Dec. 31, 1957 J. L. BUTLER 2,818,563

REFRACTIVE ANTENNA

Filed May 3, 1954 3 Sheets-Sheet 1

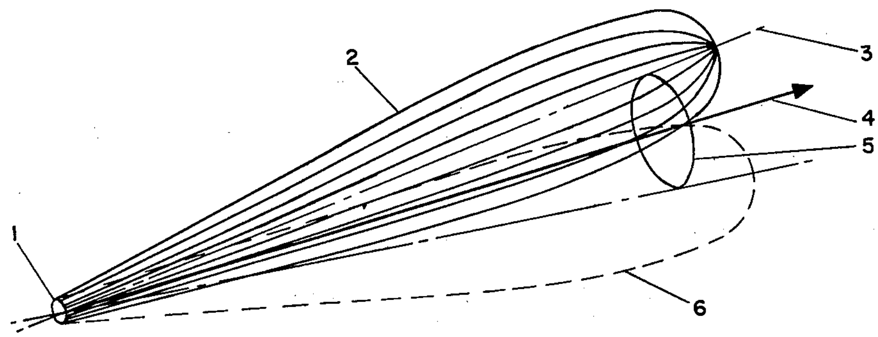

Fig. 1

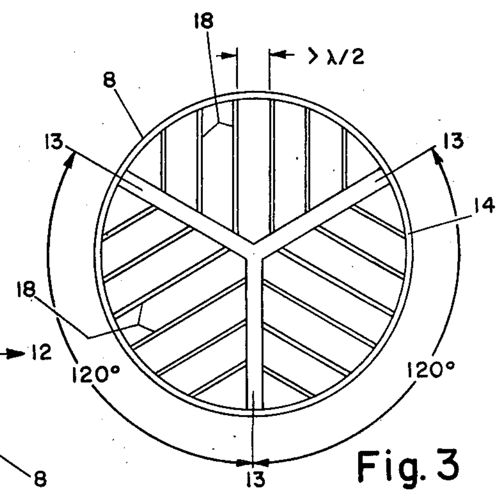

Fig. 3

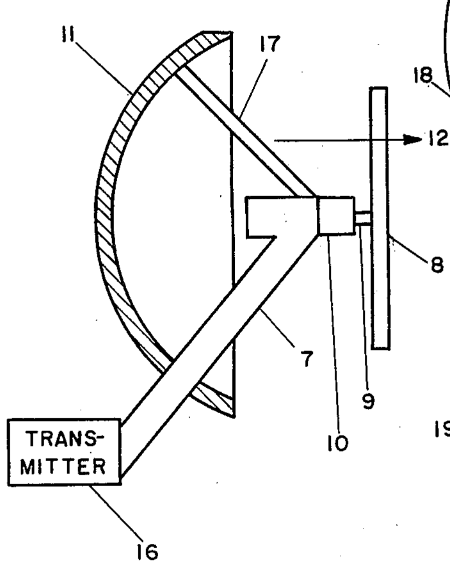

Fig. 2

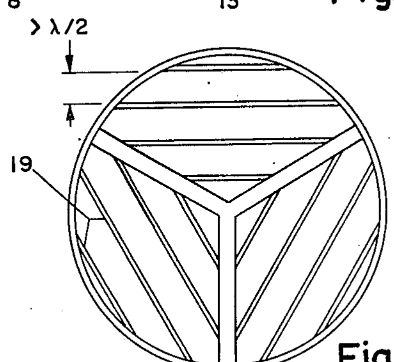

Fig. 4

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REFRACTIVE ANTENNA

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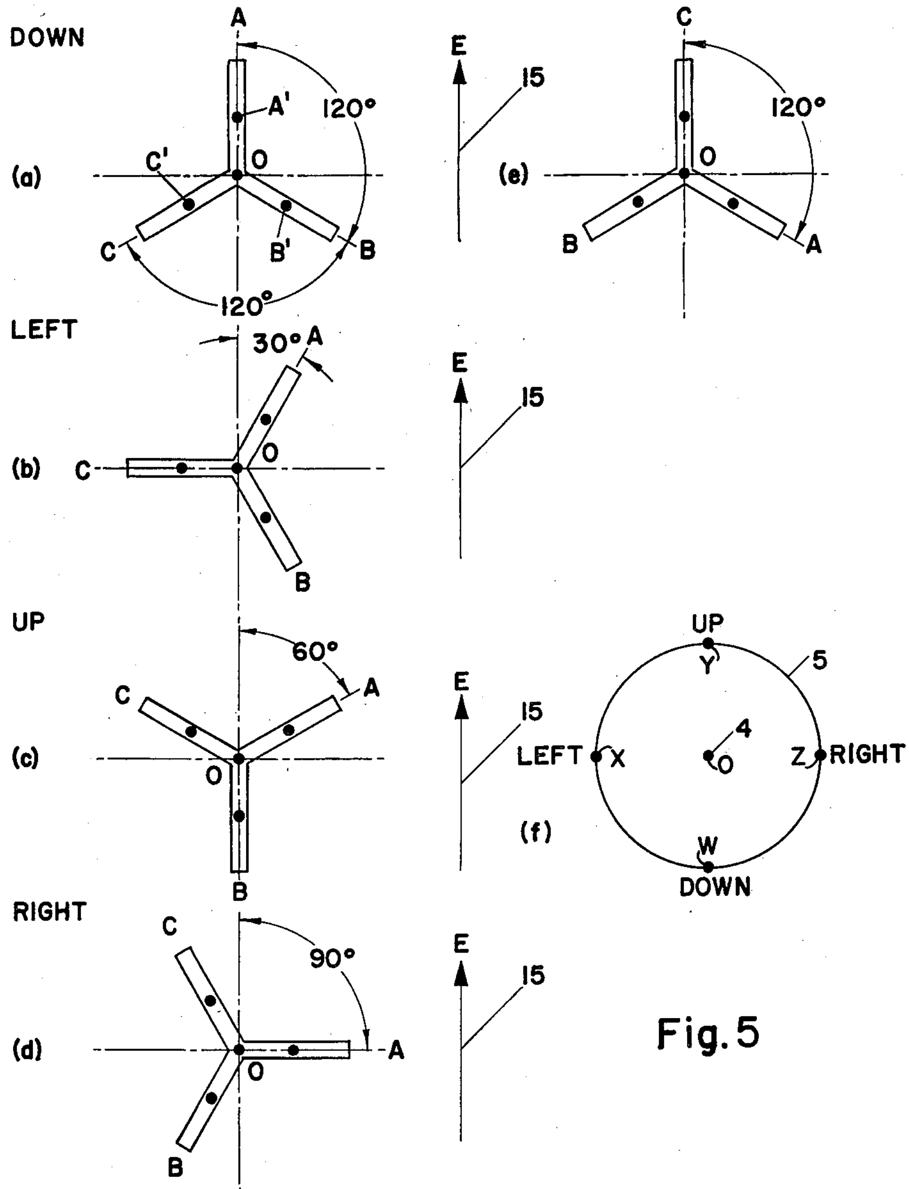

Fig. 5

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REFRACTIVE ANTENNA

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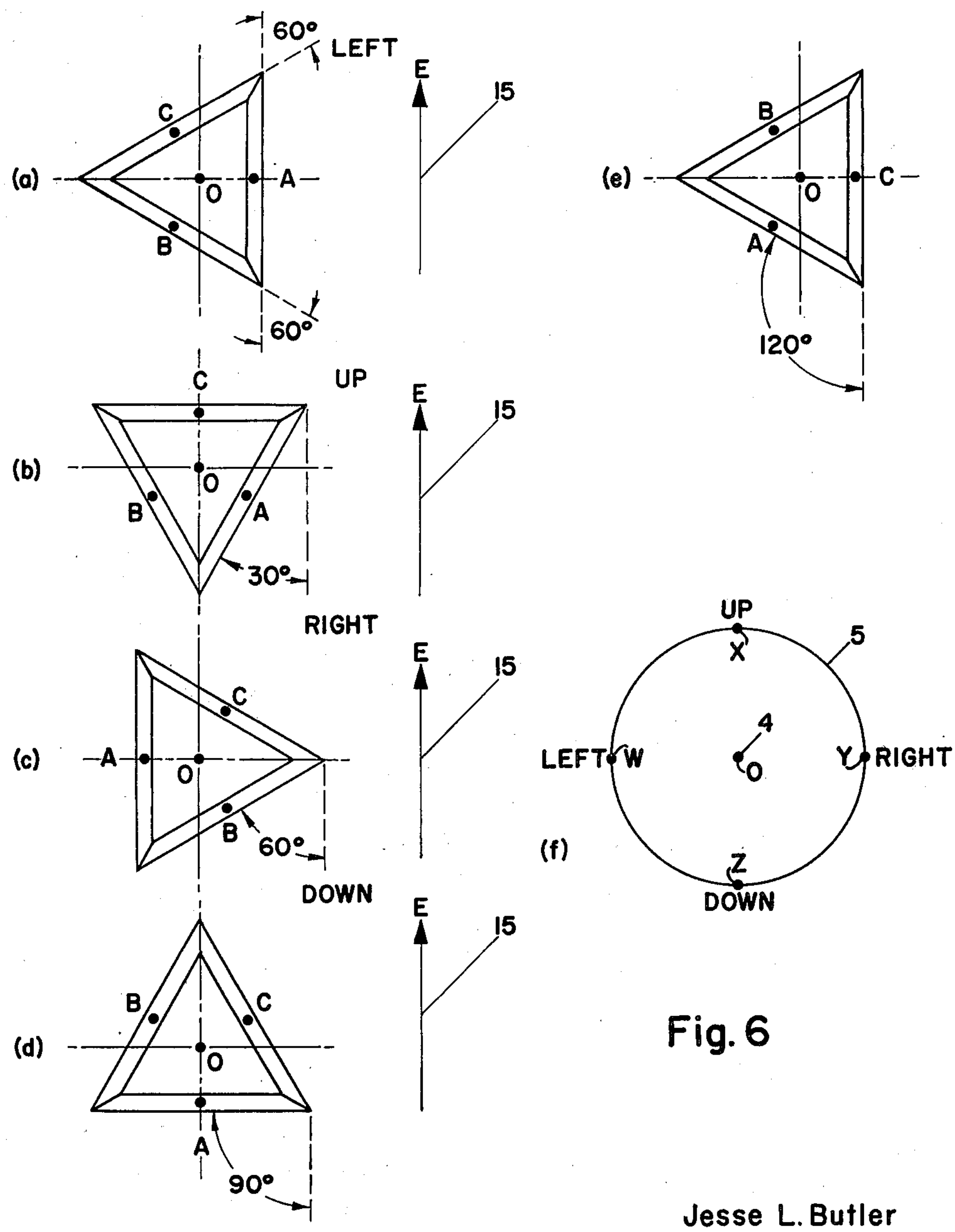

Fig. 6

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REFRACTIVE ANTENNA

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Application May 3, 1954, Serial No. 427,146

5 Claims. (Cl. 343—756)

The present invention relates to the art of radiating electromagnetic energy. More particularly, this invention relates to conical scanning antenna systems such as are used in certain systems of radar.

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 as "conical scanning" in the art. 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 usually characterized by essentially unbalanced mechanical rotational systems. The speed which conical scanning requires in the most modern radar techniques has been unattainable by such systems.

It is therefor an object of the present invention to provide an improved antenna system capable of ultra-high speed conical scanning.

It is a further object of the present invention to provide a rotating conical scanning antenna system that is at all times electrically and mechanically balanced.

A still further object of the present invention is to provide an improved conical scanning antenna system that is reliable under all operating conditions.

Other and further objects of the 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 refractive antenna system which comprises the combination of a source of plane-polarized electromagnetic energy characterized by an electric vector having a predetermined direction of polarization and a lens in the form of a grating disk having a plurality of wave guide elements disposed in adjacent 120° sectors. Each sector of the lens effects a different predetermined refraction of the energy in accordance with the relative positions of the element and the direction of polarization of the polarized energy to effect the rotation of the center of radiation about an axis when the lens is rotated. Means are provided for directing the energy toward the lens with the plane of polarization parallel to the plane of the elements. Means are further provided for rotating the lens and effecting a resultant beam conically scanning at three times the frequency of rotation of the lens.

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 an enlarged, detailed end view of a radio frequency lens as used in the embodiment of Fig. 2;

Fig. 4 is an enlarged, detailed end view of a modified form of the lens in Fig. 3;

Fig. 5 is a series of diagrams illustrating the operation of the invention employing the lens of Fig. 3; and

Fig. 6 is a series of schematic diagrams illustrating the operation of the invention employing the lens of Fig. 4.

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, as shown. The main axis **3** of the beam is caused to rotate about the antenna system axis or boresight **4**, as illustrated. 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, the antenna of the present invention comprises a primary radiator **7** (for example, a rectangular waveguide) developing a beam of electromagnetic energy for the system. A transmitter **16**, coupled to the primary radiator **7**, provides a source of plane-polarized electromagnetic energy. The energy is radiated from radiator **7** to the paraboloidal reflector **11** and directed through the lens **8** in the direction as indicated at **12**. A shaft **9** mechanically couples the lens **8** to a motor **10**. The motor **10** is supported by the radiator **7**, as shown. The reflector **11** is attached to and supported by the waveguide **7** and support rod **17**.

Referring now to Fig. 3 the lens **8** is here shown in detail. A web structure comprising three metallic members **13** connected together and to a metallic ring member **14**, is provided as shown. The metallic members **18** are disposed greater than a half-wave length apart at the operating frequency, for example, 10 kilo-megacycles. The members **13** define three equal sectors of the ring **14** and in conjunction with the members **18** provide gratings of stacked waveguides. The central radii of the adjacent sectors are disposed substantially 120 degrees apart.

It is to be noted that the members **18** are connected parallel to the radii of their respective sectors. Each pair of parallel members **18** defines a waveguide element.

In the lens as shown in Fig. 4, the construction is similar to the embodiment of Fig. 3 with the exception that the members **19** are perpendicular to the central radii of their respective sectors.

The operation of the system employing the lens of Fig. 3 can be better understood with particular reference to Fig. 5. Electromagnetic energy, plane polarized such that its electric vector **15** is vertical as shown, is directed through the lens. A waveguide element effects a maximum phase change in the energy that passes through it when the elements bounding the frequency sensitive dimension are parallel to the electric vector and a minimum, substantially zero, when the elements are perpendicular to the electric vector. In particular, such a waveguide element effects a change in phase angle of the energy passing through it in accordance with the expression:

$$\varphi = n \cos^2 \theta$$

In the above expression, φ equals the change in phase angle in degrees of the electromagnetic energy passing through the waveguide element having an electric vector parallel to the electric vector **15**. The factor n equals the maximum phase displacement in degrees that may take place and is a function of the spacing of the boundary elements and the length of the lens. The angle θ equals the angle between the waveguide boundary, elements and the electric vector **15**.

Of particular significance in the present invention is the characteristic of the lens as described, whereby a single rotation through 360 degrees effects three rotations of the resultant beam of energy as will be presently shown. In the diagrams (*a*) through (*e*) the lens of Fig. 3 is schematically illustrated by the central waveguide elements A, B and C abstracted from their respective sectors and disposed such that the angles AOB, BOC and COA equal 120 degrees, as shown. The effect of increasing the phase velocity within each element is to cause the resultant beam to be refracted in the direction of the energy having least phase change.

Thus, in the diagram (*a*) the element A is positioned at zero degrees with respect to the electric vector **15** and effects a phase change φ_A of n degrees in the energy that passes through it. In accordance with the expression for φ above, the elements B and C effect a phase change of φ_B and φ_C equal to $.25n$ degrees, respectively. Since the elements B and C are symmetrically disposed about the vertical axis, there exists no tendency for the axis of the resultant beam to be directed to the right or left. Since the centers of radiation B′ and C′ of the elements B and C are disposed below the common center O, the principal axis of the resultant beam is directed down as at **6** in Fig. 1. In particular, the main axis of the resultant beam is directed at an angle with respect to the boresight axis (see **4**, Fig. 1) in proportion to the differences $\varphi_A-\varphi_B$ and $\varphi_A-\varphi_C$, which equals $.75n$ degrees.

In the diagram (*b*) the element A has been rotated 30 degrees. The element C is then precisely perpendicular to the electric vector and effects zero degrees phase change. The elements A and B effect $.75n$ degrees, respectively, and are symmetrically disposed about the horizontal axis. Here again, $\varphi_A-\varphi_C$ equals $\varphi_A-\varphi_B$, which equals $.75n$ degrees. In this case, the main axis of the resultant beam is directed to the left.

In the diagram (*c*) the element A has been rotated 60 degrees with respect to the electric vector **15**. The element B is precisely parallel to the electric vector **15** and accordingly effects n degrees of phase change in the energy that passes through it. The elements B and C effect $.25n$ degrees of phase change and $\varphi_B-\varphi_A$ equals $\varphi_B-\varphi_C$, which equals $.75n$ degrees. The main axis of the resultant beam is directed up.

In the diagram (*d*) the element A is shown rotated 90 degrees with respect to the electric vector **15** and accordingly effects zero degrees of phase change. The elements B and C effect $.75n$ degrees of phase change to direct the main axis of the resultant beam to the right. In the diagram (*e*) the element A is shown rotated 120 degrees with respect to the electric vector **15**. The element C is now positioned such that the operation of the system as described with respect to the element A above is repeated.

In the diagram (*f*) the locus of the main axis of the resultant beam due to the rotation of the lens through an angle of 120 degrees is illustrated. The points W, X, Y and Z relate to the positions as illustrated by the diagrams (*a*), (*b*), (*c*) and (*d*), respectively. By this analysis, it is clear that the main axis of the beam rotates through 360 degrees three times while the lens mechanically rotates through 360 degrees once.

The operation of the system employing the lens of Fig. 4 can be better understood with particular reference to Fig. 6. In the diagrams (*a*) through (*e*) the lens of Fig. 4 is schematically illustrated by the central waveguide elements A, B and C (perpendicular to their respective central radii) abstracted from their respective sectors and disposed substantially in the form of an equilateral triangle as shown.

In the diagram (*a*) the element A is positioned at zero degrees with respect to the electric vector **15** and effects a phase change φ_A of n degrees of the energy that passes through it. Since the elements B and C are symmetrically disposed about the horizontal axis, there exists no tendency for the main axis of the resultant beam to be deflected up or down. The elements B and C effect phases changes φ_B and φ_C equal to $.25n$ degrees, respectively, and $\varphi_A-\varphi_B$ equals $\varphi_A-\varphi_C$, which equals $.75n$ degrees. Thus, the main axis of the resultant beam is directed to the left.

In the diagram (*b*) the element A has been rotated 30 degrees and accordingly effects a phase change of the energy passing through it of $.75n$ degrees. The element C is precisely perpendicular to the electric vector **15** and effects zero degrees phase change; thus, $\varphi_A-\varphi_C$ equals $\varphi_B-\varphi_C$, which equals $.75n$ degrees. Thus, since the elements A and B are symmetrically disposed about the vertical axis, the main axis of the resultant beam is directed up.

In the diagram (*c*) the element A has been rotated 60 degrees with respect to the electric vector **15** and accordingly the element B effects n degrees phase change. The elements A and C effect $.25n$ degrees phase change, respectively, and the main axis of the resultant beam is directed to the right.

In the diagram (*d*) the element A has been rotated 90 degrees with respect to the electric vector **15** and effects zero degrees phase change. The elements B and C effect $.75n$ degrees of phase change; hence, the resultant beam is directed down. In the diagram (*e*) the element A has been rotated 120 degrees with respect to the electric vector **15**. The element C is positioned such that the operation of the system as described with respect to the element A above is repeated.

In the diagram (*f*) the locus of the main axis of the resultant beam due to the rotation of the lens through an angle of 120 degrees is illustrated. The points W, X, Y and Z relate to positions as illustrated by the diagrams (*a*), (*b*), (*c*) and (*d*), respectively. By this analysis, it is clear that the main axis of the beam rotates through 360 degrees three times while the lens mechanically rotates through 360 degrees once.

From the above descriptions it is to be noted that the systems as described are inherently electrically and mechanically balanced. Since the motor, shaft and lenses may be very light and are mechanically balanced, the physical speed of rotation may be so increased that conical scanning rates may be increased from a typical value of 50 cycles per second to as high as 1,000 cycles or more per second.

The present invention greatly enhances the effectiveness of modern radar techniques as used in the detection and control of supersonic aircraft.

While there has been hereinbefore described what are at present considered preferred embodiments of the invention, it will be apparent that many and various changes and modifications may be made with respect to the embodiments 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. An antenna system comprising the combination of a source of plane-polarized electromagnetic energy characterized by an electric vector having a predetermined direction of polarization; a lens in the form of a grating disk having a plurality of wave guide elements disposed in three adjacent 120 degree sectors with their boundary conductors perpendicular to the central radius of their respective centers providing gratings effecting predetermined refractions of said energy in accordance with the relative positions of said elements and the direction of polarization of said polarized energy to effect the rotation of the center of radiation about an axis when said lens is rotated; means directing said energy toward said lens with said plane of polarization perpendicular to the plane of said elements; and means rotating said lens and effecting a resultant beam conically scanning at three times the frequency of rotation of said lens.

2. An antenna system comprising the combination of a source of plane-polarized electromagnetic energy characterized by an electric vector having a predetermined direction of polarization; a lens in the form of a grating disk having a plurality of wave guide elements disposed

in adjacent 120 degree sectors, each sector effecting a different predetermined refraction of said energy in accordance with the relative positions of said elements and the direction of polarization of said polarized energy, to effect the rotation of the center of radiation about an axis when said lens is rotating; a parabolic reflector directing said energy toward said lens with said plane of polarization parallel to the plane of said element; and means rotating said lens and effecting a resultant beam conically scanning at three times the frequency of rotation of said lens.

3. A refractive antenna system comprising the combination of: a source of plane-polarized electromagnetic energy characterized by an electric vector having a predetermined direction of polarization; a lens in the form of a grating disk having a plurality of wave guide elements disposed in adjacent 120 degree sectors, each sector effecting a different predetermined refraction of said energy in accordance with the relative positions of said elements and the direction of polarization of said polarized energy, to effect the rotation of the center of radiation about an axis when said lens is rotated; means for directing said energy through said lens with said plane of polarization parallel to the plane of said elements; and means for rotating said lens and effecting a resultant beam conically scanning at three times the frequency of rotation of said lens.

4. A refractive antenna system comprising the combination of: a source of plane-polarized electromagnetic energy characterized by an electric vector having a predetermined direction of polarization; a lens in the form of a grating disk having a plurality of wave guide elements disposed in three adjacent 120 degree sectors with their boundary conductors parallel to the central radius of their respective centers to provide gratings for effecting predetermined refractions of said energy in accordance with the relative positions of said elements and the direction of polarization of said polarized energy to effect the rotation of the center of radiation about an axis when said lens is rotated; means for directing said energy toward said lens with said plane of polarization parallel to the plane of said elements; and means for rotating said lens and effecting a resultant beam conically scanning at three times the frequency of rotation of said lens.

5. In a refractive antenna system, the combination of a source of plane-polarized electromagnetic energy characterized by an electric vector having a predetermined direction of polarization; a lens having a plurality of wave guide elements transparent to said energy, each said element selectively increasing by a first predetermined increment the phase velocity of energy passing therethrough in accordance with a first predetermined disposition of said element relative to the direction of polarization of said energy, and increasing said phase velocity a second predetermined increment differing from said first predetermined increment in accordance with a second disposition of said element relative to said direction of polarization orthogonal to said first disposition, said elements being so disposed in adjacent 120° sectors as to cause a resultant beam to be offset from the principal axis of incident energy and rotate about an axis when said lens is rotated; means directing said energy toward said lens with said plane of polarization substantially parallel to the plane of said elements; and means rotating said lens effecting thereby a resultant beam conically scanning at three times the frequency of rotation of said lens.

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