Nov. 28, 1961 D. E. ISBELL 3,011,168

FREQUENCY INDEPENDENT UNIDIRECTIONAL ANTENNA

Filed Oct. 20, 1958 2 Sheets-Sheet 1

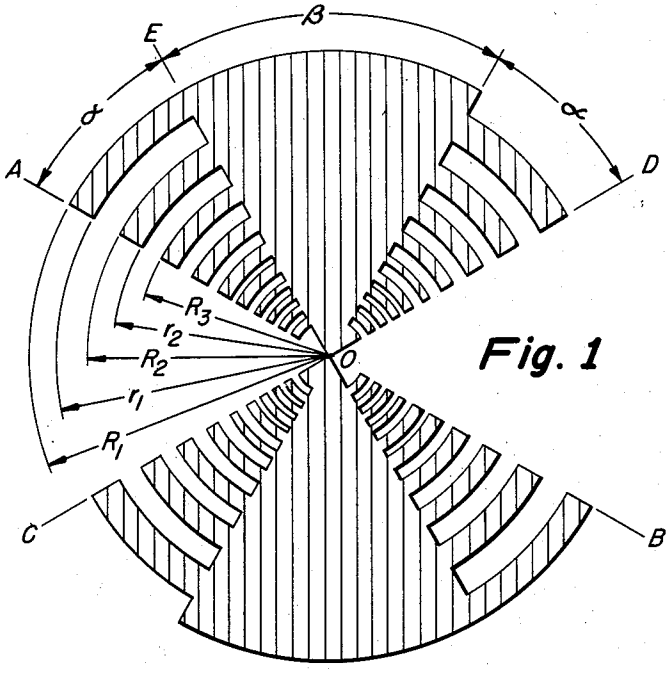


Fig. 1

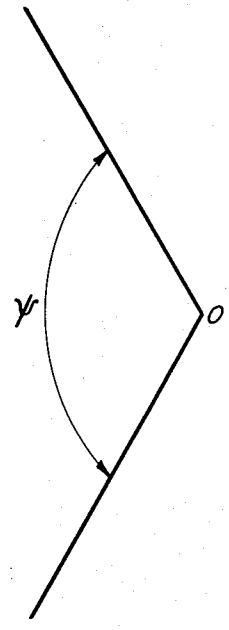


Fig. 2

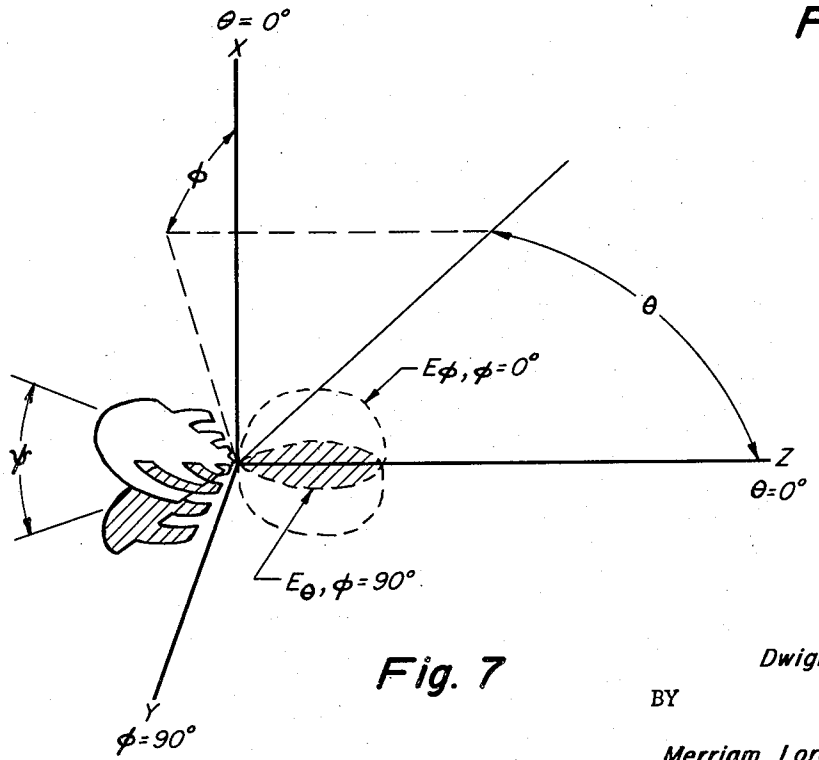


Fig. 7

INVENTOR.
Dwight E. Isbell

BY

Merriam, Lorch & Smith
ATTORNEYS

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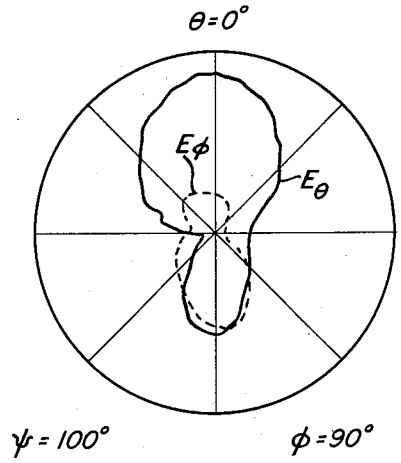


Fig. 3

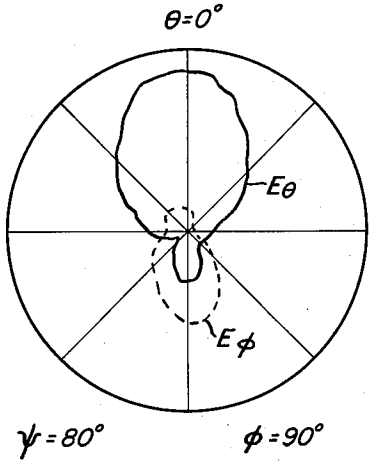


Fig. 4

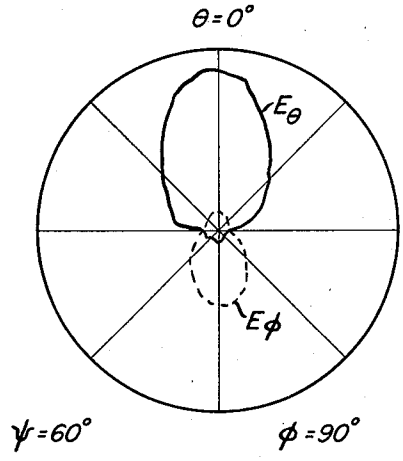


Fig. 5

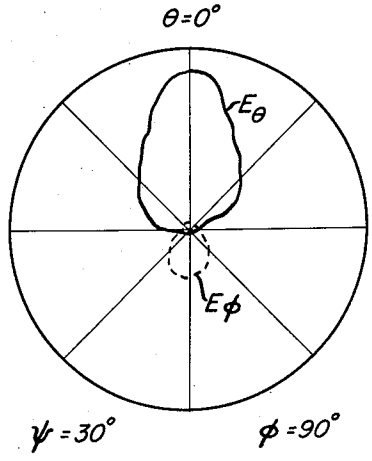


Fig. 6

INVENTOR.
Dwight E. Isbell

BY

Merriam, Lorch & Smith
ATTORNEYS

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FREQUENCY INDEPENDENT UNIDIRECTIONAL ANTENNA

Dwight E. Isbell, Urbana, Ill., assignor to The University of Illinois Foundation, a non-profit corporation of Illinois

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3 Claims. (Cl. 343—908)

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.

It is known that an antenna whose geometry is described completely by angles, such as an infinite biconical antenna, would make an ideal broadband radiator since its operation is theoretically completely independent of frequency. The theoretical performance of the infinite biconical antenna is not achieved in practice, however, since such an antenna must be of finite length, and the "end effect," i.e., the effect of finite rather than infinite length, leads to radiation characteristics showing considerable variation with frequency.

A planar antenna closely related to the biconical antenna, the "bow-tie" antenna, is likewise theoretically frequency-independent when infinite in size. The "end-effect" of an actual bow-tie antenna, however, limits the range of frequencies for which the radiation pattern is essentially constant to a bandwidth of 2 or 3 to 1.

It is known that "bow-tie" antennas can be modified in a way which reduces the "end-effect" to such an extent as to permit bandwidths of 10 to 1 or more to be achieved with structures of practical size. In general, this result is achieved by introducing periodic discontinuities along the marginal edges of the bow-tie antenna, the geometry of the discontinuities being such that all dimensions involved are directly proportional to the distance from the feed point of the antenna, i.e., the vertex or the narrowest portion of the "bow-tie." Planar antennas of this type have bidirectional radiation patterns extending perpendicularly to the plane of the antenna.

It has now been found that the above-described modified planar "bow-tie" antennas can be further modified to exhibit unidirectional radiation patterns while maintaining the broadbandwidths which such antennas possess. The unidirectional radiation patterns are achieved by rotating one half of the "bow-tie" about an axis passing through the vertex in the plane of the antenna perpendicular to the line which bisects both halves of the antenna, so that the antenna is no longer planar. In the preferred embodiments of the invention, the angle formed at the vertex by the planes of the halves of the antenna lies within the range from about 30° to about 100°.

The construction of the antennas of the present invention will be better understood from the following detailed description thereof, in which reference is made to the accompanying diagrams, wherein:

FIGURE 1 is a plan view of an antenna embodying the features of the invention.

FIGURE 2 is a side view of the antenna shown in FIGURE 1.

FIGURES 3, 4, 5 and 6 are typical radiation patterns for the antenna of FIGURE 1.

FIGURE 7 is a sketch identifying the co-ordinate system used in FIGURES 3, 4, 5 and 6.

As shown in FIGURE 1, the antennas of the present invention comprise two identical substantially V-shaped, electrically conducting elements, each of which is partially defined by intersecting straight lines (e.g., AO and OD) the apexes of said elements almost meeting (i.e., no electrical connection) at point O (the feed-point of the antenna). The marginal edges of each element (e.g., AO

and OD) contain a plurality of similar slots and teeth bounded by straight lines (e.g., EO and AO) and arcs of concentric circles having their common center at the feed-point (O) and having radii R_1, R_2, . . . , R_n, R_{n+1}, and r_1, r_2, . . . , r_n, r_{n+1}. The radii R_1, R_2, . . . and r_1, r_2, . . . form a geometric series of terms wherein the geometric ratio of terms in the series is defined by

$$\tau=\frac{R_{n+1}}{R_n}=\frac{r_{n+1}}{r_n}=\text{a constant less than 1.}$$

The radii r_1, r_2, . . . bear a constant relationship to radii R_1, R_2, . . . which is defined by

$$\sigma=\frac{r_n}{R_n}=\text{a constant greater than } \tau \text{ and less than 1.}$$

The value of σ thus determines the width of the slots and teeth.

It can be seen that, because of the geometry of the antenna as defined above, the dimensions of any tooth (or slot) are directly proportional to its distance from the feed point.

Referring to FIGURE 2, a side view of the antenna of FIGURE 1, it can be seen that an angle ψ (less than 180°) exists between the elements of the antenna. This configuration is produced from the similar planar antenna by rotating one of the elements about an axis lying in the plane of the antenna, said axis passing through the feed point perpendicular to the line bisecting the vertex angles of the elements.

Infinite antenna structures of the type of the invention have the property that, when energized at the vertex, the fields at a frequency f_1 will be repeated periodically at all other frequencies given by $\tau^n f_1$ where n may take on any integral value. The parameter τ determines what may be considered the bandwidth of a period of operation. That is,

$$\frac{f_2}{f_1}=\tau$$

where f_1 and f_2 are two frequencies exactly one period apart ($f_1>f_2$). The shape of the antenna structures of the invention is such that the variation of the radiation pattern and impedance is small over one period, and because of the periodically repeating nature of the fields, the same will be true for all periods, the result being an extremely broadband antenna. For the finite structures of the invention it has been found that the fields along the antennas decay very rapidly after passing a point where a resonant discontinuity, such as a tooth one quarter wavelength long, exists. This decay of the field causes the "end effect" of the antennas of the invention to be small, so that wide bandwidths are readily obtained with structures of finite size.

The lower and upper limits of the frequency band in which the radiation patterns are independent of frequency are determined by the longest and the shortest teeth, respectively, in the antenna. The low frequency limit is that for which the longest teeth are ¼ wavelength long. Likewise, the high frequency limit is that for which the shortest teeth are ¼ wavelength long. It can therefore be seen that the bandwidth of the antenna can be adjusted as desired by making the shortest and the longest teeth in the antenna correspond to ¼ wavelength of the desired frequency limits.

It is known that for planar antennas, including the planar versions of the antennas of this invention (i.e., $\psi=180°$), any antenna which has the same shape as its complement has a constant impedance which is independent of frequency. The complement of a planar antenna is defined as the portion of the plane which is not covered by the original antenna: when an antenna and its complement are fitted together they cover the whole

plane without overlapping. It is preferred that the antennas of the invention be self-complementary in the plane in order to minimize the variation of impedance with frequency. This can be accomplished in the antenna of FIGURE 1, for example, by making the sum of angle α and angle β equal to 90°.

Although the particular embodiment of FIGURE 1 (i.e., in which the slots and teeth are defined by circular arcs) is preferred, the invention is not limited thereto. Other types of discontinuities can be used along the edges of the antenna, such as trapezoids, triangles, etc., provided that the dimensions of all such discontinuities are proportional to the distances from the feed point. Regardless of the actual configuration used for the discontinuities, it is preferred that all discontinuities in a given antenna have similar shapes.

It can be seen that the antenna of FIGURE 1 possesses no axis of symmetry but is symmetrical about the feed point only when the elements are coplanar, i.e., when $\psi=180°$. Symmetry about the feed point is defined as a configuration such that for every point in the antenna falling on a straight line passing through the feed point, there exists a corresponding point on the same line at an equal distance on the other side of the feed point. Although antennas made in accordance with the invention which possess one or more axes of symmetry exhibit some broadband characteristics, the bandwidths thereof are in general inferior to those of antennas which are symmetrical about the feed-point only, and which are therefore preferred.

In the preferred embodiment the same arcs which define the teeth and slots at one marginal edge of one of the elements of the antenna also define the teeth and slots on the other marginal edge of the same element. However, in order to avoid symmetry about any axis, the slots and teeth on the edges are arranged such that each tooth has a corresponding slot and each slot has a corresponding tooth on the opposite edge of the element at the same distance from the feed point, the corresponding slot or tooth being a mirror image of the tooth or slot to which it corresponds.

In order to demonstrate the performance of the antennas of the invention, a number of antennas of the type shown in FIGURE 1 were constructed of light gauge copper sheet, approximately 1/32 inch thick. The periodic discontinuities were in the form of teeth defined by arcs of circles connected to a sector-shaped central conducting strip. In order to maintain an equi-complementary condition, the sum of angles α and β was made equal to 90°. A small area near the center of the antenna was left as solid conductor since continuation of the teeth in that direction requires an infinite number of teeth of zero width in the limit. For all models tested, the ratio σ, as defined above, was taken equal to the square root of the ratio τ, also defined above, providing a ratio of tooth to slot width which is the same for all rows of teeth. This, however, is not a necessary condition since σ can assume any value greater than τ but less than 1.

Example I

An antenna of the type of FIGURE 1 was constructed with the following values affixed to the variables:

$R_1=9$ inches
$\tau=0.81$
$\sigma=\sqrt{\tau}$
$\alpha=45°$
$\beta=45°$

The antenna was fed across the vertex with a coaxial line having its outer conductor bonded to one half of the antenna and its inner conductor extended across the vertex and connected to the other half. The radiation patterns for this antenna were measured at a frequency of 1400 mc. of various values of angle ψ. The effect of rotating the elements of the planar antenna out of the plane about an axis passing through the vertex was to cause it to radiate more in one direction than in the other. The front to back ratio was found to increase as the angle ψ was reduced, the change being gradual down to about 100°, with a rapid increase as the angle was further reduced. The radiation patterns for four values of ψ are shown in FIGURES 3, 4, 5 and 6. In FIGURES 3–6 the vertical axis at 12 o'clock represents $\theta=0°$, and the radiation patterns are orientated on this basis. The designation $\phi=90°$ represents a constant condition applicable to each figure, indicating that the radiation patterns are those taken in the $\phi=90°$ plane (i.e., the YZ plane as seen in FIGURE 7). The E_θ variations represent the horizontally (i.e., YZ plane) polarized component of the beam while the E_ϕ variations represent the vertically (i.e., perpendicular to the YZ plane) polarized component of the beam. It can be seen that excellent unidirectional performance was obtained as a result of inclining the elements of the antenna as described.

The electric field produced by an antenna of the invention lies in the horizontal or YZ plane when the antenna is positioned as shown in FIGURE 7. It is, therefore, evident that the polarization of these antennas differs from that of a dipole having its arms folded to form a V, which has its electric field in the plane determined by the elements of the folded dipole.

It was further found that the radiation patterns for this antenna were independent of frequency over a bandwidth of more than 10 to 1. In addition, the bandwidth was found to be independent of angle ψ for the range from 30° to 100°.

Several additional models identical to that of Example 1 except for values of τ were tested. Essentially no change was noted in the radiation patterns as τ was reduced until a value of 0.5 was reached, at which point beamwidth and pattern variations were noted for the smaller values of ψ. Although the patterns remained essentially intact, they were inferior in frequency independence to those obtained for the higher values of τ, which are accordingly preferred.

Example II

An antenna similar to that of Example 1 was constructed having the following parameter values:

$R_1=9$ inches
$\tau=0.7$
$\sigma=\sqrt{\tau}$
$\alpha=60°$
$\beta=30°$

The radiation patterns for this antenna were found to be similar to those for the antenna of Example 1.

The input impedance of the non-planar antennas of the invention exhibit somewhat more variation with frequency than is found in the similar planar antennas, which variation increases with decreasing values of ψ. The impedance characteristics of the antennas tested were found to be essentially the same for all models, showing little variation with the values of τ and tooth angle α. The mean resistance level, however, was found to decrease with decreasing ψ, ranging from 165 ohms at $\psi=180°$ to approximately 70 ohms at $\psi=30°$.

The two halves of the antennas of the invention are fed at the vertices thereof either with a balanced two wire line or with a coaxial line having the outer conductor bonded to the vertex of one half of the antenna and the inner conductor attached to the vertex of the other half. In either case there should be no electrical connection between the halves of the antenna (other than through the transmission line) in order to avoid a short-circuit.

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. An antenna comprising a pair of opposed electrically conducting substantially V-shaped elements lying in different planes, the apexes of said elements being immediately adjacent each other and together constituting the feed point of said antenna, said elements forming an angle at said feed point of about 30° to about 100°, each of said elements having an outline partially defined by a respective pair of intersecting straight lines, the edges of each of said elements defined by said straight lines containing a plurality of alternating slots and teeth, the dimensions of each of said slots and teeth being proportional to its distance from said feed point.

2. A non-planar antenna comprising a pair of opposed planar, electrically conducting, substantially V-shaped elements lying in different planes, the apexes of said elements being adjacent each other and together constituting the feed point of said antenna, the planes of said elements forming an angle at the feed point of about 30° to about 100°, each of said elements comprising an imperforate central sector shaped portion and slotted sector-shaped portions of equal angular width on either side of said central portion, said slotted portions containing a plurality of alternating slots and teeth, the dimensions of each of said slots and teeth being proportional to its distance from said feed point.

3. An antenna as described in claim 2 which is equal to its complement.

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