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## LOG PERIODIC BACKWARD WAVE ANTENNA ARRAY

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**10 Claims. (Cl. 343—792.5)**

This invention relates to antennas and more particularly it relates to antennas having unidirectional radiation patterns that are essentially independent of frequency over wide bandwidths.

In the copending application of Dwight E. Isbell, Ser. No. 26,589, filed May 3, 1960, there are described certain antennas comprising coplanar dipole arrays which have an unusually wide bandwidth over which the performance of the antennas is essentially frequency independent and the input impedance nearly constant, the antennas also having a unidirectional pattern with a directivity comparable to a Yagi array. As described in the aforementioned application, these arrays comprise a number of dipoles arranged in side-by-side relationship in a plane, the length of the dipoles and the spacing between adjacent dipoles varying according to a definite mathematical formula, with each of the dipoles being fed at its midpoint by a common feeder which introduces an added phase shift of 180° between connections to successive dipoles. The dipoles which are used to make up the array vary progressively in length, the longest dipole element being about ½ wavelength long at the low frequency limit of a given antenna's effective range and the shortest element being about ⅜ wavelength long at the upper frequency limit.

In accordance with the present invention, it has been found that the directivity of an antenna of the type described in the aforementioned application may be increased and the effective frequency range of an antenna of fixed size may be extended by inclining the dipoles of Isbell to form V-elements, each of which consists of two straight arms of equal length defining an apex which points away from the direction of radiation of the antenna which is also the direction in which the element size decreases. The modification of the straight dipoles of Isbell to V-shaped elements permits the antenna to be operated over bands of frequencies higher than those established, as described above, by the length of the shortest dipole in the antenna, with increased directivity, thus obviously increasing the effective frequency range of a given antenna.

The invention will be better understood from the following detailed description thereof taken in conjunction with the accompanying drawings, in which the same numbers are used to denote corresponding elements in the several views and in which:

FIGURE 1 is a schematic plan view of an antenna made in accordance with the principles of the invention;

FIGURE 2 is a perspective view of a practical antenna embodying the invention; and

FIGURE 3 is a fragmentary view of an improved and preferred form of an antenna similar to that shown in FIGURE 2, as seen from a point directly in front of and above the narrow end of the antenna.

Referring to FIGURE 1, it will be seen that the antennas of the invention are composed of a plurality of V-elements, e.g., **11** and **12**, each of which consists of a pair of arms, e.g., **13** and **14**, defining an apex in the middle of the V-elements, said V-elements being arranged in a herringbonelike pattern. The arms of a given V-element are equal in length and corresponding arms of the several V-elements, i.e., the arms on the same side of a line passing through the apexes of the V-elements, are

substantially parallel to each other. It will be noted that the lengths of the arms of successive V-elements and the spacing between the apexes of the elements are such that the extremities of the elements fall on a pair of straight lines which intersect to form an angle $\alpha$. In the preferred embodiment of the invention the antenna is symmetrical about a line passing through the apexes of the V-elements, as shown.

The antenna is fed at its narrow end from a conventional source of energy, depicted in FIGURE 1 by alternator **16**, by means of a balanced feeder line consisting of conductors **17** and **18**. It will be seen that the feeder lines 17 and 18 are alternated between connections to consecutive V-elements, thereby producing a phase reversal between such connections.

The lengths of the arms in the antenna, and the spacing between the V-elements, are related by a constant scale factor $\tau$ defined by the following equations:

$$\tau=\frac{l_{(n+1)}}{l_n}=\frac{\Delta S_{(n+1)}}{\Delta S_n}$$

where $\tau$ is a constant having a value less than 1, $l_n$ is the length of an arm in any intermediate V-element in the array, $l_{(n+1)}$ is the length of an arm in the adjacent smaller V-element, the subscript $n$ designating the $n$th arm running in an order from larger to smaller, $\Delta S_n$ is the spacing between the apex of the V-element having the arm length $l_n$ and the apex of the adjacent larger V-element, and $\Delta S_{(n+1)}$ is the spacing between the apex of the V-element having the arm length $l_n$ and the apex of the adjacent smaller V-element.

The arms of the individual V-elements forming the antenna array are inclined to point in the direction of decreasing V-element size so that the apex of each of the elements points in a direction away from the angle $\alpha$ formed by the lines passing through the extremities of the individual V-elements.

The angle formed by the arms of a V-element is designated as $\psi$. It will be seen that when the angle $\psi$ is equal to 180°, the antennas of the invention are identical with those described by Isbell in the application mentioned above. In the instant invention, however, the angle $\psi$ preferably has a value between about 50° and 150°.

It will be seen from the geometry of the invention as given above that the distances from the base line O at the vertex of the angle $\alpha$ to the apexes of the V-elements forming the array are defined by the equation:

$$\tau=\frac{X_{(n+1)}}{X_n}$$

where $X_n$ is the distance from the base line O to the apex of the V-element having the arm length $l_n$, $X_{(n+1)}$ is the corresponding distance from the base line to the apex of the adjacent smaller V-element, the $\tau$ has the significance previously given.

The radiation pattern of the antennas of the invention having the geometrical relationship among the several parts, as defined above, is unidirectional in the negative X direction, i.e., extending to the left from the narrow end of the antenna of FIGURE 1.

The use of V-elements in the antennas of the invention, rather than dipoles, increases the directivity of the invention and also permits more effective utilization of a given antenna since the same structure can be used in several frequency modes to achieve coverage of different frequency bands. In the special case of an antenna having straight dipoles rather than V-elements (i.e., when $\psi=180°$), the effective frequency range is that in which the low limit corresponds to that frequency in which the largest dipole in the antenna is about ½ wavelength long and the upper frequency limit to that frequency in which the smallest dipole in the antenna is about ⅜ wavelength long. In general, therefore, it may be said that the frequency range of the straight dipole array corresponds to the mode of operation in which the lengths of the dipoles in the array are about ½ wavelength long. As the frequency is raised above the upper limit of the ½ wavelength mode in the dipole array, the antenna will also be found to radiate effectively at frequencies in which the dipoles are about 3/2 wavelengths long (the 3/2 wavelengths mode), 5/2 wavelengths long (the 5/2 wavelengths mode) and so on. At frequencies above the half-wavelength mode, however, the radiation pattern of the dipole array becomes multilobed and is, therefore, of limited usefulness. By including the arms of the dipole to form the V-elements of the instant invention, it has been found that a single lobe of improved directivity may be obtained as the frequency is raised from the half-wavelength mode through the intervening ranges to the 9/2 wavelengths mode and beyond. For each mode of operation there exists an optimum value for the angle $\psi$, ranging from about 114° for the half-wavelength mode to about 62° for the 9/2 wavelengths mode. By using a compromise value for $\psi$ within this range, however, a practical antenna can be made to achieve acceptable performance over several modes of operation, thereby increasing its effective range without increasing the number of elements therein. This result is possible since many of the elements forming the antenna array are used at more than one frequency.

The construction of an actual antenna made in accordance with the invention is shown in FIGURE 2. In this antenna the balanced line consists of two closely-spaced and parallel electrically conducting small diameter tubes **21** and **22** which also act as a mechanical support for the dipole elements and to which are attached the arms which form the V-elements of the invention. It will be noted that each of the two arms, e.g., **23** and **24**, making up one V-element is connected to a different one of said conductors **21** and **22**. Moreover, considering either one of the conductors **21** and **22**, consecutive arms along the length thereof extend in opposite directions. It will be seen that this construction has the effect of alternating the phase of the connections between successive V-elements, as depicted schematically in FIGURE 1. Although the V-elements of FIGURE 2 are not precisely coplanar, differing therefrom by the distance between the parallel conductors **21** and **22**, in practice this distance is usually small so that the arms of the V-elements are substantially coplanar and the advantages of the invention are maintained. In some instances, however, it may be advantageous to bend the individual arms, e.g., **27** and **28**, close to the point of attachment to the feeder line, as shown in FIGURE 3, so as to position all the arms in the same plane. The antennas of FIGURES 2 and 3 may be conveniently fed by means of a coaxial cable **25** positioned within conductor **21**, the outer conductor of the cable making electrical contact with conductor **21** and the central conductor **26** of the cable extending to and making electrical connection with conductor **22**, as shown.

The antennas of the invention may also be fed by a balanced two wire line which is twisted between elements to achieve the desired phase reversal. Other methods of achieving the desired phasing may be employed, e.g., transmission line loops or stubs.

As an example of the invention, an antenna of the type shown in FIGURE 3 was constructed using 0.125" diameter tubing for the balanced line and 0.050" diameter wire for the arms of the V-elements. The arms were soldered to the feeder line and the array was fed by a miniature coaxial cable inserted into one of the conductors of the balanced line. The antenna had 25 arms, the largest of which was 1 ft. long with the shortest being about 3½" long. The antenna was further defined by the parameters $\tau=0.95$ and $\psi=70°$. This antenna exhibited typical directivity gains ranging from 12 db over isotropic in the 3/2 wavelengths mode to 17 db in the 7/2 wavelengths mode, with essentially constant input impedance within each mode.

Except with respect to the angle of inclination of the arms of the V-elements, the parameters which define the antennas of the invention are essentially similar to those of the corresponding straight dipole arrays in which the arms extend at right angles from the feeder lines. Thus, the parameter $\tau$ preferably has a value betwen about 0.8 and 0.95 and the angle $\alpha$ suitably ranges between 20° and 100°. Moreover, the upper and lower limits of the bandwidth for the ½ wavelength mode of operation can be adjusted as desired by making the longest V-element correspond in length to about ½ wavelength at the lower limit and the shortest V-element to about ⅜ wavelength at the upper frequency limit.

In addition to its use as a direct radiator or receiver, the resonant-V array of the invention has several advantages over other antennas currently used as primary feeds for parabolic and other reflectors. Its independence of frequency in any single mode assures constant illumination of the reflector. Moreover, the input impedance remains essentially independent of frequency so that no tuning is required as the frequency is varied.

The foregoing detailed description has been given for clearness of understanding only, and no unnecessary limitations should be understood therefrom, as modifications will be obvious to those skilled in the art.

What is claimed is:

1. A broadband unidirectional antenna comprising an array of a plurality of V-elements in a planar herringbonelike arrangement, each of said elements having a pair of equal arms defining an apex, the apexes of said V-elements lying on a straight line, the corresponding arms of said elements progressively increasing in length and spacing, the extremities of the arms of said V-elements substantially falling on a V-shaped line forming an angle $\alpha$ at its vertex, the apexes of said V-elements pointing in a direction away from the vertex of said angle $\alpha$, the ratio of the arm lengths of any pair of adjacent V-elements being given by the formula

$$\frac{l_{(n+1)}}{l_n}=\tau$$

where $l_n$ is the length of an arm in the larger of said pair of V-elements, $l_{(n+1)}$ is the length of an arm in the adjacent smaller V-element of said pair, the subscript $n$ designating the $n$th arm running in an order from larger to smaller, and $\tau$ is a constant having a value less than 1, the spacing between the apexes of said V-elements being given by the formula

$$\frac{\Delta S_{(n+1)}}{\Delta S_n}=\tau$$

where $\Delta S_n$ is the spacing between the V-element having the arm length $l_n$ and the adjacent larger V-element, $\Delta S_{(n+1)}$ is the spacing between the V-element having the arm length $l_n$ and the adjacent smaller V-element, and $\tau$ has the significance previously assigned, said V-elements being adapted to be fed as a group from the small end of the individual V-elements fed at the apexes thereof by a common feeder which introduces an additional 180° phase shift between successive V-elements.

2. The antenna of claim 1 wherein the angle formed by the arms of any V-element at the apex thereof has a value within the range from about 50° to about 150°.

3. The antenna of claim 1 which is symmetrical about a line passing through the apex of each V-element therein, and in which the corresponding arms of the V-elements are parallel.

4. The antenna of claim 1 in which the angle $\alpha$ has a value between about 20° and 100° and the constant $\tau$ has a value between about 0.8 and 0.95.

5. A broadband unidirectional antenna comprising a balanced feeder line consisting of two closely spaced, straight and parallel conductors, a plurality of substan-

tially coplanar V-elements, each V-element comprising a pair of arms of equal length defining an apex, one of said arms of each V-element being connected at the apex of said V-element to one of said conductors, the other of said arms being connected directly opposite the first to the other of said conductors, the arms of any V-element extending in opposite directions at an acute angle to the plane determined by said conductors, consecutive arms on each of said conductors extending on opposite sides of said plane, the ratio of the lengths of the arms in adjacent V-elements being given by the formula

$$\frac{l_{(n+1)}}{l_n}=\tau$$

where $l_n$ is the length of an arm of a V-element, $l_{(n+1)}$ is the length of an arm in the adjacent smaller V-element, the subscript $n$ designating the $n$th arm running in an order from larger to smaller, and $\tau$ is a constant having a value less than 1, the spacing of the apexes of the V-elements along said feeder line being given by the formula

$$\frac{\Delta S_{(n+1)}}{\Delta S_n}=\tau$$

where $\Delta S_n$ is the spacing between the V-element having the arm length $l_n$ and the adjacent larger V-element, $\Delta S_{(n+1)}$ is the spacing between the V-element having the arm length $l_n$ and the adjacent smaller V-element, and $\tau$ has the significance previously assigned.

6. The antenna of claim 5 in which the angle formed by said arms with the plane determined by said feeder line, measured in a plane perpendicular to said plane, has a value between about 25° and about 75°.

7. The antenna of claim 5 in which $\tau$ has a value of about 0.8 to 0.95.

8. An aerial system for wide-band use comprising a plurality of herringbone-like conducting V-elements planarly arranged, a two-conductor balanced feeder connected to each of said elements at substantially the inner end thereof, each two opposite V-elements forming a pair constituting dipole halves, the connection from each adjacent dipole section being to a different feeder, said V-elements being selectively spaced from each other, each V-element of each pair having arms of substantially equal length substantially defining an apex with the apexes of the plurality of V-elements all lying in substantially a straight line and terminating at the feeder, the said dipoles of each pair being of different electrical lengths with successive dipoles differing in electrical length with respect to each other by substantially the same scale factor, each dipole and the feeder between successive dipoles constituting a cell, and the selective spacings between adjacent dipoles decreasing from one end to the other with the greater spacing being between the longest dipoles and being such that the combination of dipole lengths and spacings provides a substantially uniform wide-band response over a plurality of frequency bands bearing substantially harmonic frequency relationships to each other, the connection between the dipoles and the feeder being made in such a manner that the directive gain of the antenna increases as operation shifts from one band to an adjacent band of higher frequencies, and means to connect the feeder to an external circuit at a location substantially removed from the longest of the V-elements and in the direction of the smallest of the V-elements.

9. An aerial system for wide-band use including a two-conductor balanced feeder extending in a selected plane, a plurality of herringbone-like conducting V-elements planarly arranged and spaced along the feeder, each of the elements having a pair of arms of substantially equal length defining substantially an apex with the apexes of the plurality of V-elements all lying in substantially a straight line and all terminating at the feeder, a connection between each of the V-elements and one of the feeders at the inner end of the elements, the two V-elements forming each pair constituting dipole halves, adjacent dipole sections being connected to different feeders, each of the pairs of dipoles being of different electrical lengths with successive dipoles differing in electrical length with respect to each other by substantially a common scale factor, each dipole and the feeder connected thereto in the region between one dipole pair and the next adjacent dipole pair constituting a cell, the spacings between the dipoles as connected to the feeders differing from each other also by substantially the same common scale factor, the scale factor being so chosen that the combination of dipole lengths and spacings providing the several cells have a substantially uniform wide-band response over several frequency bands bearing substantially harmonic frequency relationships to each other, the connection between the feeder and the dipoles being made in such a manner that the directive gain of the antenna increases with operational shift from one band to another band of higher frequency, and means to connect the feeder to an external circuit at a location substantially removed from the longest of the V-elements in the direction of the smallest of the V-elements.

10. An aerial system for wide-band use including an elongated two-conductor balanced feeder, a plurality of herringbone-like conducting V-elements planarly arranged and spaced along said feeder, each of the elements having a pair of arms of equal length defining substantially an apex with the apexes of the plurality of V-elements all lying in a substantially straight line, a connection between each of the V-elements and the feeder to terminate the elements substantially at the feeder, the two V-elements forming each pair constituting dipole halves, adjacent dipole sections of the plurality being connected to different feeders and the dipoles being relatively spaced so that the spacings between successive dipoles differ from each other by substantially a common scale factor, adjacent dipole sections having different electrical lengths, each dipole and the feeder connected between it and the adjacent dipole constituting a cell, the lengths of the dipoles increasing from end of array where spacings between adjacent dipoles is less to end of the array where adjacent dipoles are spaced the greatest distance, the spacings by the scale factor variation between adjacent dipoles being such that a combination of the various dipole lengths and spacings provides a substantially uniform wide-band response over several frequency bands bearing substantially harmonic frequency relationships to each other, the connection being made in such a manner that the directive gain of the antenna increases as the operation shifts from one band to another band of higher frequency, and means to connect the feeder to an external circuit at a location substantially removed from the longest of the V-elements in the direction of the smallest of the V-elements.

**References Cited** in the file of this patent

UNITED STATES PATENTS

| | | |
|---|---|---|
| 2,192,532 | Katzin | Mar. 5, 1940 |
| 2,429,629 | Kandoian | Oct. 28, 1947 |
| 2,817,085 | Schwartz et al. | Dec. 17, 1957 |

FOREIGN PATENTS

| | | |
|---|---|---|
| 408,473 | Great Britain | Apr. 12, 1934 |
| 574,323 | Canada | Apr. 21, 1959 |

OTHER REFERENCES

IRE Transaction on Antennas and Propagation, May 1960; vol. AP-8, No. 3, pages 260-267.

Channel Master Corp., "K.O." Antenna, copyright 1955, 3 pages.

## UNITED STATES PATENT OFFICE

# CERTIFICATE OF CORRECTION

Patent No. 3,108,280 October 22, 1963

Paul E. Mayes et al.

It is hereby certified that error appears in the above numbered patent requiring correction and that the said Letters Patent should read as corrected below.

Column 3, line 13, for "including" read -- inclining --.

Signed and sealed this 26th day of May 1964.

(SEAL)
Attest:

ERNEST W. SWIDER
**Attesting Officer**

EDWARD J. BRENNER
**Commissioner of Patents**