Oct. 8, 1963 V. P. MINERVA 3,106,714

LOG PERIODIC ANTENNA WITH ACCORDIONED RADIATORS TO INCREASE SHUNT CAPACITANCE

Filed Oct. 18, 1960

4 Sheets-Sheet 1

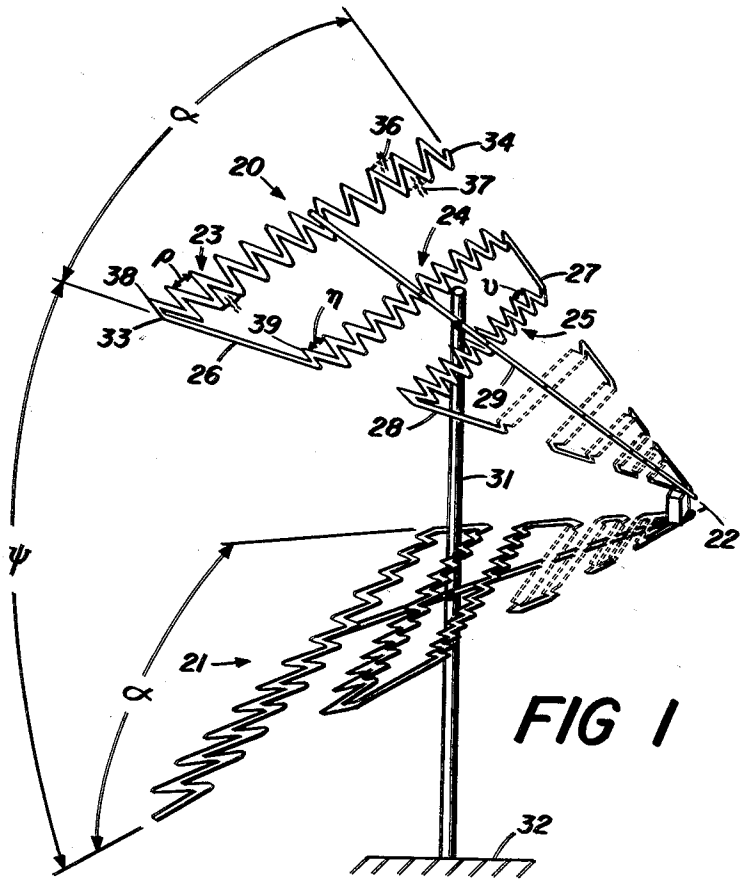


FIG 1

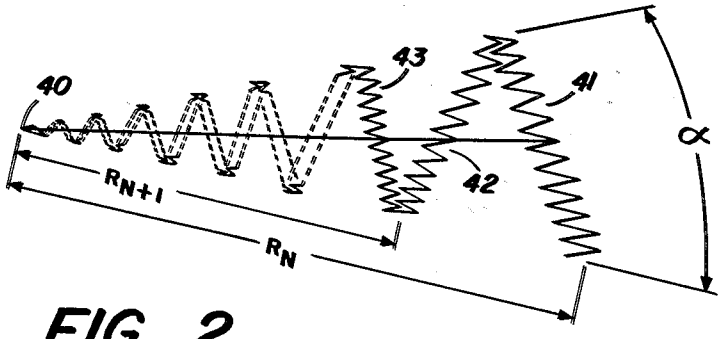


FIG 2

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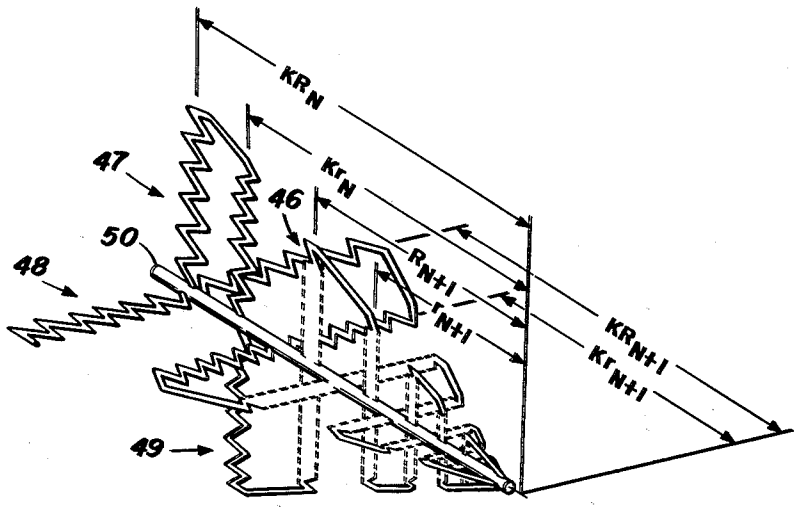


FIG 3

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LOG PERIODIC ANTENNA WITH ACCORDIONED RADIATORS TO INCREASE SHUNT CAPACITANCE

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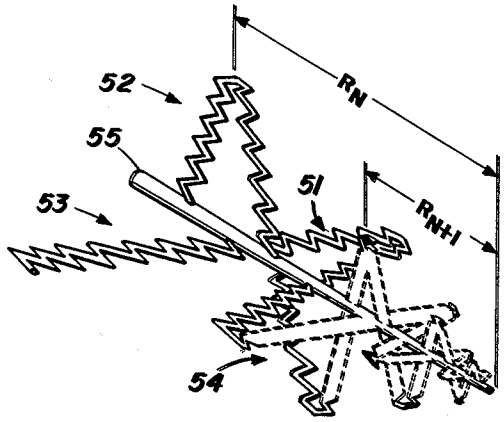


FIG 4

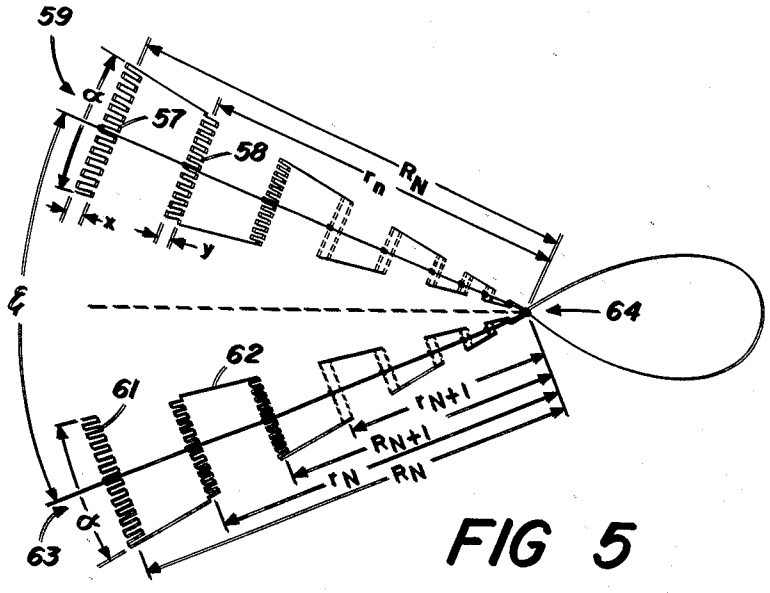


FIG 5

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Oct. 8, 1963 V. P. MINERVA 3,106,714

LOG PERIODIC ANTENNA WITH ACCORDIONED RADIATORS TO INCREASE SHUNT CAPACITANCE

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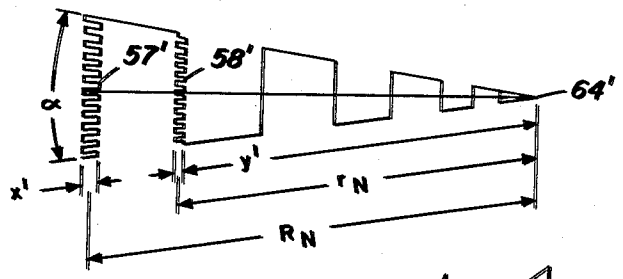


FIG 5a

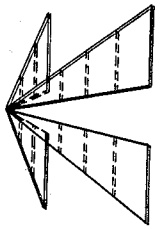


FIG 6

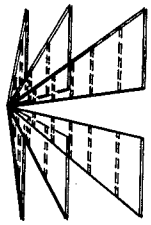


FIG 7

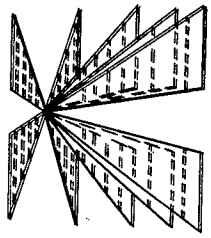


FIG 8

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United States Patent Office 3,106,714 Patented Oct. 8, 1963

3,106,714

LOG PERIODIC ANTENNA WITH ACCORDIONED RADIATORS TO INCREASE SHUNT CAPACITANCE

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Filed Oct. 18, 1960, Ser. No. 63,372
10 Claims. (Cl. 343—792.5)

This invention relates generally to logarithmically periodic antennas and, more specifically, to a logarithmically periodic type antenna in which the lower limit frequency is extended without a corresponding increase in the size of the antenna.

Logarithmically periodic antennas, hereinafter sometimes referred to as log periodic antennas, are a recent development in the antenna art. The most important feature of log periodic antennas is their ability to maintain a constant radiation pattern over large frequency changes of the order of 10 or 15 to 1. Such antenna systems (log periodic antenna systems) may be described generally as consisting of individual antenna elements, each antenna element being generally triangular in shape, having a vertex, and having side elements defined by an angle α extending from the vertex. More specifically, each antenna element is comprised of at least two radial sections defined on one side by the center line of the antenna element and on the other side by a radial line extending from the vertex at an angle $\alpha/2$ with respect to the center line of the element. Each radial section has a plurality of teeth comprised of elements generally transverse to the center line of the antenna element. Said teeth are all similar to one another in shape, but become progressively larger and spaced progressively farther apart as the distance from the vertex increases. The above relationship may be expressed by stating that the radial distance from the vertex to any given tooth in a given radial section bears a constant ratio τ to the radial distance of a corresponding point on the next adjacent tooth which is farther removed from the vertex than said given tooth. In the most general case, where each element employs two radial sections lying in the same plane, the teeth of one of the radial sections are positioned opposite the gaps between the teeth of the other radial section.

It is to be noted that throughout this specification the phrases "transverse dipole element" and "transverse conductive element" shall mean the conductive elements spanning the entire distance across an antenna element (i.e., normal to the center line thereof). Thus the conductive element which spans the distance across a single radial section is herein defined as a half-length transverse dipole or conductive element.

The log periodic antenna elements described in the preceding paragraph may be arranged in many different combinations to perform desired functions. Usually, the antenna elements are employed in multiples of two. For example, a pair of such antenna elements may be positioned with respect to each other so that the vertices are positioned near each other although not quite touching (i.e., the vertices are separated electrically) and which extend out from the common vertex in such a manner as to assume positions corresponding to opposite sides of a pyramidal-shaped structure. Such an arrangement is known in the art as a nonplanar array of two log periodic antenna elements. An alternative is to arrange two or more log periodic antenna elements in such a manner that their vertices are near each other (but not quite touching), and which lie in the same plane. Such an arrangement is known in the art as a co-planar array of log periodic antennas. Various combinations of co-planar and nonplanar arrays can be built up to produce different radiation patterns, such as steerable beams, circularly polarized beams, and other desirable radiation patterns. Although such structures will be described in some detail later herein, the reader's attention is directed to the following patent applications which are hereby incorporated by reference into the present specification: United States patent application, Serial No. 721,408 filed March 14, 1958, by Raymond H. Du Hamel and Fred R. Ore entitled "Logarithmically Periodic Antenna," now Patent No. 3,079,602; United States patent application, Serial No. 804,357, filed April 6, 1959, by Raymond H. Du Hamel and David G. Berry entitled "Uni-Directional Frequency Independent Coplanar Antenna," now Patent No. 2,989,749; United States patent application, Serial No. 841,391, filed September 21, 1959, by Raymond H. Du Hamel et al. entitled "Antenna Arrays," now Patent No. 3,059,234; United States patent application, Serial No. 841,400, filed September 21, 1959, by Raymond H. Du Hamel et al. entitled "Broadside Antenna Arrays," now Patent No. 2,984,835; United States patent application, Serial No. 31,068, filed May 23, 1960, by David G. Berry entitled "Uni-Directional Circularly Polarized Antenna."

The lower frequency limitation of the prior art log periodic antenna elements is determined almost entirely by the length of the longest transverse dipole element which ordinarily has a length equal to one-half the half wavelength of the lowest frequency of the usable bandwidth of the log periodic antenna element. For example, if the longest transverse element of a log periodic antenna element is 7 feet long, then the lower frequency limit of the antenna element would be about 72 mc. In order to extend the lower frequency limit to, say, 60 megacycles it would be necessary to increase the size of the antenna element so that the longest transverse dipole would be about 8.4 feet long. Such an increase in the size of the antenna element, however, carries with it an increase in the cost of the antenna. Such increase in cost is greater than the proportionate increase in size, since roughly speaking, the total weight of the antenna varies approximately as the cube power of an increase in lineal distance. A further consideration is the fact that more space is required for a log periodic antenna in which the longest transverse dipole is 8.4 feet, than is required for a log periodic antenna element in which the longest transverse element is only 7 feet.

It would mark a definite improvement in the art to provide a log periodic antenna element in which the lower frequency limit of operation thereof could be extended without increasing the over-all length of the longest transverse dipole elements of the log periodic antenna element. A means by which such objective can be accomplished is to increase the shunt capacitance of the longest transverse dipole element. The foregoing statement will become clearer perhaps when it is considered that a dipole element normally presents a capacitive reactance to a signal having a frequency less than the resonant frequency of the dipole element. Thus, if the capacitive reactance of the transverse dipole element can be reduced, the resonant frequency of the transverse dipole element will also be decreased. Since capacitive reactance is inversely proportional to the capacitance and since capacitances add when in parallel, it follows that the capacitive reactance of a transverse dipole element and thus the frequency of resonance will be decreased if shunt capacitance can be created across the transverse dipole element.

An object of the present invention is to increase the shunt capacitance of the antenna elements transverse dipole elements in order to extend the lower frequency of the log periodic antenna element.

A further object of the invention is to increase the frequency range, particularly the lower frequency limit, of

a log periodic antenna element without increasing the over-all dimensions of the antenna element.

The third aim of the invention is to provide a compact, more versatile, log periodic antenna element without any substantial increase in cost.

Another object of the invention is the improvement of log periodic antenna elements, generally.

In accordance with the invention each of the individual tranverse dipole elements of each antenna element of an array is comprised of a conductive element which is accordioned inwards upon itself to form a conductor which folds back and forth substantially across a center line joining together the two end points of the transverse dipole element to provide additional shunt capacitance across said dipole elements.

In accordance with one form of the invention the transverse dipole elements may be accordioned in upon themselves to form a triangular or zigzag-shaped configuration. Alternatively the accordioned transverse dipole elements may be formed into a square wave or rectangular-shaped configuration. In either configuration, nearby portions of the transverse dipole element will present conductive surfaces to each other which have capacitance therebetween. Such capacitance is substantially distributed capacitance which is primarily in shunt with the transverse dipole element. It is this shunt capacitance which effectively lowers the resonant frequency of the accordioned transverse dipole element to extend the lower frequency limit of the antenna element.

It is to be noted that the antenna elements employing accordioned transverse dipole elements may be employed in any antenna array in which the non-accordioned version of the antenna element may be employed.

Other objects and features of the invention, in addition to those specifically set forth above, will become apparent from the following detailed description of the invention when read in conjunction with the drawings in which:

FIG. 1 shows a perspective view of a nonplanar, nonimage array of two log periodic antenna elements in which the transverse dipole elements have been accordioned into a zigzag or triangular-shaped configuration;

FIG. 2 shows an antenna element having triangular-shaped teeth in which the dipole elements have been accordioned into a triangular-shaped or zig-zag configuration;

Fig. 3 shows an antenna element for producing a circularly polarized beam pattern and comprising four radial sections having a common side and comprising rectangularly shaped teeth with the dipole elements being accordioned into a zigzag configuration;

FIG. 4 shows an antenna element for producing a circularly polarized beam pattern and comprising four radial sections having a common side and comprising triangularly shaped teeth with the dipole elements being accordioned into a zig-zag configuration;

FIG. 5 shows a mirror image co-planar array of two log periodic antenna elements having rectangular-shaped teeth and in which the transverse dipole elements are accordioned into a square wave or rectangular-shaped configuration;

FIG. 5*a* shows a modification of the structure of FIG. 5, which modification is also applicable to the structures shown in FIGS. 1, 2, 3, and 4; and

FIGS. 6, 7, and 8 illustrate typical arrays in which the antenna structures shown in FIGS. 1 through 5*a* can be employed.

Referring now to the structure shown in FIG. 1, there is shown two antenna elements 20 and 21 arranged in a nonimage, nonplanar array with a common vertex 22. The common vertex 22 is not an actual vertex of the two antenna elements. The actual vertex terminations of the two antenna elements must be separated by a small distance since the applied signal is impressed across the

two antenna elements. However, for purposes of discussion, it is convenient to assume that the vertices of the two antenna elements are coincident. The side boundaries of the antenna elements are defined by radial lines extending from the common vertex 22 which form an angle α. The separation of the two antenna elements 20 and 21 is defined by the angle ψ. Individual transverse dipole elements such as elements 23, 24, and 25 are joined together by side elements such as side elements 26, 27, and 28 to provide a series of alternately positioned teeth having a generally rectangular shape (but with the transverse dipole elements thereof having the zigzag configuration shown in FIG.1). The transverse dipole elements are mounted upon a boom such as boom 29, which is of conductive material such as aluminum and which, in turn, is mounted upon, but electrically insulated from, a mast 31 which may be suitably mounted upon some support means 32.

Ordinarily, the lower frequency limit of a log periodic antenna element such as antenna element 20 is determined by the length of the longest transverse dipole element which distance is equal to the distance between points 33 and 34. If such length is designated by the letter "*l*," then

$$f=\frac{C}{2l}$$

while *l* is the half wavelength of the signal.

Ordinarily, at resonance a dipole has an impedance which is purely resistive. At a frequency below resonance the impedance of the dipole becomes capacitive and at a frequency above resonance the impedance of the dipole becomes inductive. Now, since capacitive reactance is inversely proportional to the magnitude of the capacitance and since capacitances in shunt add arithmetically, it follows that the resonant frequency of a given dipole length will decreased if the shunt capacitance of such dipole is increased. Worded in another way, increasing the shunt capacitance of a dipole decreases the capacitance reactance of the dipole and effectively increases the length of such dipole as it appears to a signal; thus, while the actual length of a zigzag dipole element from one end to the other may be the same at the length of a straight dipole element, the apparent length of the zigzag dipole element will appear longer to a given signal.

Typical shunt capacitances produced as a result of the zigzaz configuration of the transverse dipole element are represented by capacitors such as capacitors 36 and 37. It is to be understood that although capacitors 36 and 37 are represented as single capacitors, actually the capacitance between the small straight sections forming the zigzag dipole element have a distributed capacitance therebetween which varies in accordance with the distance between the adjacent straight portions of the transverse dipole element. The over-all effect of such distributed capacitance is a capacitance in shunt with the dipole element 23, which shunt capacitance effectively lowers the capacitive reactance of the dipole element.

To maintain uniformity of design and to minimize distortion introduced by the zigzag configuration the dipole element 23 is similar to the dipole element 24. More specifically, each of the dipole elements 23 and 24 has the same number of peaks therein and corresponding peaks lie on the same radial line extending from the vertex 22. For example, peak 38 of transverse dipole element 23 and peak 39 of transverse dipole element 24 both lie on the same radial line extending from the vertex 22.

Additional minimizing of the distortion introduced into the radiation pattern by the use of zigzag configuration is accomplished by making the degree of zigzag in successively shorter transverse dipole elements about the same. Thus, the angle ρ in transverse dipole element 23 is equal to the angle η of transverse dipole element 24 and the ratio

of the peak-to-peak amplitude of the dipole element 24 to the peak-to-peak amplitude of the dipole element 23 is equal to τ.

The number of peaks in any particular zigzag configuration and the value of the angles ρ and η are not critical. There is an area, however, in which optimum performance has been obtained experimentally. More specifically, it has been found that about 12 cycles of zigzag in a transverse dipole element with an angle $\rho \cong 83\%$, will produce a near maximum shunt capacitance. Adding more peaks will not increase the capacitance proportionately. Consequently, it appears that the added weight and difficulty of manufacturing the antenna elements with such additional peaks is not warranted. With a given number of peaks the angle ρ or η is determined by the ratio of the stretched out length of the dipole element to the accordioned length. It has been found that for a near optimum performance such ratio is about 3 to 2. With such a ratio the angle ρ is about 83° or 84°, as indicated above.

The number of zigzag cycles can be decreased below the number 12. For example, eight zigzagging cycles could be employed over the length of a transverse dipole element rather than twelve. Such decrease in zigzag cycles would tend to decrease the shunt capacitance across the dipole element and, consequently, would extend the lower frequency element of the antenna somewhat less than in the case where twelve zigzag cycles were employed. On the other hand, if the angle ρ is decreased this will result in an increase of the stretched out length of the dipole to the compressed length with a concomitant increase in the shunt capacitance, thereby extending the lower frequency limit of the antenna element. But it is to be noted that similarly to increasing the number of zigzag cycles, a point is reached where decreasing the angle ρ no longer produces sufficient increase in shunt capacitance to justify the added material.

In the structure of FIG. 1 only the first three transverse dipole elements are shown as actually having a zigzag configuration. Actually, all of the transverse dipole elements can be of the zigzag configuration. It should be noted, however, that the number of peaks in each transverse dipole element should be the same as contained in the dipole elements 23 and 24 and that corresponding peaks should fall on the same radial lines extending from the vertex 22. It also should be noted that the ratio of the peak-to-peak amplitudes of adjacent transverse dipole elements should bear the relationship τ similar to the relationship existing between the peak-to-peak amplitudes of the transverse dipole elements 23 and 24.

Referring now to FIG. 2, there is shown a log periodic antenna element having triangularly shaped teeth in which the transverse dipole elements are accordioned in upon themselves so that they have a trinagularly or zigzagged shaped configuration similar to that shown in the structure of FIG. 1. The same design considerations discussed in connection with structure of FIG. 1 are applicable to the structure shown in FIG. 2. More specifically, each transverse dipole element should have the same number of zigzag cycles and the corresponding peaks of the zigzagged transverse dipole elements should lie on the same radial line extending from the vertex 40. Near optimum performance has been found to occur when the number of zigzag cycles is in the order of twelve and when the ratio of the stretched out length of the longest transverse dipole 41 to the compressed length thereof is about 1.5. Further the peak-to-peak amplitude of a given transverse dipole element should bear the ratio τ to the peak-to-peak amplitude of the transverse dipole element next farthest removed out from the vertex 22.

Referring now to FIG. 3, there is shown a structure capable of producing a circularly polarized radiation pattern. The structure in FIG. 3 is composed of four radial sections 46, 47, 48 and 49, each of said radial sections being composed of a plurality of rectangularly shaped teeth which are positioned at 90° intervals around the common conductive boom member 50. For simplicitiy of drawing as in the case of FIGS. 1 and 2, only the two longest transverse dipole members on each radial section are shown compressed to form a zigzag or triangular-shaped configuration. The specific number of zigzag cycles and the ratio of the stretched out length of the transverse dipole elements to the compressed length thereof for near optimum performance are substantially the same as in the case of the structures shown in FIGS. 1 and 2.

Referring now to FIG. 4, there is shown another log periodic antenna array constructed to produce a circularly polarized radiation pattern. The antenna array of FIG. 4 is composed of 4 radial sections 51, 52, 53, and 54, which are spaced at 90° intervals around the common conductive supporting boom member 55. The two longest transverse dipole members of the structure of FIG. 4 are shown to have a zigzag configuration. The same considerations with respect to the number of zigzag cycles and the ratio of stretched out length to compressed length of the dipoles, and the relation of peaks of one dipole element to the other are the same as has been discussed with respect to the structure of FIGS. 1, 2 and 3.

Referring now to FIG. 5, there is shown a co-planar array of two mirrored image antenna elements; each of the type having rectangular-shaped teeth formed of a conductive rod. In the structure of FIG. 5, however, an alternate form of accordioning or compressing the longest transverse dipole elements is shown. More specifically, in FIG. 5 the two longest transverse dipole elements 57 and 58 of antenna element 59 and the transverse dipole elements 61 and 62 of antenna element 63 are shown as comprising a plurality of teeth having a rectangular-shaped configuration. As in the case of the zigzag configuration the number of square wave cycles for optimum performance is about twelve. The amplitude X of square wave configurations for good performance has been found to be equal to about 4% or 5% of the total length of the compressed dipole.

As in the case of the triangularly shaped transverse dipole elements, the corresponding points of the dipole element 58 and the dipole element 57 should lie on the same radial line extending from the vertex 64 of the array. The amplitude Y of the square wave cycles of transverse dipole 58 bears a ratio τ to the amplitude X.

It is to be noted that in the case of each of the type antenna elements discussed above, all of the transverse elements of each antenna element are formed into a zigzag or square wave, or some other accordioned configuration; the amplitude of any given configuration of a given transverse conductive element bearing a ratio τ to the amplitude of the configuration of the transverse conductive element next farthest removed out from the vertex of the antenna element. However, the invention is not intended to be limited in scope to such an arrangement. More specifically, the amplitude of the configuration of any given transverse conductive element can bear a ratio less than τ to the amplitude of the configuration of the transverse element next farthest removed out from the vertex. With this last-mentioned relationship, the zigzag or otherwise accordioned configuration can be made to substantially disappear from the antenna element in the course of three or four of the longest transverse conductive elements, while maintaining a fairly smooth transition, impedance-wise, from the accordioned transverse elements to the straight transverse conductive elements. This is shown more specifically in the structure of FIG. 5*a* wherein the ratio Y'/X' is less than τ. However, even though the ratio τ no longer defines the amplitude relationship between Y'/X' it is to be specifically noted that the number of cycles of the transverse conductive elements 57′ and 58′ remain the same and, further, that corresponding points on the transverse dipole elements lie on the same radial lines extending from the vertex 64′.

Referring now to FIGS. 6, 7, and 8, there are shown

various arrays in which the antenna elements of FIGS. 1, 2, 5, and 5*a* may be employed. It will be apparent that the arrays of FIGS. 6, 7, and 8 are constructed of combinations of co-planar and nonplanar arrays shown in FIGS. 1 and 5. It is to be understood that the individual antenna elements in the arrays of FIGS. 6, 7, and 8 are presented schematically, with zigzag or square wave configurations not being specifically shown, although at least the longer transverse dipole elements do have such configurations.

For a more detailed explanation and description of the function of the arrays shown in FIGS. 6, 7 and 8 reference is made to United States patent application Serial No. 841,391, mentioned hereinbefore.

It is to be noted that the forms of the invention as shows and described herein are but preferred embodiments thereof and that various changes may be made in relative sizes and shapes without departing from the spirit and scope of the invention.

I claim:

1. In an antenna array, a plurality of log periodic antenna elements each having a center line, each antenna element comprising a plurality of radial sections having a generally triangular shape with one side of the triangle coincident with said center line and comprising a plurality of teeth, each of said plurality of teeth being comprised of half-length transverse conductive elements, at least the longest half-length transverse conductive elements of the radial sections forming each antenna element being accordioned inwards upon itself to form a conductor which folds back and forth across a line joining together the two end terminals of the accordioned half-length transverse conductive element.

2. An antenna array in accordance with claim 1 in which said teeth are formed of a conductive rod bent to form a plurality of rectangularly shaped teeth alternately positioned on opposite sides of the center line of the antenna element, the radial distance from the vertex of the antenna element to any given point on any given tooth of a given radial section bearing a constant ratio τ to the radial distance from the vertex to the corresponding point on the next adjacent tooth farther removed from said vertex and on said given radial section.

3. An antenna array in accordance with claim 1 in which said teeth are each formed of a solid trapezoidally shaped conductive member and are disposed alternately on opposite sides of the center line of the antenna element, the radial distance from the vertex of the antenna element to any given point on any given tooth of a given radial member bearing a constant ratio τ to the radial distance from the vertex to the corresponding point on the next adjacent tooth farther removed from said vertex and on said given radial member.

4. An antenna array in accordance with claim 1 in which said teeth are formed of a conductive rod bent to form a plurality of triangularly shaped teeth alternately disposed on opposite sides of the center line of said antenna element, the radial distance from the vertex of the antenna element to any given point on any given tooth of a given radial section bearing a constant ratio τ to the radial distance from the vertex to the corresponding point on the next adjacent tooth farther removed from said vertex and on said given radial section.

5. An antenna array in accordance with claim 1 in which each of said log periodic antenna elements comprises first, second, third and fourth radial sections having a substantially common vertex and disposed at 90° intervals about a common center line in the order enumerated, the radial distance from said common vertex to any given point on any given tooth of any radial section bearing a constant ratio τ to the radial distance to the corresponding point on the next adjacent tooth farther removed out from said vertex, said first and third radial sections which are positioned 180° apart having their teeth alternately positioned along said center line, the second and fourth radial sections having their teeth alternately positioned along said center line, the radial distances of points on the teeth of said first and third radial sections bearing a constant ratio K to the radial distances of corresponding points on said second and fourth radial sections, respectively.

6. An antenna array in accordance with claim 5 in which the teeth of each radial section comprise a rod bent to form trapezoidally shaped teeth.

7. An antenna array in accordance with claim 5 in which the teeth of each radial section comprise a rod bent to form triangularly shaped teeth.

8. An antenna array in accordance with claim 1 in which the second longest half transverse conductive element of the radial sections forming each log periodic antenna element is accordioned inwards upon itself to form a conductor which folds back and forth across a line joining together the two end terminals of the said second longest transverse conductive elements, the radial distance from the vertex of the log periodic antenna element to the point of intersection of any given radial line and said second longest transverse conductive element bearing a constant ratio to the radial distance from said vertex to the intersection of said given radial line and said longest transverse conductive element.

9. An antenna array in accordance with claim 8 in which said teeth are formed of a conductive rod bent to form a plurality of rectangularly shaped teeth alternately positioned on opposite sides of the center line of the antenna element, the radial distance from the vertex of the antenna element to any given point on any given tooth of a given radial section bearing a constant ratio τ to the radial distance from the vertex to the corresponding point on the next adjacent tooth farther removed from said vertex, and on said given radial section.

10. An antenna array in accordance with claim 8 in which said teeth are formed of a conductive rod bent to form a plurality of triangularly shaped teeth alternately disposed on opposite sides of the center line of said antenna element, the radial distance from the vertex of the antenna element to any given point on any given tooth of a given radial section bearing a constant ratio τ to the radial distance from the vertex to the corresponding point on the next adjacent tooth farther removed from said vertex and on said given radial section.

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