal to the feeding point impedances of the antennae. The impedance Z looking into the antenna system is to be made equal to the characteristic impedance of the coaxial cable 21. If this is done the cable 21 will be properly terminated and will exhibit non-resonant resistive characteristics.

The sections 17, 18 and 19 of the transmission line interconnecting the antennae can be regarded as impedance matching transformers. In the case of a quarter-wave transmission line terminated in an impedance, the following relation holds:

$$Z_s = Z_o^2 / Z_r \quad (1)$$

where Z_s equals the sending end impedance looking into the line, Z_o equals the characteristic impedance of the line and Z_r equals the receiving end impedance. If the receiving end impedance is resistive, all of these impedances will be

From the above relationship a proper impedance match between all elements of the array may be determined. As an illustration, the following values have been found suitable in a practical embodiment of the system. By proper design and construction the feeding point impedance of each of the folded dipoles 10 and 11 was made equal to a resistance of about 300 ohms at resonance. Similarly, the feeding point impedance of each of the three-section dipoles 12 and 13 was made equal to a resistance of about 600 ohms at the operating frequency of the system. It was desired to match the input impedances of the system to a coaxial cable having a characteristic impedance of 150 ohms. By calculation it was found that the proper values for the characteristic impedances of the quarter-wave sections 17, 18 and 19 were about 300, 212, and 200 ohms, respectively.

The fact that a proper impedance match between all elements of the system was obtained with the above values will become apparent upon analysis. From Equation 1, the impedance looking into the section 17 from the terminals of antenna 11 was 300 ohms. Therefore, a resistive impedance of 150 ohms was seen looking into this resistive impedance of 300 ohms in parallel with the resistive impedance of antenna 11, also of 300 ohms. Proceeding in like manner with the analysis the impedance looking upward

into the terminals of antenna 12 was equal to 200 ohms and the impedance of the entire system looking into the terminals of the antenna 13 was 150 ohms, which was correct for proper termination of the 150 ohm coaxial cable 21.

It is believed unnecessary to detail the precise method for determining the impedances of the various antenna elements and transmission line sections. These may be determined by ordinary methods familiar to those skilled in network analysis. Furthermore, this is often more easily accomplished by cut and try methods in the case of a simple system, such as the one illustrated.

As previously mentioned, if all sections of the array are properly matched, there will be an equal division of power between all antennae and, furthermore, the proper phase relations for the currents in the elements are automatically established.

It can be shown that the energy radiated from the particular form of array illustrated will be concentrated horizontally and that the radiation pattern will be fairly uniform in all horizontal directions when all the component elements are properly matched, as just described. It will be appreciated that this type of radiation pattern is well adapted for broadcast service, particularly in the high and ultra high frequency bands.

The foregoing principles can readily be extended to cover antenna arrays having more or less than four radiating elements. It will be appreciated that, in general, the radiation pattern will not be symmetrical if an odd number of antenna sections is employed. Furthermore, even in the case of an even number of antenna sections, the impedances must be properly matched as described above to produce a symmetrical pattern. Application of the principles of my invention to modified forms of antenna arrays must of course take into account the limitations imposed by the physical dimensions of the various elements.

Although my invention finds particular application in a transmitting antenna system, and although the foregoing description has been presented with emphasis on that fact, it will be apparent that my improved antenna system may be employed with receiving equipment. The fact that the directivity, current distribution, and other characteristics of a particular antenna array are the same whether it is employed to abstract energy from an incident high frequency electromagnetic wave or radiate such a wave are so well known as to require no elaboration.

While I have shown a particular embodiment of my invention, it will of course be understood that I do not wish to be limited thereto since various modifications may be made, and I contemplate by the appended claims to cover any such modifications as fall within the true spirit and scope of my invention.

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

1. A directive antenna array comprising a plurality of linear antenna elements spaced apart from each other by substantially one quarter of a wave length at the operating frequency, adjacent elements being disposed in different mutually perpendicular planes, a pair of transmission line conductors extending between said elements, said elements being connected to said conductors at quarter-wave points along said line.

2. A directive antenna array comprising a plurality of linear antenna elements spaced apart

from each other by substantially one quarter of a wave length at the operating frequency, adjacent elements being disposed in different mutually perpendicular planes, and a two-conductor transmission line extending between said elements, said elements being connected to said conductors at quarter-wave points along said line and the conductors of said line being effectively transposed once between adjacent elements in each plane.

3. A directive antenna array comprising a plurality of half-wave antenna elements having their centers disposed substantially on a common axis and being spaced apart from each other by substantially one quarter of a wave length at the operating frequency, adjacent elements being disposed in different mutually perpendicular planes intersecting along said axis, a transmission line comprising a plurality of quarter-wave sections disposed substantially along said axis and carrying oscillatory currents of said operating frequency, and means to connect corresponding points on the elements in each plane to points of like phase between the sections of said line.

4. A high frequency directive antenna system comprising a plurality of horizontal half-wave radiating elements having their centers disposed substantially on a common vertical axis and being spaced apart from each other by substantially one quarter of a wave length at the operating frequency, adjacent elements being disposed in different mutually perpendicular planes intersecting along said axis, a pair of transmission line conductors extending along said axis, means to energize said conductors with high frequency currents of said operating frequency, and means to connect said elements to said conductors at quarter-wave points along said line.

5. A high frequency directive antenna system comprising a plurality of horizontal half-wave radiating elements having their centers disposed substantially on a common vertical axis and being spaced apart from each other by substantially one quarter of a wave length at the operating frequency, adjacent elements being disposed in different mutually perpendicular planes intersecting along said axis, a pair of transmission line conductors extending along said axis, means to energize said conductors with currents of said operating frequency, and means to connect said elements to said conductors at quarter-wave points along said line, said conductors being effectively transposed once between adjacent elements in each plane.

6. A high frequency directive antenna array comprising a plurality of dipoles having their centers disposed substantially on a common axis and being spaced apart from each other by substantially one quarter of a wave length at the operating frequency, adjacent dipoles being disposed in different mutually perpendicular planes intersecting along said axis, a common transmission line having a plurality of quarter-wave sections disposed along said axis, means to energize said line with currents of said operating frequency, and means to connect corresponding points on the dipoles in each plane to points of like phase between the sections of said line, the feeding point impedances of said dipoles being matched to the characteristic impedances of said quarter wave sections.

7. A high frequency directive antenna system comprising a plurality of horizontal dipole radiators having their centers disposed substantially on a common vertical axis and being

spaced apart from each other by substantially one quarter of a wave length at the operating frequency, adjacent radiators being disposed in different mutually perpendicular planes intersecting along said axis, a common transmission line having a plurality of quarter-wave sections disposed along said axis, a source of high frequency power connected to said line, and means to connect said dipoles to said line at points between said sections, the conductors of said line being effectively transposed once between adjacent dipoles in each plane and the feeding point impedances of said dipoles being matched to the characteristic impedances of said quarter-wave sections so that the power supplied over said line is substantially equally divided among said dipoles.

8. A directive antenna array for concentrating radiated high frequency energy horizontally comprising an even number of horizontal half-wave radiating elements having their centers disposed substantially on a common vertical axis and being spaced apart from each other by substantially one quarter of a wave length at the operating frequency, adjacent elements being disposed in different mutually perpendicular planes intersecting along said axis, a transmission line having a plurality of quarter-wave sections disposed along said axis between said elements, means for supplying high frequency power to said lines at said operating frequency, center feed connections from the elements in

each plane to points of like phase between said sections, the feeding point impedances of said elements being matched to the characteristic impedances of said sections for substantially equal power transfer from said line to each element.

9. A high frequency directive antenna array for radiating horizontally polarized waves comprising four horizontal half-wave radiating dipoles of the folded type spaced apart by substantially one quarter of a wave length at the operating frequency along a common vertical axis passing through their centers, adjacent dipoles being disposed in different mutually perpendicular planes intersecting along said axis, a two-conductor transmission line having three quarter-wave sections disposed along said axis between said dipoles, means connecting one end of said line to a source of high frequency power, and center feed connections between the dipoles in each plane and adjacent quarter wave points on said line, the conductors of said line being effectively transposed once between adjacent dipoles in each plane and the feeding point impedances of said dipoles being matched to the characteristic impedances of said sections, whereby the dipoles in one plane are similarly energized in phase quadrature to the dipoles in the other plane and all said dipoles receive substantially equal power from said source over said line.

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