343-754 CROSS REFERENCE SEARCH ROOM

March 17, 1959 J. L. BUTLER 2,878,470

# CONICAL BEAM ANTENNA SYSTEM

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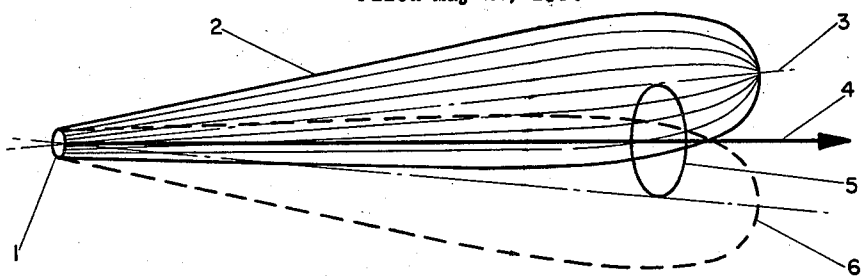



Fig. 1

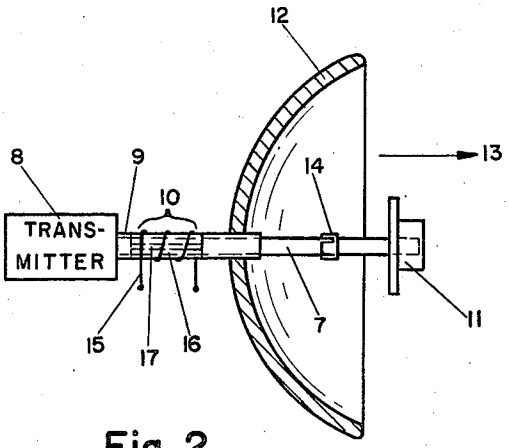



Fig. 2

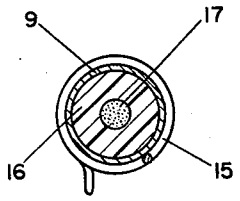



Fig. 3

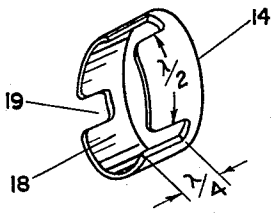



Fig. 4

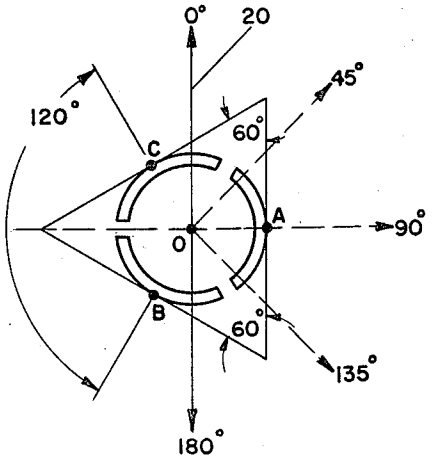



Fig. 5

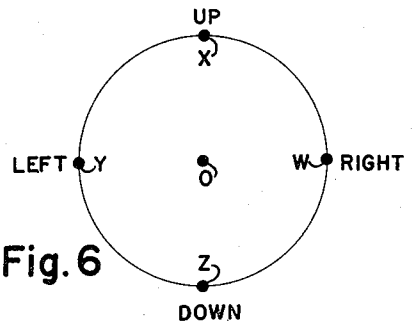



Fig. 6

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# CONICAL BEAM ANTENNA SYSTEM

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Application May 27, 1954, Serial No. 432,740

7 Claims. (Cl. 343—763)

The present invention relates to the art of radiating electromagnetic energy. More particularly, this invention relates to conical scanning systems such as are used for the directive radiation and reception of high frequency electromagnetic energy in certain systems of radar and guidance control.

In the prior art, various systems have been proposed for developing a conical beam of electromagnetic energy by causing the beam to rotate about the axis of the antenna system. This type of beam rotation is generally known in the art as "conical scanning." It is to be distinguished from the azimuth and elevation scanning functions of the system as a whole.

Conical scanning systems, as employed in the prior art, are characterized by the use of essentially mechanical rotational systems. The rate of conical scanning which is required, in contemplated modern radar techniques, is unattainable by such mechanical systems. A further disadvantage of prior art systems involves their construction techniques which cause shadows in the path of the radiated beam.

It is therefore an object of the invention to provide an improved conical scanning antenna system having an ultra high speed conical scanning capacity.

Another object of the invention is to provide an improved conical scanning antenna capable of being fed from behind the principal reflector.

It is a further object of the invention to provide an improved ultra high speed conical scanning antenna system having no mechanically moving parts.

Other and further objects of the present invention will be apparent from the following description of a typical embodiment thereof, taken in connection with the accompanying drawings.

In accordance with the invention there is provided a conical beam antenna system. The system includes a source of plane-polarized electromagnetic energy having a path of propagation. An annular radiating member is disposed coaxial with the path. The radiating member has three radiating elements circumferentially disposed at equal angles in a plane perpendicular to the path. Means are provided in the path of propagation for rotating the electric vector of the energy. Excitation of the radiating member by the energy develops an offset beam of the energy which rotates about the path at a multiple of the frequency of the rotating vector, thereby providing a rotating conical beam of the energy.

The novel antenna system disclosed in this specification is related to systems disclosed in concurrent applications 430,924 and 490,649 by the same inventor. The application 430,924 is directed, in general, to an antenna system utilizing a novel annular radiator. The application 490,649 is directed, in general, to an antenna system in which the electric vector of the electromagnetic energy is rotated with respect to a stationary annular radiator by means of a rotating antenna element. The present application is, in general, directed to the broad



concept of obtaining high-speed scanning by utilizing a rotating electric vector in combination with a three element radiating member and, in particular, to the combination of an electromagnetic gyrator to effect rotation of the electric vector with respect to the annular radiator.

In the accompanying drawings:

Fig. 1 is a schematic diagram illustrating conical scanning as provided by the present invention;

Fig. 2 is a side view, partly in section, of a preferred embodiment of the present invention;

Fig. 3 is a cross-sectional view of the gyrator in Fig. 2 taken at its center;

Fig. 4 is an enlarged, detailed perspective view of a radiating member as used in the embodiment of Fig. 2;

Fig. 5 is a schematic diagram illustrating the operation of the invention; and

Fig. 6 is a graph illustrating the operation of the invention.

Referring now in more detail to the drawings and with particular reference to Fig. 1, an antenna system indicated at **1** is illustrated as radiating a beam **2** of electromagnetic energy. The main axis **3** of the beam is caused to rotate about the antenna system axis or boresight **4**, as shown. The rotating or circular motion of the beam axis **3** is indicated by the path **5**. The extreme lower position of the beam is illustrated by the phantom lines **6**. This rotation of the beam thus provides what is known as "conical scanning."

Referring now to Fig. 2, in an antenna system embodying the present invention, a primary radiator comprising a dielectric rod **7** coupled at its opposite ends to a cylindrical wave guide **9** and reflector **11**, develops a beam of electromagnetic energy for the system. The rod **7** may be fabricated, for example of polystyrene, having an outer diameter of .625 inch. The reflector **11** may be fashioned from aluminum with the reflecting surface 2 inches in diameter. The cylindrical part of the reflector **11** may be approximately a quarter-wave length long at the operating frequency, for example .2 inch at 10 kilomegacycles. The guide **9** may be formed of copper tubing having an outer diameter of .75 inch. A transmitter **8** is coupled to the rod **7** through the cylindrical wave guide **9**. Part of the guide includes an electromagnetic gyrator as shown at **10**. The radiator **7** is connected to a reflector **11** which reflects energy in the direction of a paraboloidal reflector **12**. The paraboloid forms the energy into a beam that is radiated in the direction as shown at **13**. A secondary radiator, comprising a metallic annular member **14** having three slots formed therein, is mounted on the rod **7**, as shown. The member **14** is located substantially at the focus point of the paraboloid **12**.

The gyrator **10**, as shown in cross-section in Fig. 3, comprises a coil **15** designed to produce a longitudinal magnetic alternating field in the guide **9** at a frequency, for example, of 100,000 cycles. Within the guide a cylindrical insulator **16** (for example, Rexolite which is a material manufactured by Rex Corporation, West Acton, Massachusetts, and having an outer diameter of .625 inch with a .25 inch hole passing centrally therethrough) is disposed. Within the .25 of an inch hole is disposed a rod **17** of ferro-magnetic material. The term ferro-magnetic as used herein includes paramagnetic as distinguished from diamagnetic. The rod **17** may be, for example, 2.4 inches long and .234 inch in diameter and composed of ML 1331 ferrite material such as manufactured by General Ceramics and Steatite Corporation.

Referring now to Fig. 4, the radiating member **14** (formed for example of copper of .050 of an inch thickness) comprises three radiating elements **18** a half-wave length long at the operating frequency. The slots **19** are a quarter-wave length deep at the operating frequency,

as shown. The slots function electrically like resonant quarter-wave length transmission line sections and, therefore, present a very high impedance across the openings although they are apparently short-circuited at the other end. It is to be noted that the centers of the elements and the slots are respectively disposed substantially 120 degrees apart.

Microwave energy characterized by an electric vector having, for example a horizontal polarization (90 degrees) is coupled to the guide **9** in the well-known manner. A relatively high frequency modulating voltage, for example 100,000 cycles, is applied to the coil **15** to cause an alternating magnetic current to flow longitudinally through the ferrite rod **17**. In accordance with the so-called ferro-magnetic Farraday effect as applied to microwave energy, the magnetic current parallel to the rod **17** causes the electric vector of the energy passing therethrough to rotate in accordance with the variations of the magnetic current. (See Farraday effect as outlined by J. H. Rowen in an article entitled, "Ferrite and Microwave Applications," published in the Bell System Technical Journal, volume 32, No. 6, November 1953.)

The amount of rotation that takes place is also a function of the length and diameter of the ferrite rod. In the preferred embodiment, the electric vector rotates plus or minus 90 degrees, that is to say, 180 degrees clockwise and 180 degrees counter-clockwise in accordance with the maximum amplitudes in opposite polarities of the magnetic field.

The operation of the system can be better understood with particular reference to Figs. 5 and 6. Electromagnetic energy incident upon the member **14** may be assumed then to be characterized by a rotatingly polarized electric vector **20** which rotates clockwise from 0 to 180 degrees and counter-clockwise from 180 to 0 degrees. The energy radiated by the elements A, B and C may be described with reasonable accuracy by assuming the elements to be linear dipoles oriented along lines tangent to their respective centers. A dipole (half-wave length) element radiates a maximum amount of energy when oriented in parallel with the electric vector, and a minimum or substantially zero amount when it is perpendicular to the electric vector. In particular, such an element radiates energy in accordance with the expression:

$$\rho = k \cos^2 \theta.$$

In the above expression $\rho$ equals the electromagnetic energy radiated by the dipole having an electric vector parallel to the electric vector **20**; $k$ is a constant and $\theta$ is the angle between the dipole element and the electric vector **20**. In this case, the dipole elements A, B and C form arcs of a circle and the angles $\theta_i$ may be taken as the angles between their respective center tangent lines and the electric vector **20**.

Of particular significance in the present invention is the characteristic of the radiating member **14**, whereby a single rotation of the electric vector clockwise from 0 to 180 degrees and from 180 to 0 degrees effects two rotations of the resultant beam of energy, 360 degrees counter-clockwise and 360 degrees clockwise, respectively, as will be shown presently. In Fig. 5 the tangent lines of the respective elements are disposed substantially in the form of an equilateral triangle, as shown; hence, the centers of the radiating elements are radially disposed substantially 120 degrees apart. Varying the radiation of each dipole element causes the resultant beam to be radiated in the direction of the element exhibiting maximum radiation.

In describing the displacement of the resultant beam it is helpful to assume that Cartesian Coordinate System in which the X-axis coincides with the horizontal axis and the Y-axis with the vertical.

The radiation center (RC) of the beam will be a function of the instantaneous radiation of each element and its position. In particular:

$$RC_X = \sum_{i=A}^{C} \frac{\rho_A x_A + \rho_B x_B + \rho_C x_C}{\rho_A + \rho_B + \rho_C}$$

and

$$RC_Y = \sum_{i=A}^{C} \frac{\rho_A y_A + \rho_B y_B + \rho_C y_C}{\rho_A + \rho_B + \rho_C}$$

where $x_i$ and $y_i$ equal coordinates of the radiation center of each element and $\rho_i$ equals the energy radiated by each element respectively.

Since the elements A, B and C are in fixed positions, the values for $x_i$ and $y_i$ may be readily calculated. Thus, assuming $x_A = x_{max} = y_{max} = 1$ unit of length:

$$x_B = x_C = -\cos 60° = -.5$$

and

$$y_A = 0,\ y_B = -\sin 60° = -.866 \text{ and } y_C = \sin 60° = 0.866$$

Assuming $k=1$ in the expression for $\rho$ above, the center of radiation of the resultant beam may be defined for the instantaneous positions of the electric vector **20**.

In particular, the positions of the center of radiation of the resultant beam for each 45 degree position of the vector **20**, as shown in Fig. 5, will be described. Fig. 6 graphically depicts the path of the center of the resultant beam.

When the electric vector **20** is oriented at 0 degrees, $\rho_A = \cos^2 \theta_A = \cos^2 0° = 1$, $\rho_B = \rho_C = \cos^2 \theta_B = \cos^2 60° = .25$ and

$\rho_A + \rho_B + \rho_C = 1 + .25 + .25 = 1.5$ units of energy. Substituting in the expression for $RC_X$ above:

$$RC_X = \frac{1 + (.25 \times -.5) + (.25 \times -.5)}{1.5} = \frac{+.75}{1.5} = .5$$

and

$$RC_Y = \frac{0 + (.25 \times -.866) + (.25 \times .866)}{1.5} = 0$$

From this analysis, it is clear that the beam is offset to the Right as illustrated in Fig. 6 by the point W. Thus, when the electric vector is oriented at 0 degrees, the beam is offset 90 degrees.

When the electric vector **20** is oriented at 45 degrees, $\rho_A = \cos^2 45° = .5$, $\rho_B = \cos^2 75° = .067$, $\rho_C = \cos^2 15° = .933$, and $\rho_A + \rho_B + \rho_C = .5 + .067 + .933 = 1.5$ units of energy. Then:

$$RC_X = \frac{(.5 \times 1) + (.067 \times -.5) + (.933 \times -.5)}{1.5} = 0$$

and

$$RC_Y = \frac{0 + (.067 \times -.866) + (.933 \times .866)}{1.5} = \frac{.75}{1.5} = 0.5$$

Accordingly, when the electric vector **20** is rotated 45 degrees clockwise the center of the beam rotates 90 degrees counter-clockwise and is now Up as indicated by the point X in Fig. 6.

When the electric vector **20** is rotated 90 degrees clockwise, $\rho_A = \cos^2 90° = 0$, $\rho_B = \rho_C = \cos^2 30° = .75$. Substituting in the expression for RC above:

$$RC_X = \frac{(.75 \times -.5) + (.75 \times -.5)}{1.5} = -.5$$

and

$$RC_Y = \frac{0 + (.75 \times -.866) + (.75 \times .866)}{1.5} = 0$$

Consequently, when the electric vector **20** is rotated 90 degrees clockwise, the center of the resultant beam rotates counter-clockwise 180 degrees and is now Left as indicated by the point Y in Fig. 6.

When the electric vector **20** is rotated 135 degrees,

clockwise, $\rho_A=\cos^2 45°=.5$, $\rho_B=\cos^2 15°=.067$, $\rho_C=\cos^2 75°=.933$ and $\rho_A+\rho_B+\rho_C=.5+.067+.933=1.5$ units of energy. Then:

$$RC_X=\frac{.5+(.933\times-.5)+(.067\times-.5)}{1.5}=0$$

and

$$RC_Y=\frac{0+(.933\times-.866)+(.067\times.866)}{1.5}=.5 \text{ units}$$

Hence, the beam is offset Down as indicated by the point Z in Fig. 6, for example, in response to a clockwise rotation of the electric vector of 135 degrees, the beam rotates counter-clockwise 270 degrees.

When the electric vector **20** is rotated 180 degrees the analysis is the same as that for 0 degree and the beam is offset again to the right, as indicated by the point W. It is to be noted that the center of the resultant beam rotates counter-clockwise 360 degrees, while the electric vector **20** rotates clockwise 180 degrees. It is obvious, from the above description, that when the electric vector rotates counter-clockwise from 180 degrees back to 0 degree, the center of the beam rotates clockwise another 360 degrees. If the vector **20** continuously rotates in the same direction, the beam would be characterized by a rotating polarized electric vector, and the resultant beam would rotate at twice the frequency of vector rotation.

In the preferred embodiment the conical scanning rate is 200 kilocycles per second (alternate counter-clockwise and clockwise) in response to 100 kilocycles per second frequency of gyration.

It is to be noted that as shown in Fig. 2 an antenna system embodying the present invention does not require supporting studs and minimizes structure in front of the paraboloid that can cause shadows in the path of the radiated energy.

Although the description as noted above has been limited to a discussion of a so-called tripole radiator, that is, the use of three radiating elements that are disposed radially about the axis of the paraboloid, the application of the present invention to devices that vary in transparency with respect to the radiated energy in some manner or selectively refract the radiated energy in accordance with relative angular positions are clearly contemplated within the present invention. Such devices are outlined in my copending applications: Serial No. 427,146 dated May 3, 1954; Serial No. 429,633 dated May 13, 1954; and Serial No. 428,933 dated May 11, 1954.

Antenna systems embodying the present invention are capable of literally unlimited scanning rates relative to the frequencies currently contemplated for such systems. Certainly the conical scanning rates possible with this system exceed the requirements of any detection system known in the prior art.

While there has been hereinbefore described what is at present considered a preferred embodiment of the invention, it will be apparent that many and various changes and modifications may be made with respect to the embodiment illustrated, without departing from the spirit of the invention. It will be understood, therefore, that all those changes and modifications as fall fairly within the scope of the present invention, as defined in the appended claims, are to be considered as a part of the present invention.

What is claimed is:

1. In a conical beam antenna system the combination of a dielectric rod for radiating electromagnetic energy; a radiating means carried by said rod having three radiating elements arranged circumferentially with respect to said rod and spaced substantially at equal angles, said elements being disposed in a plane perpendicular to the central axis of said rod; and an electromagnetic gyrator in said rod for effecting rotation of the electric vector of said energy so as to excite said radiating means to transmit an offset beam of said energy, which rotates about the axis of said rod at a frequency twice that of said rotating vector, to provide said conical beam.

2. In a conical beam antenna system the combination of a dielectric rod for radiating electromagnetic energy; an annular radiating member carried by said rod and having three open-ended slots formed therein circumferentially disposed substantially 120 degrees apart, said slots being axially substantially one-quarter of a wave length long at the operating frequency and substantially non-radiating; and an electromagnetic gyrator in said rod for effecting rotation of the electric vector of said energy so as to excite said radiating means to transmit an offset beam of energy, which rotates about the axis of said rod at a frequency twice that of said rotating vector, to provide said conical beam.

3. In a conical beam antenna system the combination of a source of plane-polarized electromagnetic energy; an electromagnetic gyrator comprising a wave guide adapted to receive said energy characterized by an electric vector having a predetermined polarity, ferromagnetic material disposed within said wave guide and insulated therefrom, means for developing an alternating magnetic field, and means for applying said field through said ferromagnetic material, thereby to effect transmission of said energy with rotation of its electric vector in accordance with variations of said fields; and an annular radiating member, responsive to said energy characterized by a rotating electric vector, having three radiating elements with their centers circumferentially disposed substantially 120 degrees apart, the plane of said elements being perpendicular to the central axis of said wave guide to effect rotation of the center of radiation about an axis to produce said conical beam.

4. In a conical beam antenna system the combination of a source of plane-polarized electromagnetic energy; an electromagnetic gyrator comprising a cylindrical wave guide adapted to receive said energy characterized by an electric vector having a predetermined polarity; ferromagnetic material disposed within said wave guide and insulated therefrom, means for developing an alternating magnetic field, means applying said field longitudinally through said ferromagnetic material, thereby to effect axial transmission of said energy with rotation of its electric vector in accordance with variations of said field; a parabolic reflector; a cylindrical dielectric rod radiator connected to said gyrator through the center of said parabolic reflector and longitudinally disposed along the central axis of said parabolic reflector; a first reflector adjacent the radiating end of said rod having a conductive surface perpendicular to and surrounding said rod to reflect the surface components of energy propagated by said rod; a second reflector in the form of a closed end tube connected to said first reflector at the center of said perpendicular surface and surrounding said radiating end of said rod; and an annular radiating member carried by said rod at the focal point of said parabolic reflector and having three radiating elements circumferentially disposed with their centers substantially 120 degrees apart, to illuminate said parabolic reflector with a directive beam which rotates about the axis of said rod at a frequency twice that of said rotating vector to provide said conical beam.

5. A conical beam antenna system comprising: a source of plane-polarized electromagnetic energy having a path of propagation; an annular radiating member coaxial with said path and having three radiating elements circumferentially disposed at equal angles in a plane perpendicular to said path; and an electromagnetic gyrator in said path of propagation for rotating the electric vector of said energy, whereby excitation of said radiating member by said energy develops an offset beam of said energy which rotates about said path at a multiple of the frequency of said rotating vector, thereby providing a rotating conical beam of said energy.

6. A conical beam antenna system comprising: a source

of plane-polarized electromagnetic energy including a dielectric rod for propagation of said energy; an annular radiating member coaxial with said rod and having three radiating elements circumferentially disposed at equal angles in a plane perpendicular to the longitudinal axis of said rod; and an electromagnetic gyrator in said rod for rotating the electric vector of said energy; whereby excitation of said radiating member by said energy develops an offset beam of said energy which rotates about said rod at a multiple of the frequency of said rotating vector, thereby providing a rotating conical beam of said energy.

7. A conical beam antenna system comprising: a source of plane-polarized electromagnetic energy having a path of propagation; an annular radiating member coaxial with said path and having three radiating elements circumferentially disposed at equal angles in a plane perpendicular to said path; and means in said path of propagation for rotating the electric vector of said energy, whereby excitation of said radiating member by said energy develops an offset beam of said energy which rotates about said path at a multiple of the frequency of said rotating vector, thereby providing a rotating conical beam of said energy.




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