April 25, 1961 A. F. WICKERSHAM, JR., ET AL 2,981,951

BROADBAND ANTENNA

Filed Sept. 11, 1959

2 Sheets-Sheet 1

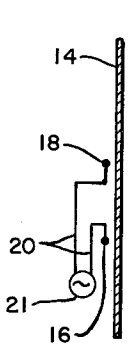


FIG-2

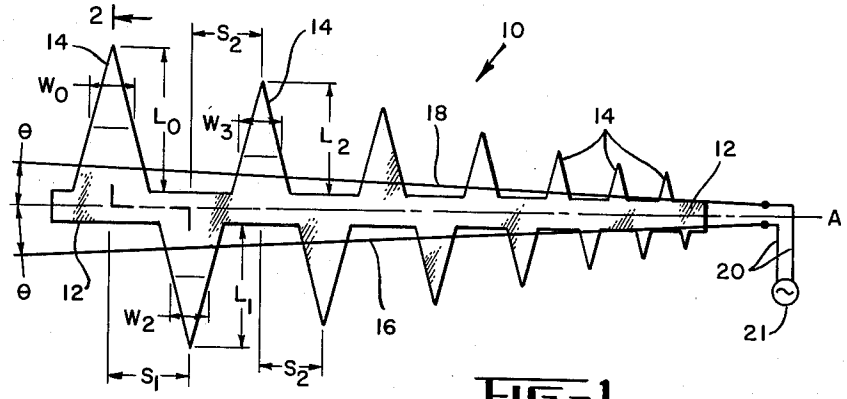


FIG-1

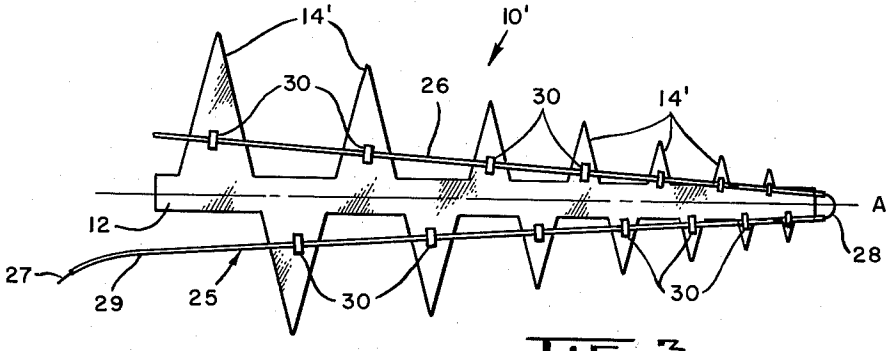


FIG-3

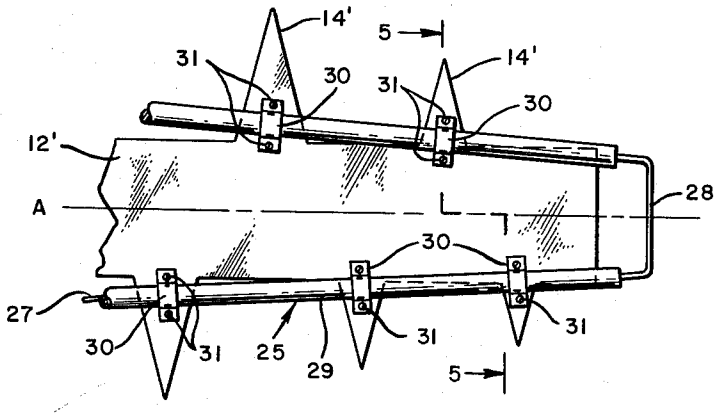


FIG-4

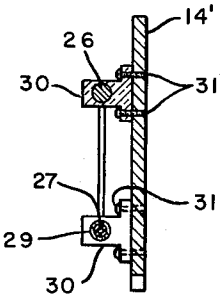


FIG-5

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BROADBAND ANTENNA

Filed Sept. 11, 1959

2 Sheets-Sheet 2

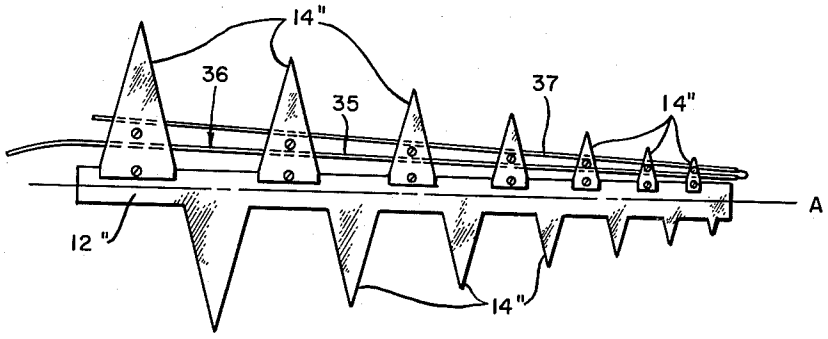


FIG-6

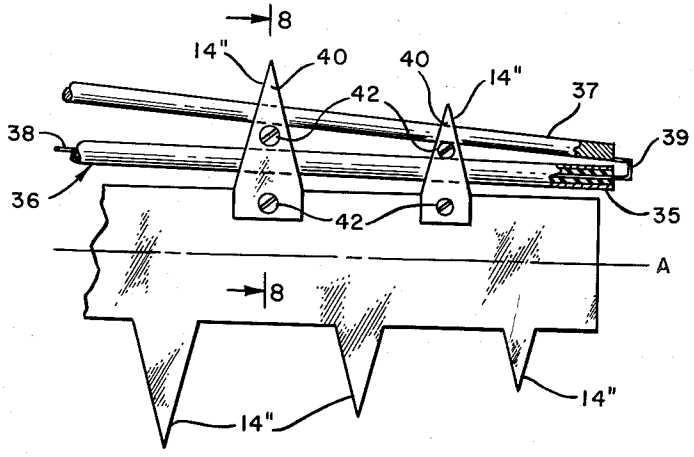


FIG-7

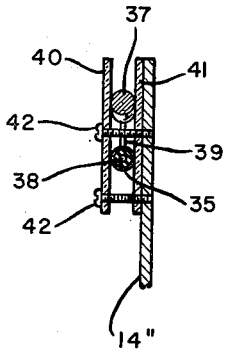


FIG-8


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United States Patent Office 2,981,951
Patented Apr. 25, 1961



2,981,951

# BROADBAND ANTENNA

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Filed Sept. 11, 1959, Ser. No. 839,504

9 Claims. (Cl. 343—807)

This invention relates to antennas and in particular to a broadband end-fire antenna. More particularly, this invention concerns an improvement in a directional antenna disclosed by W. A. Cumming in Institute of Radio Engineers Transactions, Antennas and Propagation AP3, page 52, (1955), called a "zig-zag" antenna.

The zig-zag antenna of Cummings comprises a wire bent into a saw-tooth configuration lying in a plane and extending outwardly from a ground plane or counterpoise. The shape results from the projection of a straight helix on a plane. The zig-zag antenna is compact and simple, and produces an end-fire beam which is fairly stable over a bandwidth of approximately ±5% of the center frequency of the antenna. The present invention is concerned with improvement in the bandwidth of the zig-zag antenna.

In accordance with this invention, the area under each "tooth" or element of the zig-zag antenna is filled with conducting material, and a twin wire transmission line, located close to the plane of the antenna, extends over its full length. The structure, then, consists of two sets of triangular radiator plates on opposite sides of the antenna axis, each plate being off-set from the axially adjacent plate. The consequence of filling the "teeth" of the antenna is to increase the coupling with the transmission line and to lower the Q of each element. The ground plane or counterpoise is no longer necessary. The antenna is then "tapered," that is, the physical dimensions and spacing of the plates and of the transmission line are uniformly decreased in accordance with a predetermined ratio. In one form, the transmission line is located asymmetrically on the antenna. This latter antenna produced satisfactory results over a 7 to 1 bandwidth, which range readily can be extended simply by increasing the length of the antenna.

A principal object of this invention is the provision of a broadband unidirectional end-fire antenna.

Another object is the provision of a compact antenna having a geometrically simple configuration and which, therefore, is relatively inexpensive to manufacture.

A more specific object is the provision of an antenna of the foregoing type which is conveniently and efficiently matched to the input feed line over a broad range of frequencies.

A further object is the provision of a feed system for a zig-zag antenna which permits the antenna to be used without a ground plane, artificial ground, or counterpoise.

These and other objects of my invention will become apparent from the following description of preferred embodiments thereof, reference being had to the accompanying drawings in which:

Figure 1 is a side elevation of a tapered zig-zag antenna with a twin wire feed system illustrated schematically;

Figure 2 is a vertical section taken on line 2—2 of Figure 1;

Figure 3 is a view similar to Figure 1 showing a twin wire feed line comprising a coaxial cable and a coextensive conductor connected to the center conductor of the cable;

Figure 4 is an enlarged view of a part of Figure 3;

Figure 5 is a section taken on line 5—5 of Figure 4;

Figure 6 is a side elevation of a tapered zig-zag antenna with the twin wire feed line disposed asymmetrically of the antenna;

Figure 7 is an enlarged view of part of Figure 6, with the ends of the feed lines broken away to show the interconnection of the two lines; and

Figure 8 is a vertical section taken on line 8—8 of Figure 7.

Referring now to the drawings, Figures 1 and 2 show an antenna **10** having an axis A and a central axially extending body member **12** from which project a series of radiating elements **14** over the length of the antenna. All of the elements **14** are in a plane containing the antenna axis and all are conductors whereas the central member **12**, which functions as a supporting "boom," may be a conductor or a non-conductor. For simplicity and economy of construction, member **12** and all of elements **14** comprise a unitary structure, preferably cut from a single sheet of conducting material.

Each element **14** is triangular in shape, is axially spaced from the adjacent element, whether on the same or opposite side of the antenna axis, and has physical dimensions that differ from those of the other elements. More particularly, the physical dimensions and spacings of the elements decrease from one end of the antenna, the left end as viewed, to the other in progressive increments of a predetermined ratio. Thus the lengths $L_0$, $L_1$, $L_2$, . . .$L_n$ of the elements, the spacing $S_1$, $S_2$, $S_3$, . . . $S_{n-1}$ between elements, and the mean width $W_0$, $W_1$, $W_2$, . . . $W_n$ of the elements, wherein $n$ is the total number of elements, uniformly decrease in magnitude in accordance with the predetermined ratio. Stated differently,

$$\frac{L_{m+1}}{L_m}=\frac{L_0}{L_1}=\frac{L_1}{L_2}\cdots\frac{L_{n-1}}{L_n}=\text{constant}$$

where $m$ designates any radiating element, and $m+1$ is the adjacent larger element. The decrease in size, called tapering, permits operation of the antenna over an indfinitely broad frequency range. The array has a taper angle designated as $\alpha$.

This broadband operation will be better understood by a brief explanation of the theory of operation of the tapered antenna. Assume that the lentgh $L_0$ of the largest radiating element **14** is equal to $\lambda_0/2$, where $\lambda_0$ approximately corresponds to the largest operating wavelength in the band, and $L_n$ approximately is equal to $\lambda_n/2$ where $\lambda_n$ corresponds to the smallest operating wavelength. The bandwidth of the antenna then is indicated by the ratio $\lambda_0/\lambda_n$. It is clear that for an intermediate wavelength $\lambda_1$ less than $\lambda_0$, some radiating element in the structure will have the same lentgh to wavelength ratio as the active element at any other frequency within the bandwidth. At half-wavelengths which fall between two adjacent elements, the total radiation must be a sum of the excitation of elements operating at a frequency displaced from their resonant lengths. This suggests, then, that the Q of the indivdual elements,which is a measure of the sharpness of resonance of the elements, must be a value such that the overlap of excitation gives a smooth transition as the wavelength changes. A low value of Q, which provides the desired smoothness of transition, is attained, in accordance with the invention, by coupling the transmission lines to the relatively broad conducting area of each radiating element.

The tapered antenna is energized by a twin wire transmission line comprising conductors **16** and **18** which ex-

tend the full length of the antenna close to but spaced from the radiating elements **14**. In one form of the invention, these conductors are symmetrically arranged about the axis A of the antenna, as shown in Figures 1 and 3. The conductors are slanted to form acute angles $\theta$ with the antenna axis and converge toward each other from the left end of the antenna, as viewed, for connection to input leads **20** from an excitation source **21**, such as a transmitter. It will be understood, of course, that the antenna may be used for receiving purposes as well as transmitting purposes, the latter being described simply for convenience as illustrative of one application of the antenna. The angle $2\theta$ of convergence of the conductors **16** and **18** is selected so as to optimize the end-fire patterns over the operating frequency range. By way of example, in one model that was built and successfully operated, an angle $2\theta$ was used which resulted in a spacing between the conductors of approximately one-fifth the length of an element **14** at the point of cross-over of the conductors with that element. Such an antenna produced unidirectional end-fire patterns that were uniform over a bandwidth of approximately 5 to 1, the average E-plane beamwidth being approximately 53°. The symmetrically fed antenna, however, is sensitive to the spacing of the twin lines which makes difficult the repeatability of performance of the antenna.

In the form of the invention shown in Figures 3 to 5, the twin wire feed line conveniently takes the form of a coaxial cable generally indicated at **25** and a solid conductor **26**, both converging toward each other and arranged symmetrically about the axis A of antenna **10'** in close proximity to the radiating elements **14'**. With the exception of these feed lines, the antenna **10'** is substantially identical to the antenna **10** of Figure 1. At the small end of the antenna, to the right as viewed in Figure 3, the inner conductor **27** of cable **25** is connected by jumper lead **28** to conductor **26**, see Figure 4, so that the latter conductor becomes essentially an extension of the inner conductor. The outer conductor **29** of the coaxial cable constitutes one of the twin wire feed lines while the conductor **26** constitutes the other of such lines. This form of transmission line is not only effective in energizing the radiating elements of the antenna, but also affords a convenient means of matching the impedance of the antenna over a wide range of frequencies to an input coaxial cable, not shown, which is connected to cable **25** at the large end of the antenna.

The feed lines are coupled to the radiating elements electromagnetically but are physically insulated from the elements by suitable means. As shown in Figures 3 to 5, the cable **25** and conductor **26** are secured to the antenna body by brackets **30** made of dielectric material and secured in place by screws **31**, see Figures 4 and 5.

In order to overcome the aforementioned sensitivity of the antenna to the location and the spacing of the twin wire feed lines, the latter are located in a laterally offset relation with respect to the axis of the antenna, as shown in Figures 6 to 8. Antenna **10''**, with radiating elements **14''** projecting from opposite sides of antenna axis A and tapering in one direction, is substantially the same as antenna **10** described above. However, the twin feed lines consisting of the outer conductor **35** of coaxial cable **36**, and conductor **37**, are offset vertically from the axis A, as shown. Cable **35** and conductor **37** converge toward each other in the direction toward the smaller end of the antenna where jumper **39** connects inner conductor **38** of the cable to conductor **37**. Each of these tapered twin lines traverses the radiating elements **14''** which are located on one side only of the axis A. In order mechanically to hold cable **36** and conductor **37** in position on the antenna, a pair of insulator plates **40** and **41** are secured to each radiating elements and on opposite sides of the feed lines. Screws **42** hold the plates to the antenna. The feed lines therefore are physically insulated from each other and from the antenna proper but are electromagnetically coupled to the several radiating elements. By simply loosening screws **42**, adjustment of the spacings of the feed lines from each other and from the axis A of the antenna to optimize performance and improve impedance matching is readily accomplished.

By way of example, an antenna of the type shown in Figure 6 having the following dimensions and characteristics, has been built and successfully tested:

| | |
|---|---|
| Overall length of antenna ——inches (approx.)— | 31 |
| Ratio: $\frac{L_{m+1}}{L_m}=\frac{W_{m+1}}{W_m}$ | |
| Taper angle $\alpha$ ——degrees— | 29 |
| Element size: | |
| $L_0$ ——cm— | 19.8 |
| $W_0$ ——cm— | 3.25 |
| Operating bandwidth (mc./s.) —— | 600–4200 |
| Typical half-power beamwidths: | |
| H-Plane ——degrees— | 53 |
| E-Plane ——do—— | 52 |
| Side lobe level: | |
| E-Plane ——db— | −15 |
| H-Plane: | |
| below 2000 mc./s. ——db— | −20 |
| at 3000 mc./s. ——db— | −13 |
| Offset of twin line from cable axis at $L_0$ | |
| Cable 36 ——cm— | 4.5 |
| Conductor 37 ——cm— | 7.5 |

Changes, modifications and improvements to the above-described embodiments of our invention may be made by those skilled in the art without departing from the precepts of the invention. The scope of the invention is defined in the appended claims.

We claim:

1. A broadband end-fire antenna having an axis and comprising a plurality of triangularly shaped conducting elements arranged in a common plane with the apex of each element remote from the axis, said elements being axially spaced apart with successive elements extending on opposite sides of said axis, the physical dimensions of successive elements decreasing toward one end of the antenna in accordance with a predetermined ratio, and means for feeding electromagnetic wave energy to said conducting elements comprising a pair of conducting lines disposed adjacent to said elements for the full length of the antenna and converging toward each other in a direction toward said one end of the antenna, said lines being electromagnetically coupled to said elements, and input means connected to said lines for energizing said elements.

2. A broadband end-fire antenna having an axis and comprising a plurality of conducting elements arranged in a single plane, said elements being arranged in succession along the axis with successive elements extending on opposite sides only of said axis, the physical dimensions of successive elements decreasing toward one end of the antenna in accordance with a predetermined ratio, and means for feeding electromagnetic wave energy to said conducting elements comprising a coaxial cable and a conducting member disposed adjacent to said elements for the full length of the antenna and converging toward each other in a direction toward said one end of the antenna, said cable having an outer conductor and an inner conductor, said inner conductor being electrically connected to said conducting member at said one end of the antenna, and input means connected to said coaxial cable for energizing said elements.

3. A broadband end-fire antenna having an axis and comprising a plurality of triangularly shaped conducting elements arranged in a common plane with the apex of each element remote from the axis, said elements being arranged in succession along said axis with successive elements extending on opposite sides of said axis, the

physical dimensions of successive elements decreasing toward one end of the antenna in accordance with a predetermined ratio, and means for feeding electromagnetic wave energy to said conducting elements comprising a pair of axially extending conducting lines disposed symmetrically about said axis and lying adjacent to and spaced from said elements for the full length of the antenna and converging toward each other in a direction toward said one end of the antenna, said lines being electromagnetically coupled to said elements, and input means connected to said lines for energizing said elements.

4. An antenna having an axis and comprising a series of triangularly shaped conducting elements lying in a common plane and arranged successively along said axis with axially adjacent elements extending in opposite directions from said axis, the dimensions of the series of elements tapering from a maximum at one end of the antenna to a minimum at the other end, and means for feeding electromagnetic wave energy to said conducting elements comprising a pair of laterally spaced conducting lines disposed adjacent to said series of elements whereby to be electromagnetically coupled thereto, said lines converging toward each other in a direction toward said one end of the antenna with both lines being located on the same side of said axis, and input means connected to said lines for energizing said elements.

5. An antenna having an axis and comprising a series of triangularly shaped conducting elements lying in a single plane and arranged successively along said axis with axially adjacent elements extending in opposite directions from said axis, the dimensions of the series of elements tapering from a maximum at one end of the antenna to a minimum at the other end, and means for feeding electromagnetic wave energy to said conducting elements comprising a coaxial cable and a coextensive conducting member laterally spaced from the cable, said cable and said member being disposed adjacent to said series of elements and converging toward each other in a direction toward said other end of the antenna, said cable having an outer conductor and an inner conductor, said inner conductor being directly electrically connected to said conducting member at said other end of the antenna, and input means connected to said cable at said one end of the antenna for energizing said elements.

6. The antenna according to claim 5 in which said cable and said conducting member are located on the same side of the antenna axis.



7. The antenna according to claim 5 with means for insulating said cable and said conducting member from said elements.

8. A broadband antenna having an axis and comprising a series of triangularly shaped conducting elements lying in a common plane and arranged successively along said axis with axially adjacent elements extending in opposite directions from said axis, the dimensions of the series of elements tapering from a maximum at one end of the antenna to a minimum at the other end, and means for feeding electromagnetic wave energy to said conducting elements comprising a coaxial cable and a coextensive conducting member, said cable and said member being closely spaced from said elements on the same side of said axis, said cable having an outer conductor and an inner conductor, said inner conductor being directly electrically connected to said member at said other end of the antenna whereby said outer conductor and said conducting member constitute twin wire feed lines, and input means connected to said cable at said one end of the antenna for energizing said elements.

9. A broadband unidirectional tapered end-fire array having an axis and a plurality of radiating elements disposed in a single plane containing said axis, said elements comprising a series of conducting plates having a profile defined by the projection of a tapered helix on a plane whereby the plates are triangularly shaped and with successive plates projecting alternately from opposite sides of the axis, and spaced twin conducting lines traversing the series of plates and located adjacent to and spaced from the plane of the plates, the physical dimensions and spacing of said elements and the spacing of said lines decreasing from one end of the array to the other in progressive increments of a predetermined ratio.

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