Nov. 1, 1932. E. J. STERBA 1,885,151
DIRECTIVE ANTENNA SYSTEM
Filed July 30, 1929 2 Sheets-Sheet 1

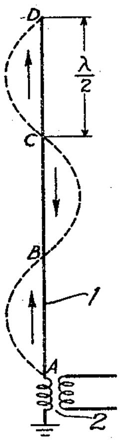

FIG. 1

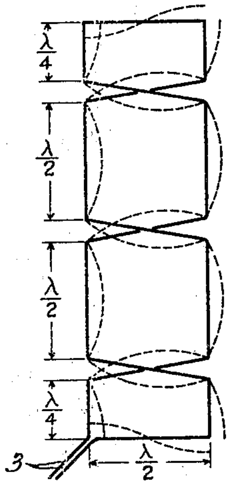

FIG. 2

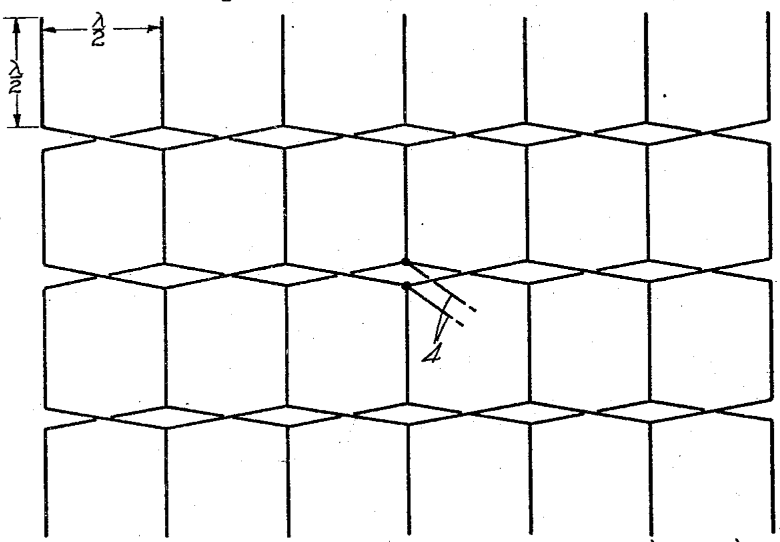

FIG. 3.

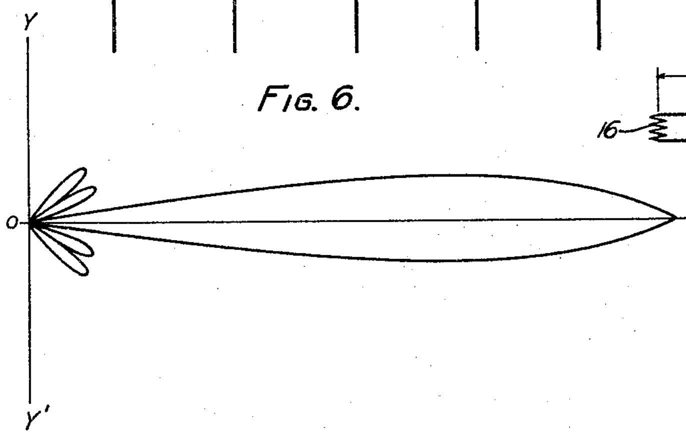

FIG. 6.

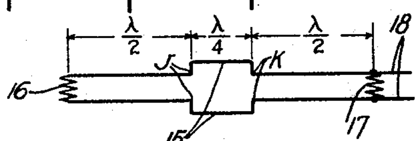

FIG. 5

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Nov. 1, 1932. E. J. STERBA 1,885,151

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Filed July 30, 1929 2 Sheets-Sheet 2

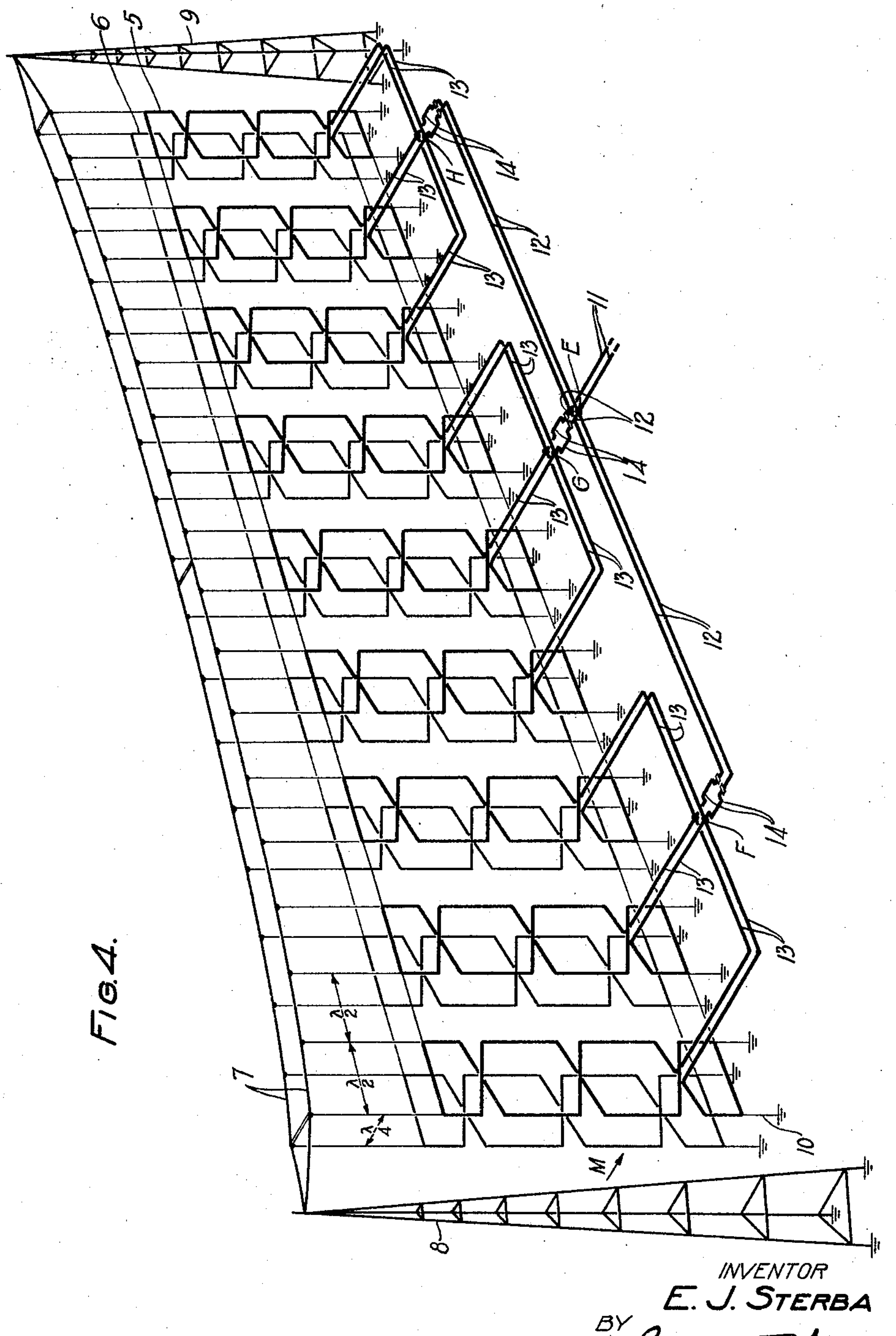

FIG. 4.

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UNITED STATES PATENT OFFICE

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DIRECTIVE ANTENNA SYSTEM

Application filed July 30, 1929, Serial No. 382,103, and in Great Britain February 13, 1929.

This invention relates to directive antenna systems, particularly systems as adapted to radiate or absorb short waves.

It is well known that various antenna systems having a uni-lateral or bi-lateral directional characteristic have been employed in the past with some success in the directional reception and transmission of Hertzian waves of relatively high frequency. In these systems, however, the methods employed for suppressing or eliminating undesired radiation or reception in the horizontal or earth's plane and for increasing the intensity of the waves transmitted in, or received from, the desired direction have not proved entirely satisfactory. Moreover, in transmitting systems, the various schemes in use at present designed to obtain a concentrated low-lying angle of projection for the purpose of preventing interference at the receiving point and of still further improving the directivity of the system have been found to possess various inherent disadvantages which have tended to prevent the desired quality of perfection from being obtained. Also, in order to obtain the proper surge impedance in the transmission system associated with various antenna systems, resort has heretofore been had to coil type surge impedance transformers which, aside from being inaccurate, are comparatively costly.

It is one object of this invention to transmit or receive radio frequency waves with greater directivity in the earth's plane than heretofore practiced.

It is another object of this invention to transmit or receive radio frequency waves in an extremely low-lying angle of projection.

By means of the invention the above two objects may be achieved jointly so as to make possible a remarkably close approach to the theoretical ideal of point-to-point communication in which all the transmitted energy is utilized at the related receivers.

It is still another object of this invention to transmit energy between the antenna elements and their associated translating apparatus with comparatively less energy loss and in a more simple and inexpensive manner than heretofore done.

According to one feature of this invention, the radiating elements of the antenna proper are arranged in a vertical plane to form a series of "verticals", the length of the top and bottom elements of each vertical being an odd multiple of a quarter of the wave length employed, whereas the remaining elements are equal to an even multiple of a quarter of the wave length employed.

According to another feature of the invention, one zig-zag line of elements forms a "section" which is oppositely superimposed on another similar zig-zag line to form a "panel" in which the horizontal or transmission elements of one section are relatively close to the corresponding horizontal elements of the other section and the corresponding vertical elements are parallel to each other but spaced a distance equal to an odd multiple of a half-wave length.

According to another feature of this invention the vertical and horizontal elements of each antenna section form a zig-zag line, the maximum width of which is equal to an odd multiple of one-half the wave length employed, whereas the height may be equal to any number of half-wave lengths.

According to still another feature of the invention the antenna elements are co-linearly arranged in such a manner that adjacent elements in one vertical are relatively close to each other.

The directivity in a vertical plane, that is, the angle of projection is a function of the number and spacing of the co-linear elements in the verticals. The directivity in a horizontal plane is a function of the number and spacing of the verticals.

In a preferred embodiment of the invention, a plurality of panels are arranged in the form of a vertical plane or warped surface to constitute an active antenna or exciter which produces a cumulative radiating effect in opposite directions when energy is supplied either directly or indirectly to the panels. An inactive antenna or reflector similarly constructed and spaced a distance equal to an odd multiple of a quarter-wave length from the active antenna is employed when it is desired to obtain uni-directional radiation.

Included in the transmission system supplying energy to the various panels are several impedance transformers such as described in my copending application, Serial No. 482,210, filed September 16, 1930, which is a division of the present application. Each comprises a line a quarter-wave length long or other odd multiple thereof and having a surge impedance or transformation characteristic such that a terminating impedance for the main line is obtained which is the proper value for transmitting energy to the antenna system with a minimum loss. More specifically, the impedance transformer is constructed so as to have a surge impedance equal to the square root of the product of the end and sending impedances connected thereto.

An antenna system as above is adaptable with obvious modifications as a directive receiving antenna system, the basic features of the invention being equally applicable thereto.

The various features mentioned above, as well as other features, will be apparent from the following description taken in connection with the accompanying drawings; in which

Fig. 1 represents an ordinary single wire vertical antenna;

Fig. 2 represents a simple antenna system constructed in accordance with the invention;

Fig. 3 is a broadside bi-directional array in which energy is supplied to the antenna at one point only;

Fig. 4 is a broadside uni-directional array and transmission system for interconnecting the various individual panels of the system;

Fig. 5 shows in detail the impedance transformer employed in the transmission system of Fig. 4;

Fig. 6 is a polar curve illustrating the directional characteristic in a horizontal plane of the system shown in Fig. 4.

Referring to Fig. 1, the relative instantaneous current distribution in an ordinary short wave vertical antenna is shown merely for the purpose of explaining the invention as illustrated in the other figures. Reference numeral 1 represents the antenna and curve ABCD, the relative direction and value of the energizing current supplied through transformer 2, the arrows also indicating the relative current direction. At any instant adjacent sections of the antenna, such as AB and BC, are energized by current flowing in opposite directions. Considering sections AB, BC and CD as three distinct antennæ, it is obvious that the electric as well as the magnetic components of the field radiated by AB and BC will oppose and substantially neutralize each other in a horizontal direction. The components of the field radiated by CD assist those radiated by AB, but it should be noted that the comparative wide separation of the antenna sections AB and CD produces a radiation field of relatively low intensity in a horizontal direction and consequently one of poor directivity in a vertical plane. Such an antenna therefore will not radiate with a low angle of projection.

In Fig. 2 an antenna panel is shown, the verticals being spaced a distance equal to one-half of the wave length for which the system is designed. Each section comprises four half-wave radiating elements, the top and bottom elements being each folded at the midpoint toward the center of the panel in such a manner that the outermost half of each top and bottom element is horizontal and therefore easily joined, as shown in the drawings, to the corresponding element of the adjacent section. The co-linear elements comprising each vertical are placed preferably about one-twentieth of a wave length apart, as this has been found to be the optimum spacing for verticals of more than two elements. Any closer spacing permits relatively large out-of-phase currents to be mutually induced in the adjacent elements. For two-element verticals it has been found that the spacing of one-quarter wave length produces the best results.

The horizontal elements are utilized as transmission lines to connect alternate radiating elements of one vertical to the radiating elements of the adjacent vertical corresponding in position to the elements intermediate the said alternate elements. In this way a closed direct current path is formed. The reference numeral 3 represents the line over which energy of the proper frequency is supplied to or derived from the panel.

When energy is supplied to the panels shown in Fig. 2 the phase relation of the radiating current in the horizontal and vertical elements is such that the currents in the vertical elements are of the same phase, whereas the currents in the adacent horizontal elements are of opposite phase. Radiation from the horizontal elements is therefore suppressed so that these elements function solely as transmitting elements and therefore do not complicate the radiation pattern or qualify the effect of the antenna elements proper.

The spacing of verticals is such as to promote bi-lateral directivity in a horizontal plane so that a maximum field strength is realized at points equi-distant from both verticals whereas, at points lying in the same plane as the vertical sections or panel, the radiation assumes a minimum value since at these last mentioned points the waves are opposing.

In view of the fact that the currents of vertical elements are in one direction, as indicated by the dotted lines in Fig. 2 and because of the extremely close spacing of the in-phase co-linear elements, as described above, the radiation is more uniform and a low lying angle of projection is secured; and this low angle insures that more of the energy transmitted will arrive at a given receiving point in phase than would otherwise be the case.

Analogous conditions subsist when the system is used for receiving. It will be understood without specific reference that the same is true in the cases of the other illustrated systems.

In Fig. 3 a schematic antenna arrangement is shown which is so designed that a great number of verticals may be energized through a single pair of feeders. On the drawings the feeders are designated by the reference numeral 4. As in Fig. 2, the verticals are spaced an odd multiple of a half-wave length apart, each vertical comprising several co-linear radiating elements similar to those shown in the last mentioned figure. The top and bottom radiating elements are not folded, however, nor joined to the corresponding elements of other verticals; and the elements of the verticals intermediate the first and last verticals are directly connected to the alternate elements of both adjacent verticals. By inter-connecting the elements in this manner the horizontal elements form long zig-zig transmission lines for supplying energy to the individual radiating elements.

In operation the antenna system shown in Fig. 3 radiates energy in a manner similar to the single-panel antenna of Fig. 2. Energy is propagated from the vertical elements so as to form a low lying angle of fire, and radiation from the horizontal elements is effectively neutralized. By increase of the number of verticals as compared with the system of Fig. 2 there is improved directivity in a horizontal plane. By not folding the top and bottom vertical elements some gain in radiation from each vertical is achieved, as compared to a vertical of the system shown in Fig. 2 since with the same wire length the effective height of each vertical is four half-wave lengths as compared with three in the latter system. On the other hand, by not joining the top and bottom elements the system is not readily adapted to transmit direct current energy for sleet melting purposes, and for cold climates the construction shown in Fig. 2 is more practicable.

In Fig. 4 a perspective view of a complete uni-directional radiating or absorbing array and associated transmission system is shown. The active antenna or exciter 5 consists of nine panels arranged in a row and in the same vertical plane, each panel being similar to the panel shown in Fig. 2, except that the transmission line is terminated at a higher point on the panel, an immaterial difference. An inactive antenna or reflector 6, also consisting of nine panels is symmetrically located a quarter of a wave length to the rear of and parallel to the exciter; but unlike the exciter, the panels of the reflector are not conductively associated with the transmission system. The exciter and reflector may be conductively associated for sleet melting purposes, a radio-frequency choke coil or other attenuator being inserted in the connecting wires.

The panels are supported and kept in position in the usual manner by means of elevated supports 7 suspended between towers 8 and 9 and by means of grounded guy wires such as 10. Each panel is insulated from the ground wires and the elevated supports. The adjacent co-linear radiating elements and the horizontal elements on the same level are interconnected by suitable stay wires properly insulated, which for the sake of clearness, have been omitted from the drawings.

Directly associated with the exciter is a transmission system in which another feature of the invention, namely, the impedance transformer, is utilized. The system comprises a main trunk line 11 connected to a source of radio-frequency energy which is not shown on the drawings; three branch lines 12 connected to the trunk line 11 at junction E; and nine feeder lines 13 arranged in groups of three lines each, one branch line 12 being associated with each group at junctions F, G and H, respectively. The reference numerals 14 refer to impedance or line transformers, one of which is inserted in each branch line. Each panel is energized from a separate feeder line. Each feeder line, and each branch line exclusive of the transformers, is equal in length to an even multiple of one-quarter of the wave length transmitted. Although the whole system is illustrated as lying in the same horizontal plane, this is, of course, not a necessary condition and at convenient points the lines may extend in a vertical direction.

The impedance transformer mentioned above is shown schematically in Fig. 5. It comprises two conductors 15, preferably copper tubing, whose length equals an odd multiple of a quarter wave length and whose spacing is such that the proper surge impedance is obtained for transforming the terminating impedance 16, corresponding to the panel input impedance, into the surge impedance, represented by numeral 17 which is desired for terminating the main trunk line designated 18 in this figure. The line impedance transformer serves therefore to prevent waves from being reflected into the power source. The surge impedance of the transformer may be determined mathematically as follows:

The sending end impedance Z_1 of a transmission line having a known terminating impedance is given on page 99 of Fleming's book entitled "The propagation of electric currents in telephone and telegraph conductors" 3rd edition, as Equation (61), which is:

$$Z_1 = Z_0 \frac{Z_r \cosh Pl + Z_0 \sinh Pl}{Z_0 \cosh Pl + Z_r \sinh Pl} \quad (1)$$

where

Z_1=sending impedance

Z_0=surge impedance of the line

Z_r=terminating impedance of the line

P=propagation constant per unit length

l=length of the line

Dividing the numerator and denominator of the above equation by sinh Pl and rearranging we have

$$Z_1 = \frac{\frac{Z_0 Z_r \cosh Pl}{\sinh Pl} + Z_0^2}{\frac{Z_0 \cosh Pl}{\sin Pl} + Z_r} = \frac{Z_0^2 + Z_0 Z_r \coth Pl}{Z_r + Z_0 \coth Pl} \quad (2$$

If there is no loss in the line the propagation constant is a pure imaginary, and letting λ=the wave length and B=the total phase shift then

$$Pl = jB, \text{ where } B = \frac{2\pi l}{\lambda}$$

But the

$$\coth jB = -j \cot B = -j \cot \frac{2\pi l}{\lambda} = \coth Pl$$

Substituting in equation (2), we have

$$Z_1 = \frac{Z_0^2 - jZ_0 Z_r \cot \frac{2\pi l}{\lambda}}{Z_r - jZ_0 \cot \frac{2\pi l}{\lambda}} \quad (3)$$

Assuming the length of the line is such that

$$l = \frac{n\lambda}{4}$$

and that "n" is any odd number, such as "1", then, in equation (3)

$$\cot \frac{2\pi l}{\lambda} = \cot \frac{\pi}{2} = 0$$

and, substituting in equation (3), we have

$$Z_1 = \frac{Z_0^2}{Z_r}$$

or

$$Z_0 = \sqrt{Z_1 Z_r} \quad (4)$$

If "n" is any even number, as for example, "2", then, in equation (3)

$$\cot \frac{2\pi l}{\lambda} = \cot \pi = \infty$$

And, substituting in, and separating the terms of equation (3) we have,

$$Z_1 = \frac{Z_0^2}{Z_r - jZ_0(\infty)} - \frac{jZ_0 Z_r(\infty)}{Z_r - jZ_0(\infty)} = o - \frac{jZ_0 Z_r(\infty)}{Z_r - jZ_0(\infty)} = Z_r$$

It appears, therefore, from the above that the terminating or receiver impedance "Z_r" will have the same value as the sending impedance "Z_1" at points an even multiple of a quarter wave length apart along a transmission line having a surge impedance Z_0 Also, if Z_1 is the ideal impedance for terminating a transmission line, the actual impedance Z_r in which the line is terminated, may be transformed into this ideal impedance by connecting the impedance Z_r to a line a quarter wave length or an odd multiple thereof long and whose surge impedance is designed to have a value of Z_0 which satisfies Equation (4). Consequently, lines an odd multiple of a wave length long may be employed as step-up or step-down impedance transformers, in place of the usual coil transformers or other similar cumbersome apparatus.

Referring again to Fig. 5, the impedance at point J will be the same as impedance 16 since point J is an even multiple of a quarter wave length from impedance 16 along the transmission line. This impedance is transformed by means of the quarter wave line transformer 15 into an impedance at point K, which, because of the half-wave length separation, has a value equal to that of impedance 17 and is, by assumption, the proper impedance for terminating the transmission line 18.

Referring once again to Fig. 4 the operation of the complete system may briefly be described as follows:

Energy supplied from the power source over line 11 is transmitted by virtue of impedance transformers 14 to the individual panels of the exciter with substantially no reflection loss. As seen from junction F the terminating impedance is equivalent to three panel impedances in parallel since each of the three sub-branch lines 13 of that group is an even multiple of a quarter wave length long. A similar impedance is seen from junctions G and H. These impedances are transformed by transformers 14 into impedances which are in parallel with each other and as seen from junction E offer a suitable impedance for terminating the main line 11, two of the branch lines 12 being equal to an even multiple of a quarter wave length and the remaining line 12 having substantially zero length.

The energy supplied to the panels of the exciter 5 is radiated in the manner already explained in connection with Fig. 2. Energy is propagated from the vertical elements and radiation from the horizontal elements neutralized. Because of the great number of verticals, however, a much more concentrated directional effect is obtained by this system than by the system shown in Fig. 2; and this concentration results in a total elimination of radiation at certain angles and, at other angles, only a slight amount of radiation. In other words, the directivity curve for the 16-section exciter shown in Fig. 4 will contain several lobes.

In Fig. 6, the directivity curve in the earth's plane for the whole system shown in Fig. 4 is represented. The reflector 6 operates to produce a uni-directional effect in a manner similar to that utilized in other directional systems. Because of the quarter wave length spacing the currents in the reflector elements lead by 90° the currents in the exciter elements and consequently the waves radiated from the exciter and reflector verticals assist each other in the direction indicated by the arrow M shown in Fig. 4 and neutralize each other in the opposite direction. As explained above, certain lobes are present because of the great number of verticals. The waves radiated will also be propagated in an extremely low angle on account of the relatively large number of properly spaced colinear elements in the various verticals and because of this fact will be reflected by the Heaviside layer a minimum number of times.

Although the invention has been illustrated and described in connection with certain transmitting systems, various features of the invention are also applicable to receiving, and other transmitting systems, and it is to be understood that the invention is not limited to the specific embodiments described. Furthermore, it is to be understood that the impedance transformer feature is not to be limited to the specific application illustrated, but may be employed in any aerial or transmitting system for properly matching impedances.

What is claimed is:

1. In an antenna system, a plurality of verticals spaced an odd multiple of one-half wave length, said verticals each comprising a plurality of co-linear radiating elements positioned relatively close together, the top and bottom radiating elements being a quarter wave length long and the intermediate elements a half wave length long, substantially horizontal elements connecting the extremities of the top elements and the extremities of the bottom elements, other horizontal elements for conveying energy from the radiating elements of one vertical to those of another, the last mentioned elements being positioned with respect to each other so as to neutralize radiation therefrom, and means for energizing the system.

2. In an antenna system, a plurality of verticals each comprising an equal plurality of radiating elements spaced from each other, means comprising transmission elements connecting each of the intermediate radiating elements of the intermediate verticals to two radiating elements in each of the two adjacent verticals, the radiating and transmission elements each being an odd multiple of one-half wave length, each of the transmission elements being adjacent to another transmission element conveying current of opposite phase, and means for supplying high frequency energy to said system.

3. In an antenna system, a zig-zag antenna comprising vertical and substantially horizontal elements, the top and bottom vertical elements being a quarter wave length long, the remaining elements each having a length equal to an odd multiple of one-half wave length, a second zig-zag antenna similarly constructed, the second antenna being oppositely superimposed on but electrically separated from the first mentioned antenna so that alternate vertical elements of one antenna are colinear with and spaced from alternate vertical elements of the other antenna, a horizontal element connecting the top vertical elements, a horizontal element connecting the bottom vertical elements and energizing means connected to the system.

4. In an antenna system, a plurality of zig-zag antennæ vertically arranged and each comprising vertical and horizontal elements, the top and bottom vertical elements being a quarter wave length long, the length of the remaining elements and the spacing between antennae being equal to an odd multiple of a half wave length, a second plurality of similarly constructed antennæ, each of the second plurality being oppositely superimposed on one of the first mentioned plurality of antennæ, half wave length conductors connecting the corresponding extremities of the top and bottom elements of each antenna and its associated superimposed antenna, a source of high frequency energy, and means connecting said source to the connected antenna.

5. In an antenna system, a plurality of zig-zag antennæ symmetrically arranged in a vertical row and each comprising vertical and horizontal elements, the length of each element and the spacing between the antennæ being an odd multiple of one-half wave length, a second plurality of zig-zag antennæ each oppositely superimposed on and relatively close to one of the first mentioned antennæ and conductively connected at the top and bottom thereto, a source of radio frequency energy, a transmission system connecting said source to the connected antennæ.

6. In an antennæ system, a plurality of vertical panels arranged in a row, each comprising two zig-zag sections oppositely and symmetrically superimposed on each other, said sections each comprising vertical and horizontal elements one-half wave length long, a high frequency source, separate means connecting said panels with said source, a second plurality of vertical panels parallel to and spaced symmetrically one-quarter wave length from the said first mentioned plurality of panels.

7. In an antenna system, a plurality of ver-

ticals arranged in a row, said verticals each comprising a plurality of colinear elements, the top and bottom vertical elements being a quarter wave length long, the length of the remaining elements and the spacing between verticals being an odd multiple of one-half wave length, means comprising horizontal elements for connecting the alternate elements of one vertical to the intermediate elements of adjacent verticals and for connecting the corresponding extremities of the top and bottom co-linear elements together, a source of energy, a transmission line connecting said source to said system.

8. In combination, an antenna system comprising an exciter and a reflector, the reflector positioned parallel to and a one quarter wave length from the exciter, the exciter and reflector each comprising a plurality of panels arranged in a line and spaced an odd multiple of a one half wave length, said panels each comprising two sets of colinear vertical elements each connected by means of horizontal elements to alternate vertical elements of the other vertical, the said elements each being one half wave length long, a source of radio frequency energy, a transmission system connecting the source to each panel of the exciter, means included in the transmission system for transforming the panel impedance into the proper impedance for preventing the reflection of waves into the source.

In witness whereof, I hereunto subscribe my name this 22 day of July, 1929.

ERNEST J. STERBA.