March 24, 1970 D. L. CARTER 3,503,074

LOG-PERIODIC ANTENNA ARRAY HAVING CLOSELY SPACED LINEAR ELEMENTS

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Fig 1.

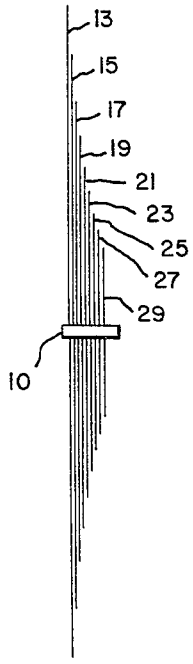


Fig 2.

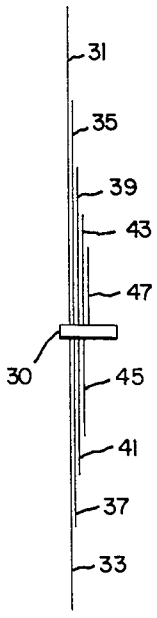
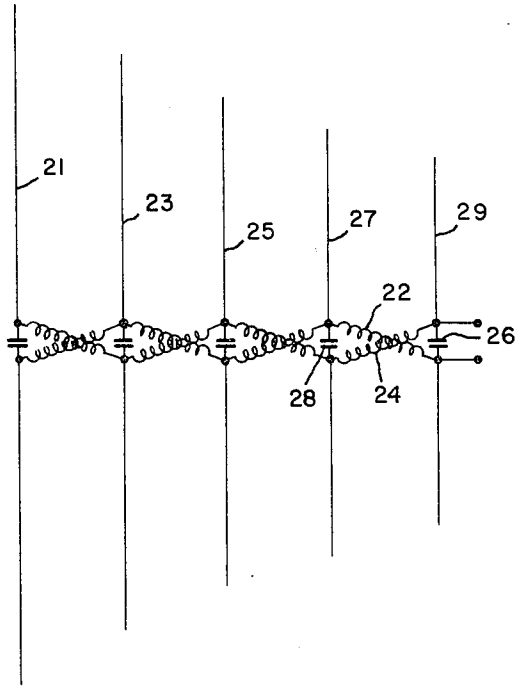


Fig 3.



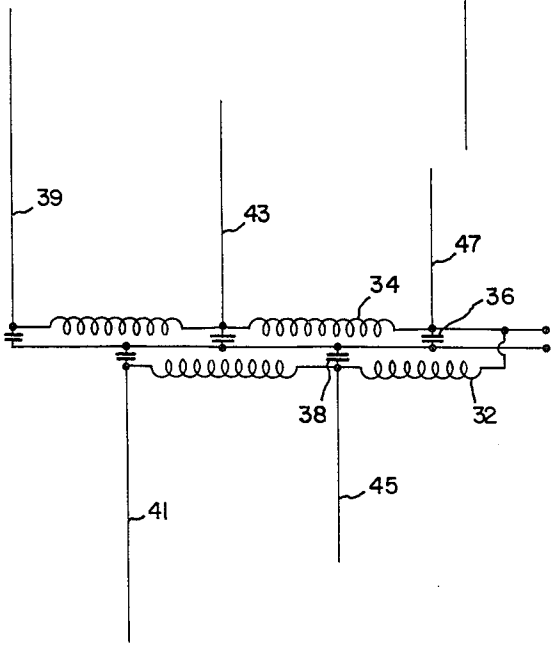


Fig 4.

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FIG 5.

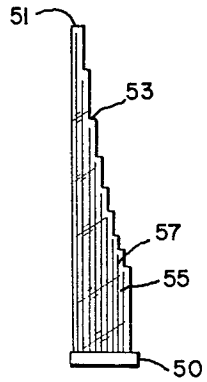


FIG 6.

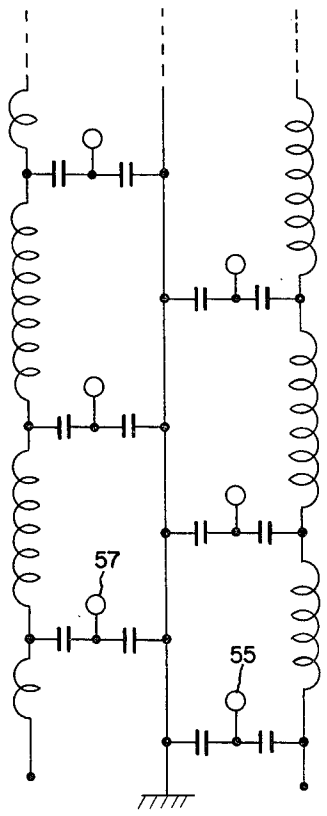
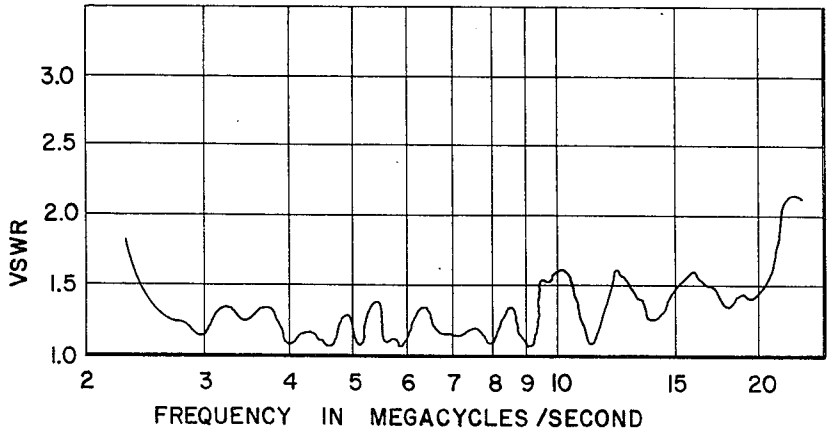


FIG 7.



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LOG-PERIODIC ANTENNA ARRAY HAVING CLOSELY SPACED LINEAR ELEMENTS

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Fig 10.

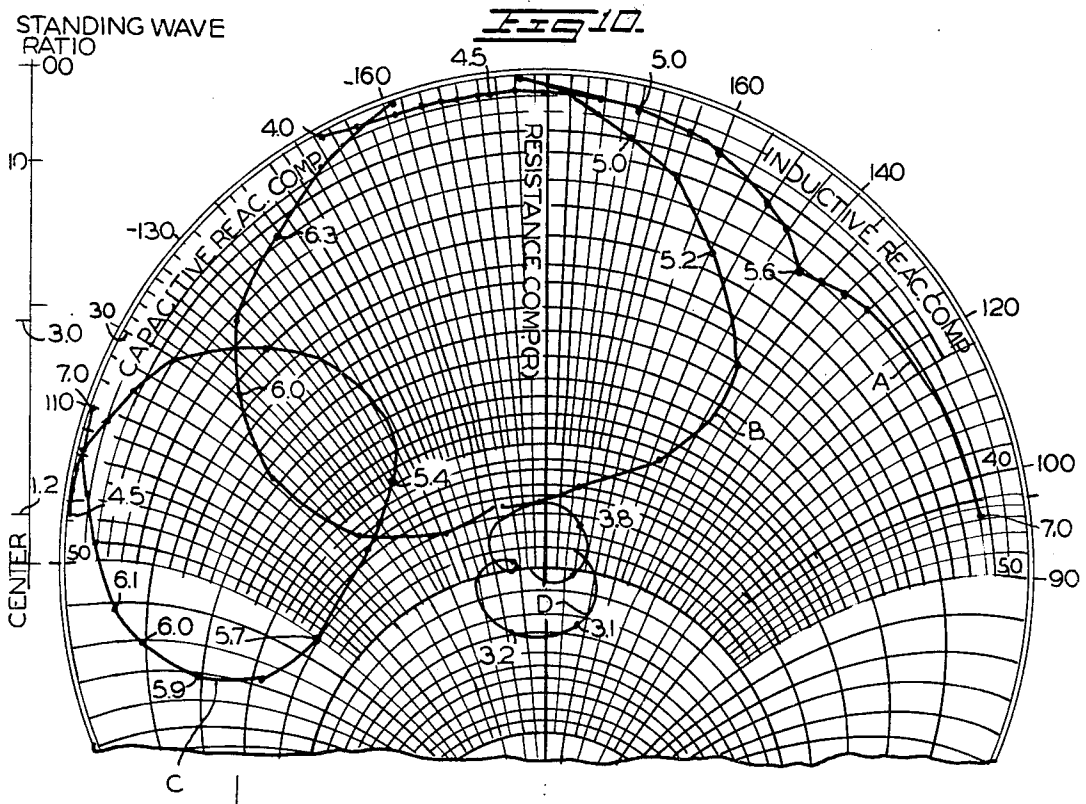
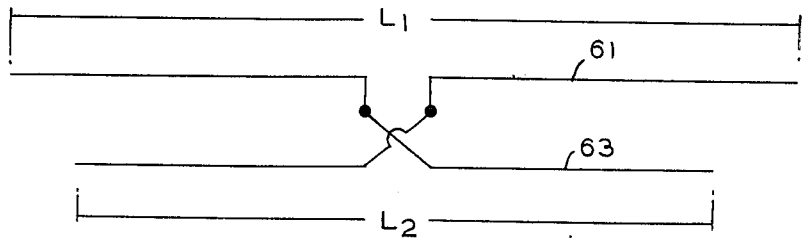


Fig 8.



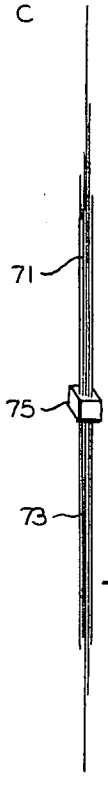


Fig 9.

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3,503,074

LOG-PERIODIC ANTENNA ARRAY HAVING CLOSELY SPACED LINEAR ELEMENTS

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Continuation-in-part of application Ser. No. 563,892, July 8, 1966. This application Dec. 5, 1968, Ser. No. 784,535

Int. Cl. H01q 11/10
U.S. Cl. 343—792.5 10 Claims

ABSTRACT OF THE DISCLOSURE

A frequency independent antenna having a plurality of closely spaced elements of unequal but predetermined related lengths, and coupling means for connecting these elements in a manner so as to provide phase reversal of current in alternate elements. The spacing may be as close as physical limitations will permit so long as the elements do not contact each other.

This invention relates generally to antennas and more particularly to antenna structures which are substantially frequency independent over a wide-band operating range and is a continuation-in-part of U.S. patent application Ser. No. 563,892, filed July 8, 1966, now abandoned.

One of the common problems relative to the use of antennas which are intended to operate over a wide-band range is the fact that a large number of antenna elements are required which each relate to a particular frequency range. Normal antenna construction techniques, therefore, result in large, bulky and heavy antennas.

The present invention provides a compact operative antenna which is substantially frequency independent over a very wide-band operating range.

Basically the invention comprises an antenna having a plurality of closely spaced antenna elements of unequal but predetermined related lengths, and coupling means for connecting these elements in a manner so as to provide phase reversal of current in alternate elements.

The invention will be more clearly understood from the following description when taken together with the drawings wherein:

FIG. 1 shows a symmetrical dipole;

FIG. 2 shows an asymmetrical half-structure dipole;

FIG. 3 shows a schematic illustration of one type of coupling network for the antenna of FIG. 1;

FIG. 4 shows one type of coupling network which may be used with the antenna of FIG. 2;

FIG. 5 shows a monopole structure made in accordance with the present invention and encased in a dielectric material;

FIG. 6 discloses a coupling network which may be used with the antenna of FIG. 5;

FIG. 7 shows graphically the results obtained from one illustrative antenna of the present invention;

FIG. 8 is a schematic illustration of a two element end fire array antenna;

FIG. 9 is a schematic illustration of the antenna from which the results shown in FIG. 7 were obtained; and

FIG. 10 depicts graphically the impedance curves obtained from actual tests of one of the antennas of the present invention.

Although not limited thereto, the present invention is described by illustrative examples which may be included in the linear log-periodic antenna structures. The basic inventive concept however may be applied to various other types of antennas as will be apparent from the following description.

For almost all current design of log-periodic dipole antennas, the impedance of the individual elements is not considered. Generally, the impedance problem is solved empirically without any real understanding of the solution of the problem, except for some cases involving shunt fed elements. Most dipole arrays are designed by selecting parameters of scale factor and spacing which give the desired directivity according to standard references (Carrel, R. L., Analysis and Design of the Log-Periodic Dipole Antenna, University of Illinois, Antenna Laboratory Technical Report No. 47, July 15, 1960), and then adjusting the feedline impedance until satisfactory impedance characteristics are obtained; this is not always a satisfactory method. For the structures which have close element spacing and/or scale factors very close to one, the element impedances approach values which often do not yield satisfactory results when the structure is handled conventionally.

The variation of mutual coupling between adjacent elements is usually considered only as a function of the spacing between two parallel linear half-wave dipole antennas, (see pp. 262–272, Kraus, J. D., Antennas, McGraw-Hill, New York, 1950). For the case of the thin center fed side-by-side ½ wavelength antenna, the self-resistance minus the mutual resistance approaches zero as the spacing between the elements goes to zero, a fact which has discouraged the construction of very closely spaced, (less than $\lambda/20$), dipole arrays. However, that applies only to dipole elements of the same length. Kraus has one short paragraph titled, "Parallel Antennas of Unequal Height," in which he cites a reference, Cox, C. R., "Mutual Impedance Between Vertical Antennas of Unequal Heights," Proc. I.R.E., 35, 1367–1370, November 1947.

For closely spaced elements of unequal length, the difference between the self resistance and the mutual resistance of the elements will always be greater than zero, even if the spacing between the elements approaches zero. Consider the two element end fire array of very close spacing as shown in FIG. 8. The elements **61** and **63** are spaced by a distance S with overall length shown as L_1 and L_2. For the case of equal element lengths, the structure would resemble two open circuited transmission line sections of length $L/2$; for which the feedpoint resistance would approach zero as the spacing approaches zero.

For unequal element lengths as shown, it is apparent that if the two elements are placed in the same alternating current electromagnetic field, it is impossible for currents of both equal magnitude and phase to be induced in the elements of the antenna. In the region where one element is longer than $\lambda/2$ and the other element is shorter than $\lambda/2$, the resultant currents at the feedpoint would tend to add, since the phase reversal caused by the transposition of the short feedline would be counteracted by the fact that one element would be capacitively reactive and the other element would be inductively reactive.

The term "closely spaced" insofar as the present invention is concerned, means that the individual conductors of the radiating element are placed together in a sufficiently small region of space that, as far as the determination of the essential radiation characteristics, the separate conductors occupy the same infinitesimal line in space. In other words, the only limit as to spacing is that the distance between individual conductors is limited only by the physical construction, that is, the spacing is only limited by the requirement that the conductors do not contact each other.

Therefore, this type of frequency independent antenna requires only one physical dimension, length, to define its physical characteristics rather than description

in two or three dimensions which all other frequency independent antennas require. In the prior art any use of the word "closely" means a spacing of adjacent elements somewhere in the general region of ¼ to 1/20 of a wavelength, almost never more or less. If these structures have spacings which are made appreciably less than 1/20 wavelengths, they cease to function as frequency independent structures. The parameter of spacing is an important parameter; either stated or implied in all cases. In none of the prior teachings can the spacing be made either very close or very far, that is outside the general range given above and still allow the antenna to function. The prior art also requires that the conductors lie in an approximation of a plane and that if the lengths of the elements are tapered they should be tapered successively as they progress along the plane. The linear log periodic antenna of the present invention has no such requirement. The elements may be bunched together in a random grouping, though derivation of the network is simplified if the conductors are arranged in some orderly manner.

As an example, the prior art relating to the physical sizes of log periodic antennas is as follows. The smallest example of the planar log periodic array in terms of size vs. wavelength for the lowest frequency which is commercially available, relates to a structure which is designed to cover a frequency range of 3 to 30 mHz. It is a half structure and outlines an area of about 176 by 100 feet. The same frequency range could be covered by a linear log-periodic dipole similar to the one described in the present invention having a length of 120 feet and a thickness varying from ½ of an inch to 1/32 of an inch, a reduction of size of about 2400 times. A linear log-periodic dipole could be built with much smaller copper wire giving an element structure no larger in the center than a single strand of #20 common hookup wire.

In FIG. 1 there is illustrated a coupling network **10** between two identical element structures so as to form a normal dipole. For purposes of clarity the elements extending to one side of the coupling network are numbered **13** through **29** with the opposing elements being a mirror image of the elements so numbered.

Referring to FIG. 3, there is shown a coupling network composed of a plurality of coils, two of which have been labeled **22** and **24** and associated capacitors **26** and **28**. As will be obvious, this coupling network provides an approximate phase reversal of current in the adjacent elements.

Generally, the spacing between each individual element will be determined by mechanical or by voltage breakdown requirements as discussed above and not by any pattern shaping requirements. The element spacings and the current magnitude and phase differences between the individual elements produce resultant far fields similar to a simple half-wave dipole at each frequency in the range covered by the antenna. Thus, the spacing between the individual elements of the frequency independent dipole as shown in FIG. 1 is small, and almost negligible as compared to the phase shift introduced by the coupling network.

The scale factor, τ, representing the relative length of the individual elements, is a function mainly of the band width of the individual elements and the desired band width of the entire antenna array. As an example, a scale factor for a structure consisting of very short loaded elements might be 0.999 and for a multicone conical monopole or dipole, the scale factor might be 0.500. Likewise, a simple dipole might have scale factors varying from 0.7 to 0.9.

The asymmetrical half-structure dipole of FIG. 2 illustrates a further embodiment of the invention. In effect, the structure represents one half of the structure of FIG. 1 with adjacent individual elements of FIG. 1 being reversed to extend on the opposite side of the coupling network **30**. For illustrative purposes, the elements are numbered **31** through **47** in the order of their length extending outwardly from the coupling network **30**. One such coupling network which may be used is shown schematically in FIG. 4 with the inductive coils indicated at **32** and **34** together with the capacitive elements **36** and **38** which again give the desired phase reversal.

FIG. 5 illustrates a frequency independent monopole with specific structural elements. Again the coupling network has the various elements such as **55** and **57** extended to the necessary matching number. In this particular embodiment, a flat cable with thin wire elements encased in a dielectric material may be adapted for use with the antenna. The various stepped structures **53** shown in FIG. 5 result from the cutting of the cable so as to conform to the desired relationship between the individual antenna elements. The coupling network **50**, which may be used with a structure such as shown in FIG. 5, is illustrated in FIG. 6 with the various inductors and capacitors connected as shown and the antenna elements connected oppositely as indicated at **55** and **57**.

It will now be obvious that the basic cell of the antenna structure of the present invention consists of two elements of unequal length closely spaced and fed so that there is an approximate phase reversal of current in the adjacent elements. A wideband structure can be constructed by repeating this process somewhat indefinitely and connecting the elements with an appropriate coupling network. As is current practice for other log-periodic structures, the highest frequency elements have been shown as connected closest to the feedpoint. The network, including the wire elements, must function as a transmission line between the active elements of the structure and the feedpoint and must function as an impedance matching network in the active region of the antenna.

It should be noted that, in the drawings, the structures are shown as series fed. However, the same technique applys to shunt fed structures. In practice, the choice between series and shunt fed structures is mainly a mechanical convenience since, electrically, the two types of connections are almost the same.

FIG. 7 shows the frequency independence of the present invention with the graph being made from a symmetrical structure of thin wire dipole elements placed together to form a cable of about ½ inch in diameter near the center of the antenna and tapering to about 1/32 of an inch at the ends of the antenna. Such a structure is shown diagrammatically in FIG. 9 with the groups of elements **71** and **73** extending outwardly in opposite directions from the coupling network **75**. A scale factor, τ, of the fifth root of ½ or approximately .87 was used, with 18 elements varying in length from 151 feet down to 14 feet. Some higher mode radiation occurs producing a slight sharpening of the dipole pattern above 10 mc. This high order radiation can be controlled to some extent by varying the antenna parameters and by placing traps in the individual elements.

FIG. 10 is a partial representation of a Smith chart relating to the development of an antenna as set forth in the above disclosure.

Curve A shows the impedance of a single element, such as schematically shown in FIG. 8, in the region where it is useful as a radiating element in the linear log periodic dipole antenna.

Using FIG. 6 as an illustrative example, Curve B illustrates the transformed impedance resulting from the addition of the shunt capacitance between terminal **57** and ground. Curve C illustrates the further transformation resulting from the addition of the series capacitance in the network, and Curve D represents the resultant impedance over a particular frequency range which occurs as a result of the use of a plurality of elements and associated networks. All of the above curves include plotted points representative of the particular frequency

in mHz. used in the tests. Such curves were used to plot the VSWR curve of FIG. 7.

The antenna of the present disclosure is the only type of log-periodic antenna which develops no increase in directivity or gain as compared to a simple dipole antenna. To my knowledge, every attempt to reduce any of the existing log-periodic arrays to a linear dipole array of very close spaced elements has failed.

It is to be understood that the above description and drawings are illustrative only and that the basic approach disclosed herein may be applied to short loaded antennas, to VHF dish feeds, to VLF systems, to elements of planar log-periodic arrays as shown, or, in short, to a very large portion of the antenna field. Accordingly, the invention is to be limited only by the scope of the following claims.

I claim:

1. A frequency independent dipole antenna comprising

at least three dipole elements of decreasing length, the relative length of individual elements being determined by a substantially constant scale factor τ which is a function of the bandwidth of the individual elements and the predetermined bandwidth of the entire antenna,

the spacing between said individual dipole elements being substantially less than $\frac{1}{20}$ wavelength and being determined by mechanical or voltage breakdown requirements,

coupling network means comprising lumped inductive and capacitive reactances feeding said elements in a manner such that there is a phase reversal of current in alternate elements such as to produce resultant far fields substantially identical to a simple half-wave dipole at each frequency in the range covered by the antenna, and

means for connecting a transmission line to the smallest of said dipole elements.

2. The antenna of claim 1 wherein said elements are mounted in a planar array.

3. The antenna of claim 2 wherein said elements are encased in a dielectrical material.

4. The antenna of claim 1 wherein said elements form a symmetrical dipole array.

5. The antenna of claim 1 wherein said elements form an asymmetrical half-structure dipole array.

6. The antenna of claim 1 wherein said elements are mounted so as to form a cable.

7. The antenna of claim 6 wherein said elements are encased in a dielectric material.

8. A frequency independent monopole antenna comprising

at least three linear elements of decreasing length, the relative length of individual elements being determined by a substantially constant scale factor τ which is a function of the bandwidth of the individual elements and the predetermined bandwidth of the entire antenna,

the spacing between said individual elements being substantially less than $\frac{1}{20}$ wavelength and being determined by mechanical or voltage breakdown requirements,

coupling network means comprising lumped inductive and capacitive reactances feeding said elements in a manner such that there is a phase reversal of current in alternate elements such as to produce resultant far fields substantially identical to a simple half-wave dipole at each frequency in the range covered by the antenna, and

means for connecting a transmission line to the smallest of said elements.

9. The antenna of claim 8 wherein said elements are mounted in a planar array.

10. The antenna of claim 9 wherein said elements are encased in a dielectric material.

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ELI LIEBERMAN, Primary Examiner

U.S. Cl. X.R.

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