Oct. 6, 1942. C. R. BURROWS 2,298,034

ANTENNA SYSTEM

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FIG. 1

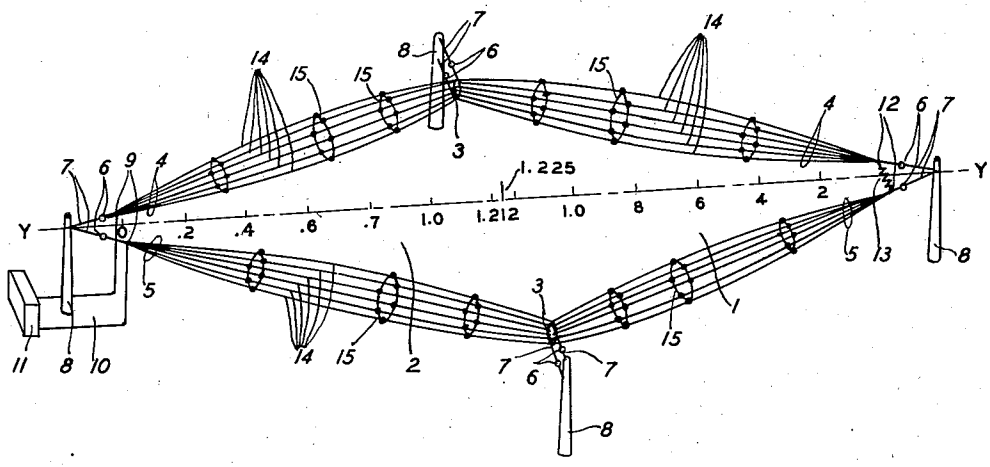


FIG. 2

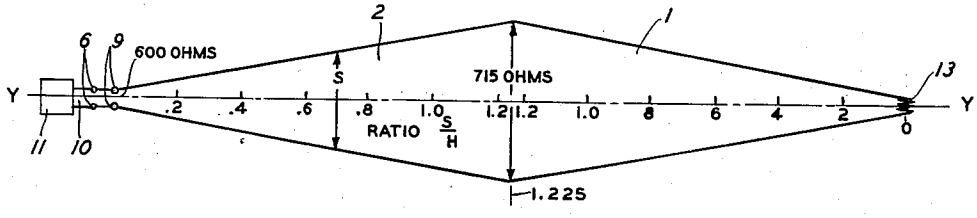
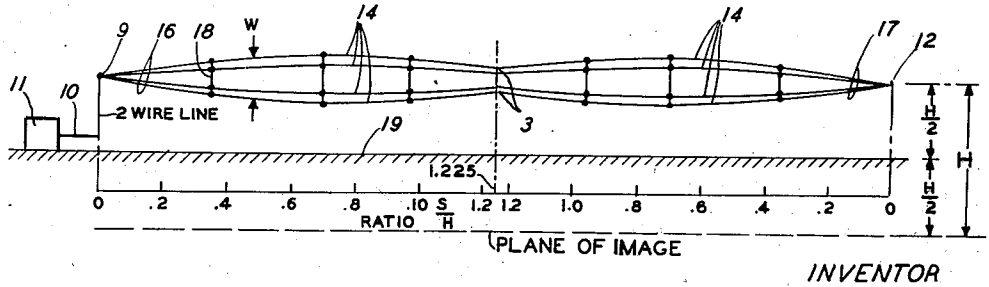


FIG. 3



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FIG. 4

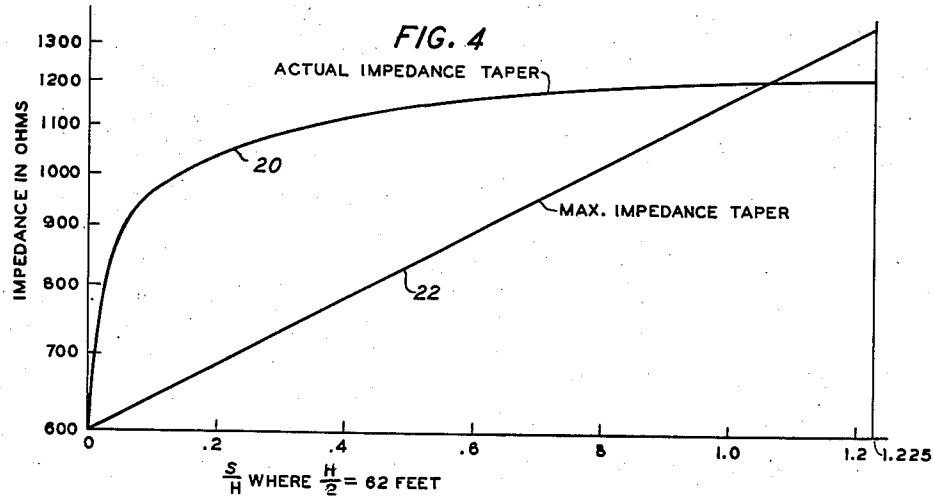


FIG. 5

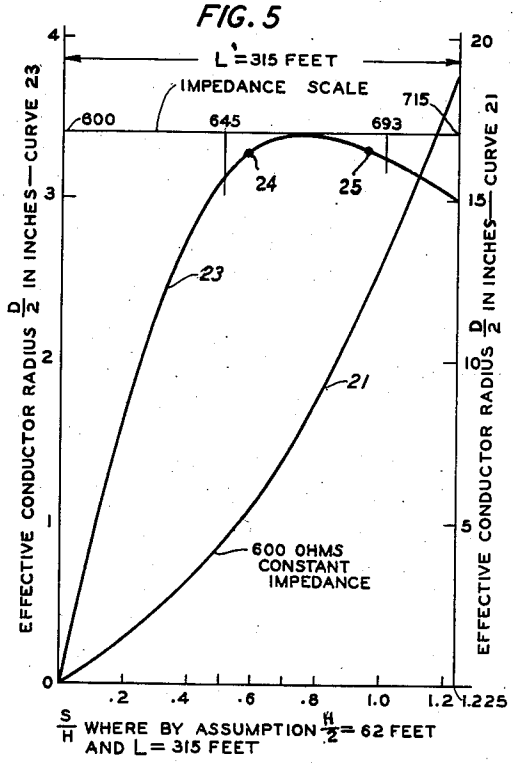
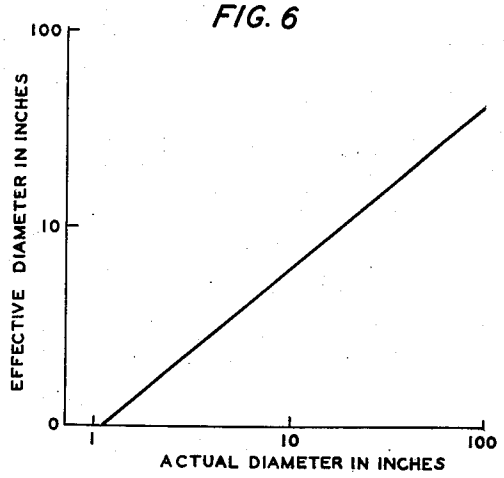


FIG. 6



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UNITED STATES PATENT OFFICE

2,298,034

ANTENNA SYSTEM

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Application July 2, 1941, Serial No. 400,739

10 Claims. (Cl. 250—33)

This invention relates to transmitting and receiving antennas and more particularly to short wave antenna systems.

As is known V and double V antennas of the type disclosed in Patent 1,899,419 to E. Bruce and in the copending application of E. Bruce, Serial No. 513,063, filed February 3, 1931, are extensively used in the short wave and ultra-short wave fields. While, in radio systems utilizing antennas of this type, undesired wave reflection at the junction of the line and antenna may be satisfactorily eliminated by properly matching the characteristic impedance of the line and the impedance at the input terminals of the antenna, reflection losses occur in the antenna structure itself since the antenna conductors are of necessity angularly related and, as a consequence, the surge impedance varies from a given amount at the input terminals to a much larger amount at the point of widest separation of the antenna conductors. In order to secure equal surge impedances throughout the antenna, the used of solid or multiwire antenna conductors, which taper in cross-sectional area so that the ratio of the conductor spacing to the conductor diameter remains constant, has been suggested, as disclosed in Patent 1,959,407, E. Bruce, May 22, 1934. While this method or arrangement is in general satisfactory, the size of the conductor diameter required at the point of widest separation is, in the case of large antennas, exceedingly large and impractical.

It is one object of this invention to increase the efficiency of V and double V antennas.

It is another object of this invention to secure a surge or characteristic impedance of uniform varation in an antenna system comprising diverging conductors having a fixed angular relation.

It is still another object of this invention to match the impedances of a line and of an antenna array comprising a horizontal V or double V antenna and its image antenna.

According to one embodiment of the invention the side elements or conductors of a horizontal V antenna are each of the multiwire type, the diameter or width of the conductor at any point being critically related to the spacing between the sides of the V antenna at said point and to the height of the antenna above ground, and such that the surge or so-called characteristic impedance of the antenna varies exponentially from a small value at the near-end or line terminals of the antenna to a larger value at the widely separated terminals. In the case of large V or double V multifrequency antennas a practical cage diameter, as, for example, three inches, may be selected for the point of widest spacing, whereby a relatively low value of surge impedance at said point may be obtained and, by properly proportioning the conductor diameter along the antenna, a desirable small exponential variation in impedance along the antenna may be obtained. In accordance with this invention the conductor size is a maximum at a point between the extremities of the conductor. The exponential impedance variation gives a uniform rate of change of surge impedance hereinafter called "impedance taper" whereby no reflection is initiated at points along the antenna and, assuming the antenna is properly terminated, no reflection occurs from the end of the antenna. In addition, the exponential impedance taper provides a satisfactory surge impedance variation over the normal operating frequency band.

The invention will be more fully understood from a perusal of the following specification taken in conjunction with the drawings on which like reference characters denote elements of similar function and on which:

Figure 1 is a perspective view of one embodiment of the invention;

Figs. 2 and 3 are, respectively, top and side views of a slightly different embodiment of the invention; and

Figs. 4, 5 and 6 are curves useful in explaining the invention.

Referring to Fig. 1 reference numerals 1 and 2 designate two horizontal V antennas connected together at their widely separated terminals 3 to form a double V or rhombic antenna. The V antennas are positioned at a distance H/2 above the earth's surface. As is known, each V antenna may, if desired, be used alone as a radiating or collecting system. Each V antenna comprises the side cage elements or conductors 4 and 5 which are supported through insulators 6 by the guy wires 7 and poles 8 and between which the spacing S varies. The near end terminals 9 are connected by means of line 10 to a translation device 11 and the far-end terminals 12 are connected together through the terminating impedance 13 which, as is well known, functions to produce a unidirectional effect. Each side cage element is of circular cross section and comprises several, for example, six wires denoted by numeral 14, the diameter d of each wire 14 being equal and uniform throughout the length L of the side conductor and the diameter D of each cage being non-uniform, in accordance with the invention, and as is explained more fully below. Annular spacers 15 of different size are utilized to secure the proper non-uniform cage diameter and to maintain the wires in each cage element equally spaced.

Referring to Figs. 3 and 4, these views illustrate a structure which is the same as that illustrated by Fig. 1 except that, the side elements 16, 17 are grid type instead of cage type. Thus the

wires 14, Fig. 3, in each element 16, 17 are in the same vertical plane and the proper spacing therebetween is obtained by means of different size spacers 18. The width W of each grid conductor is, for any given spacing S between the side elements 16, approximately the same as the diameter D of the cage conductor. The side view, Fig. 3, of the conductors 16 and 17 is drawn somewhat out of scale since, as will be explained, the maximum dimension W has a maximum value of slightly different from three inches whereas the mean or average distance H/2 of the system above the ground 19 is in the order of sixty feet or more and the distance H between the horizontal antenna and its image is in the order of one hundred and twenty feet or more. Considered in the horizontal plane passing through the two V antennas 1 and 2, Figs. 2 and 3, the side elements 16, 17 are linear and the structure, therefore, conforms to the preferred geometric arrangement disclosed in the above-mentioned copending application of E. Bruce.

Referring to Figs. 4, 5 and 6 the manner of determining the variable diameter D of the cage conductor for securing a uniformly changing surge impedance will be explained. For the purpose of this explanation it is assumed that the line 10 has a characteristic impedance of 600 ohms, the side length L of the rhombic antenna of Figs. 1, 2 and 3 is approximately 315 feet, the distance H is approximately 124 feet and that the acute angle between the side conductors of each V antenna is approximately 28 degrees. Considering first the prior art V or double V antenna having single wire side conductors, the surge impedance Z for any point of the antenna is given by the following equation, it being assumed that the antenna is positioned over perfect ground

$$Z_x = 120 \log_e \left[\frac{SH}{R\sqrt{S^2+H^2}} \right] \quad (1)$$

that is

$$Z_x = 120 \log_e \frac{S}{R} - 60 \log_e \left(1+\frac{S^2}{H^2}\right) \quad (2)$$

where R is the actual radius if the conductor is cylindrical. If the conductor is of the cage type, R is the radius of the cylindrical conductor which has the same capacity per unit length as the cage conductor and is somewhat smaller than the corresponding actual cage radius; x is the distance along the antenna axis Y—Y from the line terminals 9; and e is the base of natural logarithms.

As shown by curve 20, Fig. 4, which is a plot of Equation 1, for the prior art structure having the dimensions specified above, the surge impedance Z increases non-uniformly from 600 ohms at the line terminals 9 to about 1200 ohms at the widely separated terminals 3. More particularly, the surge impedance comprising distributed capacity and distributed inductance rises sharply in the neighborhood of the closely spaced line terminals 9, the ratio S/H, Fig. 4, being directly proportional to the distance along the axis Y—Y from the line terminals 9 and the distance H being a constant. In fact, the surge impedance almost reaches its maximum value one-third the distance down the antenna and as a result of the abrupt change in surge impedance near the line terminals 9 considerable reflection occurs. Minimum or zero reflection along the antenna may be secured by making the rate of change in surge impedance uniform throughout the antenna and this may be accomplished by causing the impedance to increase in accordance with the following exponential law or equation

$$Z_x = Z_o e^{bx} \quad (3)$$

where Z_o is the surge impedance at the line terminals 9 and under the assumed condition, is 600 ohms; and b is the taper or rate change in impedance per unit length of antenna. For a smooth line comprising parallel conductors $b=o$ curve 22, Fig. 4, illustrates the uniform or straight line impedance characteristic obtained when a taper of 2 to 1 in 165 feet or 50 meters is utilized, the shortest operating wave length being 50 meters. If the maximum or largest suitable impedance taper, mentioned above, is used, the conductor radius at terminals 3, at which point the impedance is 1200 ohms, is of a practical size and relatively small but the reflection from terminals 3 is not a minimum since the exponential taper is relatively large, and the larger the taper the greater the reflection from the termination. Stated differently, the smaller the taper the more nearly the characteristic impedance approaches the ideal pure resistance value. The reflection may be decreased and, at the same time, a practical cage effective radius may be employed by selecting arbitrarily a larger cage radius say, three inches, for the side elements at the point of widest separation whereby a smaller taper may be used. After the determination of the impedance at said wide point for conductors of the selected radius, the diameter of each side conductor may be proportioned to secure the particular impedance taper which, in a sense, matches the relatively large impedance at the widest terminals 3 to the much smaller impedance at the line terminals 9. Thus, from Equation 1 the impedance Z_x at the wide point is 715 ohms for the structure assumed and for an effective conductor radius of 3 inches at said point, the factors R and S being known. The exponential taper b suitable for smoothly changing 715 ohms to 600 ohms is next determined from Equation 2, the term x being given the value of 315 feet. With the taper b ascertained, the impedance at any other point x along the antenna may be determined from Equation 2 and the corresponding effective conductor radius ascertained from Equation 1. Curve 23, Fig. 5, illustrates the relation between the ratio S/H which, as previously indicated, is proportional to x and the effective conductor radius R. It will be noted that the maximum radius for the side conductor is at the intermediate point corresponding approximately to $S/H=0.7$. This may follow in part from the fact that the factor S varies from a value smaller than the constant H to one larger than H as the distance x increases and at some intermediate point x, $S=H$. It should be noted that every point on curve 23 represents a different surge impedance as indicated by the impedance scale, Fig. 5, on which, by way of example, the values of 600, 645, 693 and 715 ohms are given. Also, it may be observed that points 24 and 25 on curve 23 represent points along the antenna conductors of different impedance but of the same effective conductor radius.

As indicated above the radius heretofore referred to for the cage side conductor is the so-called "effective" radius. The actual conductor radius corresponding to the effective conductor radius may be determined as follows. The Scientific Paper No. 568, United States Bureau of Standards, pages 586 and 593 gives the following relation for

the effective and actual diameter of cage conductors.

$$D_n=\left[d\pi\frac{k=n-1}{k=1}2F\sin\frac{k\eta}{n}\right]^{1/n} \quad (4)$$

where d is the diameter of each wire. F is the actual diameter of the circle on whose circumference the wires are evenly spaced. π indicates the product of factors with different values of k from 1 to $n-1$. $\eta=3.14$. n is the number of wires. k is 1, 2, 3 up to $n-1$.

For $n=4$, 6 and 8 we have

$$D_4=1.414\ d^{1/4}\ F^{3/4} \quad (5)$$
$$D_6=1.348\ d^{1/6}\ F^{5/6} \quad (6)$$
$$D_8=1.300\ d^{1/8}\ F^{7/8} \quad (7)$$

For effective diameters of the order of twelve inches a practical cage appears to be six wires of No. 10 B. & S. wire gauge. Fig. 6 illustrates the relation between the effective and actual diameters for such a cage conductor. An effectime diameter of 6.8 inches, the maximum required by the exponential design corresponds to an actual diameter of 10.8 inches which is practical and satisfactory. Referring again to Fig. 1 the cage conductors 4, 5 constituting the V antennas 1 and 2 and comprising six wires, have an actual diameter D determined in accordance with Equation 5. As previously discussed, if desired, the six wires of each multi-wire side conductor may be arranged in the same vertical plane to form a grid conductor as explained in connection with Figs. 2 and 3. The grid conductor modification or compromise is simpler and less expensive both as to first cost and maintenance.

Although the invention has been described in connection with certain types of antenna systems it is to be understood that it is not limited to such systems. Moreover, conductors other than cage or grid type, as for example, solid conductors may be satisfactorily employed in practicing the invention.

What is claimed is:

1. An electrical conducting system comprising angularly related straight conductors and having an exponential distributed impedance taper, at least one of said conductors having a given cross-sectional area at one of its extremities and a variable cross-sectional area along its length, the variation in said area being dependent upon said given cross-sectional area and the difference in distributed impedance at the conductor extremities.

2. An electrical conducting system comprising angularly related straight conductors and having a given exponential distributed impedance variation or taper, at least one of said conductors having a curvilinear variation in cross-sectional area, said variation being a function of the impedance taper.

3. A V antenna comprising angularly related multiwire conductors and having a uniformly changing surge impedance, said conductors each having a curvilinear variation in cross-sectional area, the variation in cross-sectional area, the variation being a function of the uniform change in the spacing between conductors and a function of the difference between the surge impedances at the closely positioned and the widely spaced conductor extremities.

4. A radio system comprising a horizontal V-shaped aerial and a portion of the earth's surface, said aerial having an exponential variation in surge impedance and comprising angularly related conductors each having a non-uniform diameter, the variation in diameter of each conductor along the conductor length being dependent upon said impedance variation and dependent upon the variable relation between the distance separating said conductors and the distance separating said aerial and said surface.

5. A horizontal antenna comprising a pair of diverging straight cage conductors each having an effective diameter at any point critically related to the ratio of the conductor spacing at said point to twice the height of the antenna above ground, whereby the surge impedance of said antenna varies uniformly along the length of said antenna.

6. A horizontal antenna system comprising angularly related linear conductors each comprising a plurality of wires, the effective conductor diameter at any point being dependent upon the ratio of the conductor spacing at said point to twice the height of said antenna above ground, whereby the rate of change in surge impedance along said antenna is uniform.

7. A horizontal rhombic antenna comprising two V-shaped sections, each V section comprising two conductors, the effective diameter at any point of each conductor being a function of the ratio of the spacing between said conductors at said point to twice the height of said rhombic antenna, whereby the characteristic impedance along each section varies exponentially.

8. A double V antenna comprising straight multiwire conductors having a fixed angle depending upon the length of said conductors, the conductors each having an effective diameter in the order of three inches at the point of widest separation, a small diameter at the point of minimum conductor spacing and a larger diameter at a point intermediate said first-mentioned points, and a translation device connected to said antenna at the point of minimum spacing.

9. A method of minimizing reflection in a system comprising angularly related cage conductors connected between a source and a terminating impedance, which comprises arbitrarily selecting for the point of maximum conductor separation a cage radius of practical size and such as to render the difference in the surge impedances at said point and at the point of minimum conductor spacing relatively small, and proportioning the radius of each cage conductor so as to secure an exponential surge impedance taper along said conductors.

10. A method of minimizing reflection along a V antenna connected to a line and comprising multiwire cage conductors of non-uniform diameter, the conductors being positioned at a fixed angle having a value dependent upon the conductor length, which comprises selecting for the widely separated terminals a practical cage diameter, ascertaining the impedance at said terminals and the impedance at the antenna terminals connected to said line, selecting a value of exponential impedance taper or rate of impedance change for said antenna to match said impedances, determining from the asecrtained exponential taper the effective conductor diameter at various points along the diameter and utilizing non-uniform conductors, each having an actual non-uniform diameter related to the ascertained effective non-uniform diameter.

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