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J. D. DYSON

2,958,081

UNIDIRECTIONAL BROADBAND ANTENNA COMPRISING MODIFIED BALANCED EQUIANGULAR SPIRAL

Filed June 30, 1959

2 Sheets-Sheet 1

Fig. 4.

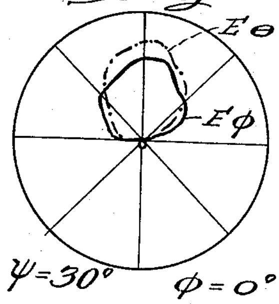
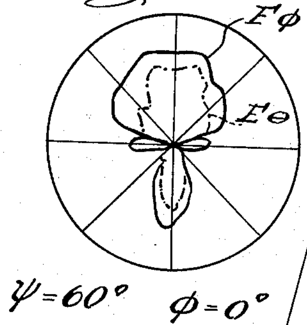


Fig. 3.



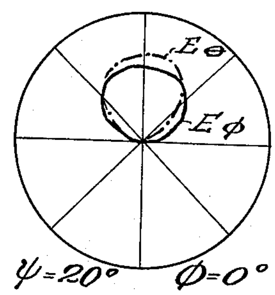


Fig. 5.

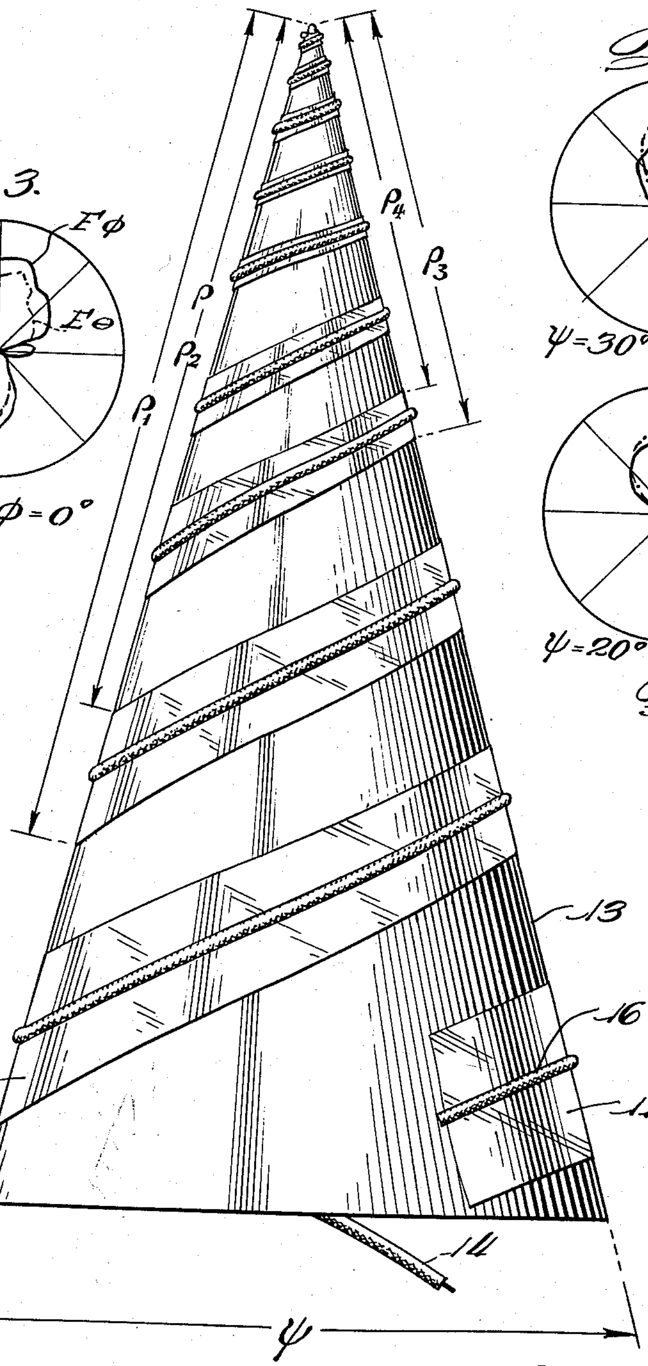


Fig. 1.

Inventor
John D. Dyson
By Merriam, Lorch & Smith
Attorneys

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Fig. 2.

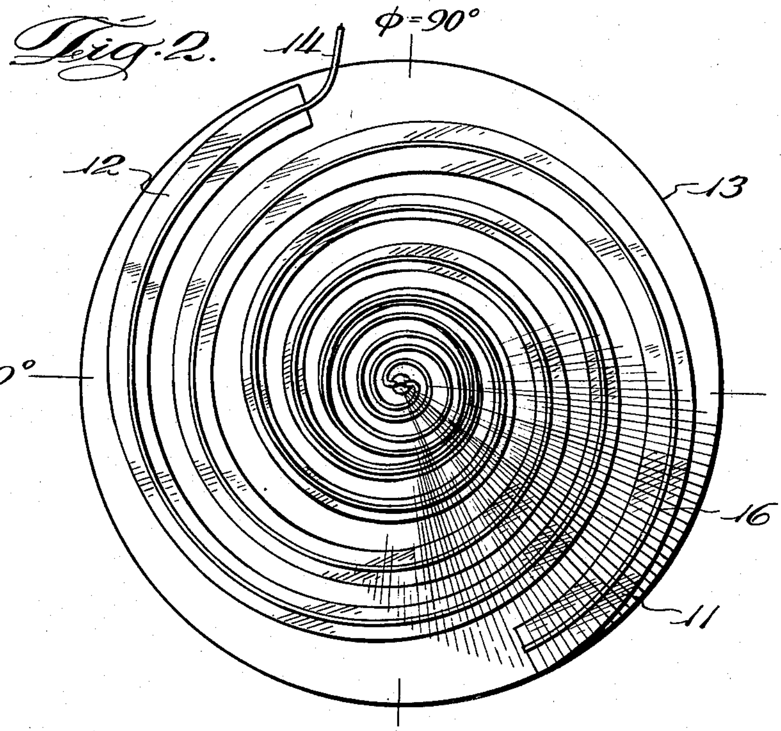
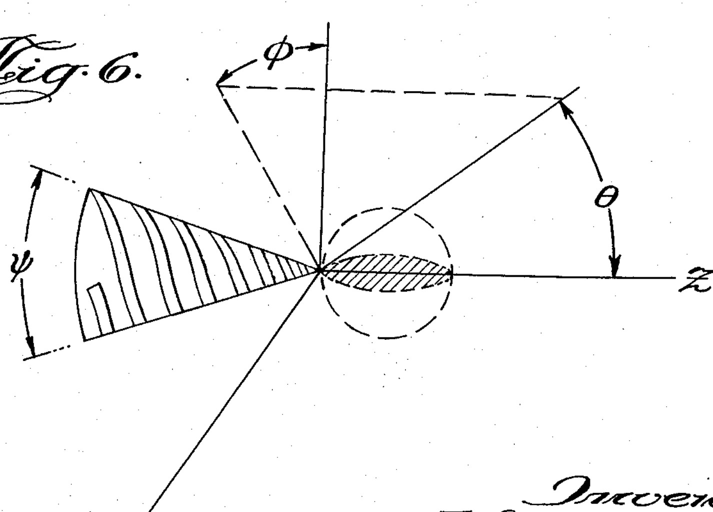


Fig. 6.



Inventor
John D. Dyson
By Merriam, Loch & Smith
Attorneys

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UNIDIRECTIONAL BROADBAND ANTENNA COMPRISING MODIFIED BALANCED EQUIANGULAR SPIRAL

John D. Dyson, Champaign, Ill., assignor to University of Illinois Foundation, a corporation of Illinois

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8 Claims. (Cl. 343—895)

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 if the shape of an antenna were such that it could be specified entirely by angles, the antenna would make an ideal broadband radiator, since its operation would be theoretically independent of frequency. All antennas which meet this criterion, however, are infinite in extent, so that it is necessary to specify at least one length for an antenna of finite size. By making this one length very large compared with the wavelength of operation of a given antenna, it is possible in some cases to achieve antenna performance which is practically independent of wavelength over wide bandwidths.

An antenna which can be made to have a very wide band of operations in which performance is independent of wavelength is the balanced equiangular spiral antenna. The one specified length for this antenna, the arm length, need not be large compared to a wavelength, and in fact need only be comparable to a wavelength at the lowest frequency of operation to obtain performance essentially independent of frequency. This antenna comprises two coplanar spiral arms, each arm being defined by two identical equiangular spiral curves, one rotated through a fixed angle around the origin (i.e., the central point of the antenna) with respect to the other. The arms themselves are also identical in shape, one being rotated through an angle of about 180° from the position of the other. Planar antennas of this type have broadband bidirectional radiation patterns extending perpendicularly to the plane of the antenna.

It has now been discovered that the balanced equiangular spiral antennas described above can be modified to exhibit unidirectional radiation patterns while maintaining the broad bandwidths which such antennas possess. The unidirectional radiation patterns are achieved by wrapping a planar balanced equiangular spiral antenna on the surface of a cone and feeding the antenna at the apex thereof by a feed cable carried along one arm. Such antennas exhibit substantially symmetric radiation patterns having a maximum on the antenna axis off the apex of the cone.

The construction of the antennas of the invention will be better understood from the following detailed description thereof taken in conjunction with the accompanying diagrams in which:

Figure 1 is a plan view of an antenna embodying the features of the invention;

Figure 2 is a top view of the antenna shown in Figure 1;

Figures 3, 4, and 5 are typical radiation patterns for the antenna of Figure 1; and

Figure 6 is a sketch identifying the coordinate system used in Figures 3, 4, and 5.

As can be seen from Figures 1 and 2, the antenna of the invention comprises two spiraling arms **11** and **12** which are wound on the surface of an electrically

nonconductive cone **13**. As shown, a small portion of the cone near the apex is truncated, since it would be physically impossible to construct this portion of the antenna because of the extremely small size of the arms in this region.

Figure 2, the top view of the antenna of Figure 1, shows a projection thereof on a plane surface. In such a projection the two arms of the antenna are each defined by an equiangular (or logarithmic) spiral. An equiangular spiral is a plane curve which may be defined by the equation:

$$\rho = ke^{a\phi}$$

or

$$a\phi = \ln\frac{\rho}{k}$$

where ρ and ϕ are the conventional polar coordinates and a and k are positive constants.

The equiangular spiral curve derives its name from one of its properties, namely, the fact that the angle formed by a radius vector and a tangent to the curve at the point of intersection with the radius vector, is always constant. The constant a determines the rate of spiral of the curve and the constant k determines the physical starting point of the curve when $\phi=0$, as will be apparent to those skilled in the art.

Considering the plane curves shown in Figure 2 (that is, the projection of the outlines of the arms of the actual antenna) it will be seen that the outer and inner edges of both arms are defined by the same curve which is rotated about the origin or central point of the figure. Thus, for example, consider the outer edge of arm **11**. This curve can be represented by an equation of the form.

$$\rho_1 = ke^{a\phi}$$

The inner edge of arm **11** is actually the same curve as that defining the outer edge, except that it has been displaced about the origin through an angle δ. The equation of the inner edge of arm **11** may therefore be represented by

$$\rho_2 = ke^{a(\phi-\delta)} = K\rho_1$$

where

$$K = e^{-a\delta}$$

In a similar manner it will be seen that the curves defining arm **12** are identical with those defining arm **11** but have been rotated through 180° (π radians) and thus have the equations

$$\rho_3 = ke^{a(\phi-\pi)}$$

for the outer edge and

$$\rho_4 = ke^{a(\phi-\pi-\delta)} = K\rho_3$$

for the inner edge.

A planar antenna having the form depicted in Figure 2 has a bidirectional radiation pattern extending perpendicularly to the plane of the paper on which the figure is printed. By wrapping the arms of the antenna about a cone **13** of a suitable electrically insulating material, such as styrofoam, as shown in Figure 1, the radiation pattern of the antenna becomes unidirectional with the maximum lying off the apex of the cone, as shown in Figure 6.

The curves defining the edges of the arms of the antenna shown in Figure 1 can be described by equations similar to those used for the planar version thereof, with the introduction of an additional variable, the cone angle ψ. The radial distance along the surface of the cone (extended if required) from the vertex to the outer edge of one arm (e.g., 11) is given by the equation

$$\rho_1 = ke^{\left(a \sin\frac{\psi}{2}\right)\phi} = ke^{b\phi}$$

where

$$b = a \sin \frac{\psi}{2}$$

and ψ is the included cone angle.

The inner edge of arm **11** is defined by

$$\rho_2 = ke^{b(\phi-\delta)} = K'\rho_1$$

where

$$K' = e^{-b\delta}$$

The edges of the other arm (i.e., **12**) are defined by the equations

$$\rho_3 = \rho_1 e^{-b\pi}$$

(outer edge) and

$$\rho_4 = K'\rho_3$$

(inner edge).

It can be seen that for an included cone angle, ψ, of 180° (i.e., the planar form of the antenna) the above equations reduce to the form

$$\rho_1 = ke^{a\phi}, \ \rho_2 = K\rho_1, \text{ etc.}$$

as previously described.

As in the case of its planar version, the performance of the conical antenna of the invention is not dependent on the constants given in the equations to any marked degree. Except for the fact that the more tightly wound antennas have somewhat smoother and slightly more rotationally symmetric patterns (determined by the value given to "a"), the rate of spiral rotation has only a secondary effect on the shape of the radiation pattern. Likewise, the value of K may vary considerably without seriously affecting the performance of the antenna.

The arms of the antenna are made of an electrically conducting material, suitably sheet copper, aluminum, or the like. The feed cable **14** comprises a coaxial cable carried by one of the arms, e.g., **12**, the outer conductor of the cable being bonded to the arm and the inner conductor being electrically connected to the other arm (i.e., **11**) at the vertex. In order to maintain the physical symmetry of the antenna a dummy feed cable **16** may be bonded to arm **11** in a manner similar to that used with cable **14**. This method of feeding the antenna and the dummy cable are not an essential requirement of the invention but are helpful in achieving the maximum bandwidth of which the antenna is capable.

The antennas of the invention can be constructed in any suitable manner. A preferred method is by drawing the outline of the arms on the development of the cone, which drawing is then transferred by a silk screen process to a thin copper-clad Teflon impregnated glass cloth. After forming the arms by etching away the undesired portions of the copper cladding, the base material is formed into a cone and the arms are soldered along the joint. The cone thus formed can be supported by any of the well-known materials which are efficient insulators at high frequencies, such as polystyrene. Since the cone of insulating material is not an essential part of the antenna and is used only to support the arms, it can be eliminated if the arms are made of a rigid material, such as a sheet of copper strong enough to support its own weight.

The upper frequency limit of the band of operation for the antennas of the invention is determined by the fineness of the construction of the spiral at the feed point, i.e., at the vertex of the cone. Since equiangular spiral curves converge to a point as a limit at the origin, it is necessary in a practical structure to terminate the central portion in a small straight or tapered section. The upper cut-off frequency of the antenna is the frequency at which the truncated apex of the cone becomes approximately ¼ wavelength in diameter. As an example, for a termination of the apex at a 1-inch diameter the upper frequency limit is approximately 3000–4000 mc.

The operating bandwidth is at the control of the designer. The low frequency limits are affected by the length and the width of the arms of the antennas and hence the diameter of the base of the cone, and are independent of the upper frequency limit. Thus, for example, the low frequency limit can be lowered by increasing the arm length and/or by increasing the width of the arms. As an example, for a cone angle ψ of 20°, and parameters of the order of $K=.85$ to .9 and $b=.053$, an apex diameter of ¼ wavelength at the highest frequency of operation and a base diameter of approximately ⅜ wavelengths at the lowest frequency of operation should provide patterns with a front to back ratio of 15 db or greater and essentially circularly polarized radiation.

Although in the preferred form the antennas of the invention have arms each edge of which is defined by an equiangular spiral, so that the width of each arm constantly increases at increasing distances from the apex of the cone, it is also possible to construct practical antennas having advantageously wide bandwidths in which the width of the arm is constant or essentially constant. Thus, for example, antennas in which the arms consist of coaxial cables alone, arranged to follow equiangular spiral paths, have acceptable patterns, although they may not have as low a frequency capability for any given antenna size as the wider true equiangular spiral structures. These "wire" versions of the antenna can most conveniently be constructed from rigid wall coaxial cable and are advantageous for use at the UHF and VHF frequencies.

The practical results which are obtainable with the antennas of the invention are demonstrated by an antenna defined by the constants $a=0.303$ and $K=0.925$ with arms 150 cm. in length. This antenna was wrapped on conical surfaces made of styrofoam, having cone angles ranging from 60° to 20°. The radiation patterns obtained with these antennas at a frequency of 2000 mc. are shown in Figures 3, 4, and 5. Figure 3 shows the radiation pattern for a cone angle of 60°, Figure 4, a 30° cone angle, and Figure 5, a 20° cone angle. It can be seen that as the cone angle drops below 60°, there is a marked increase in the ratio of front to back radiation. The absence of back radiation for $\psi=20°$ (Figure 5) is evident. For all these antennas there was no basic tilt to the patterns and the lobes were rotationally essentially symmetric. The patterns rotate with frequency but this rotation is masked in the symmetrical structure since the pattern beamwidth is independent of the angle ϕ. As an example, the beamwidth for the pattern as shown in Figure 5 at 2000 mc. is 70°±2° for $E\phi$ polarization and 90°±3° for $E\phi$ polarization for any angle ϕ. The average beamwidths of the same antenna on a 30° cone (Figure 4) are approximately 80° and 100°.

Antennas in accordance with the invention can be made to have bandwidths of 10 to 20 or more to 1 over which the radiation patterns and input impedance are essentially constant. In order to obtain the maximum bandwidth, however, it should be noted that these are balanced antennas and a balanced feed is necessary for optimum performance. The feed may be brought in perpendicular to the antenna by a balanced feed line or by an unbalanced line and balancing transformer or balun. The bandwidth of this latter method, of course, depends upon the bandwidth of the balun. The rapid decay of the current along the arms however, makes possible the previously mentioned highly useful method of feeding the balanced antenna with an unbalanced transmission line. The cable is bonded to the ground screen between the arms of the metal structure and is carried to the origin where the center conductor is tied to the opposite arm. Since the ends of the antenna arms do not carry appreciable antenna currents except at the very lowest frequency of operation, the arms themselves act as an "infinite balun," the feed terminals are isolated from ground in a balanced manner and the outside of the feed cable beyond the antenna arm does not carry a significant amount of antenna current. However, as the frequency of operation is decreased a point will be reached where the presence and location of this cable alters the radiation pattern. This frequency, however, is below that at which the antenna should be expected to operate satisfactorily. In order to compensate for the presence of the feed cable insofar as possible, a dummy cable may be placed on the other arm to maintain physical symmetry.

The input impedance of the antennas of the invention remains relatively constant over a wider frequency range than the usable pattern bandwidth.

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 unidirectional broadband antenna comprising two substantially identical electrically conducting elements wound so as to lie on a conical surface, each of said elements having at least one edge which projected on a plane perpendicular to the axis of said conical surface is substantially in the form of an equiangular spiral, the first of said elements being displaced from the second of said elements by rotation through an angle of about 180°.

2. The antenna of claim 1 wherein the cone angle of said conical surface is less than about 60°.

3. A unidirectional broadband antenna comprising two substantially identical electrically conducting elements wound so as to lie on a conical surface, each of said elements being defined by a pair of curves which when projected on a plane perpendicular to the axis of said conical surface have the form of equiangular spirals, the first of said elements being displaced from the second of said elements by rotation about the axis of said conical surface through an angle of about 180°.

4. The antenna of claim 2 wherein the cone angle of said conical surface is less than about 60°.

5. A unidirectional broadband antenna comprising two substantially identical elements formed of a thin electrically conducting sheet material, said elements being wound so as to lie on a conical surface, the first of said elements being partially defined by the curves having the equations

$$\rho_1 = ke^{\left(a \sin \frac{\psi}{2}\right)\phi}$$

and

$$\rho_2 = ke^{\left(a \sin \frac{\psi}{2}\right)(\phi-\delta)}$$

the second of said elements being partially defined by the curves

$$\rho_3 = ke^{\left(a \sin \frac{\psi}{2}\right)(\phi-\pi)}$$

and

$$\rho_4 = ke^{\left(a \sin \frac{\psi}{2}\right)(\phi-\pi-\delta)}$$

where ρ represents the distance along the conical surface from the apex to any point on one of said curves, e is the natural logarithm base, ψ is the cone angle of the conical surface, ϕ is the angle of rotation from a base line in a plane passing through the apex of said conical surface perpendicular to the axis thereof, to the projection in said plane of the line representing the distance ρ, and a, k and δ are constants.

6. The antenna of claim 5 wherein ψ is an angle of less than about 60°.

7. The antenna of claim 5 which is fed at the apex by a feed cable which is carried on one of said elements.

8. The antenna of claim 7 in which a dummy feed cable is carried by the other of said elements.

No references cited.