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[54] MILLIMETER WAVE-SCANNING LENS ANTENNA

5 Claims, 6 Drawing Figs.

[52] U.S. Cl. **343/754,** 343/763, 343/757, 343/766
[51] Int. Cl. H01q 19/06
[50] Field of Search 343/754, 757, 758, 759, 763, 766

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ABSTRACT: The apparatus of the present invention provides a high-speed mechanical scanner that operates in the millimeter range of frequencies with a cylindrical quartz lens as a focusing device. A split annular waveguide with one half in constant rotation provides 355° of scan and presents angular information as a function of time. The disclosed electromechanical scanner generates a 3° beam with 16 db. sidelobes and may be scanned at a rate in excess of 10,000 angular degrees per second.

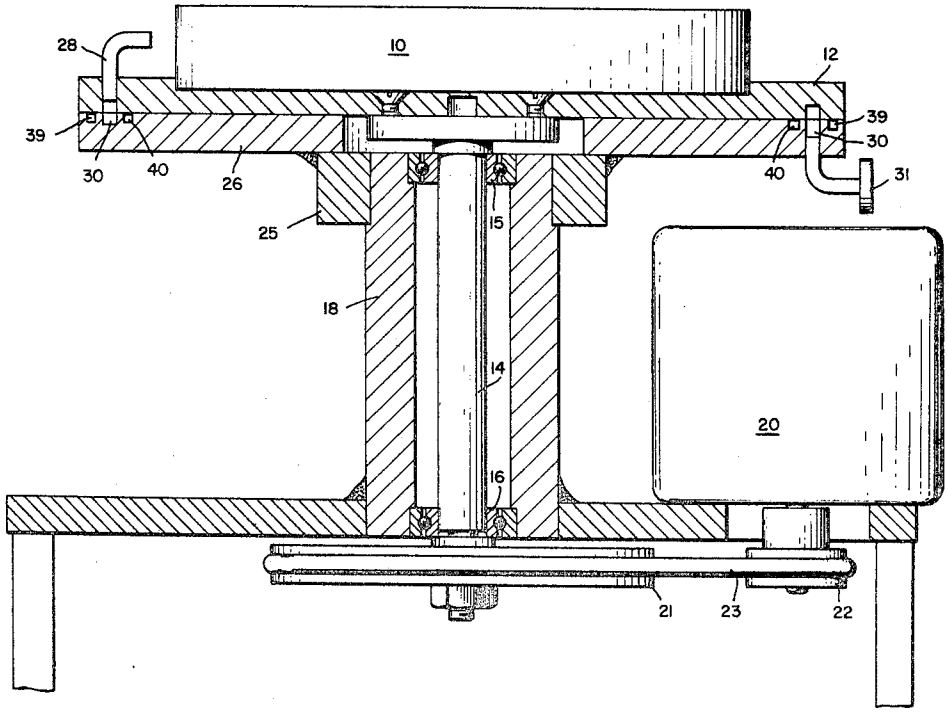
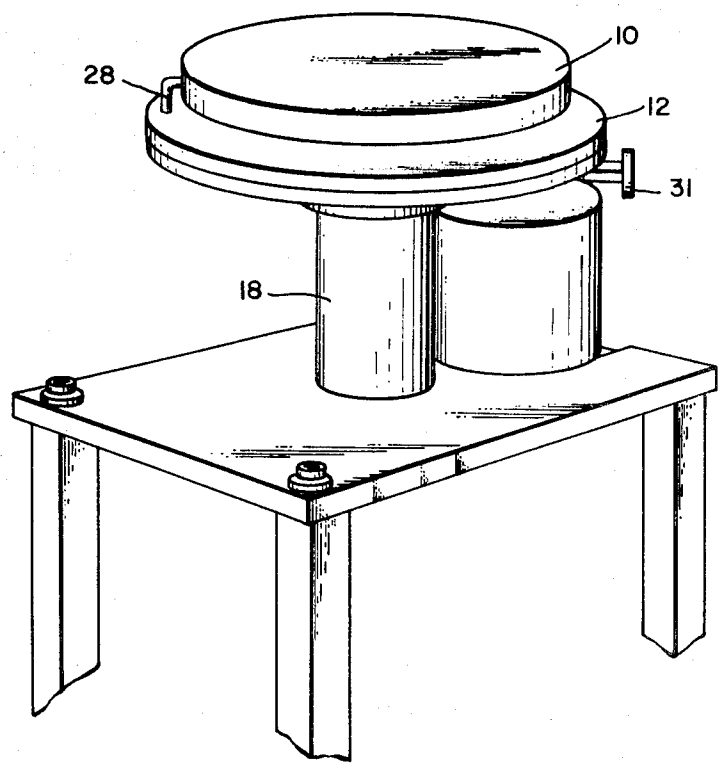


Fig. 1.



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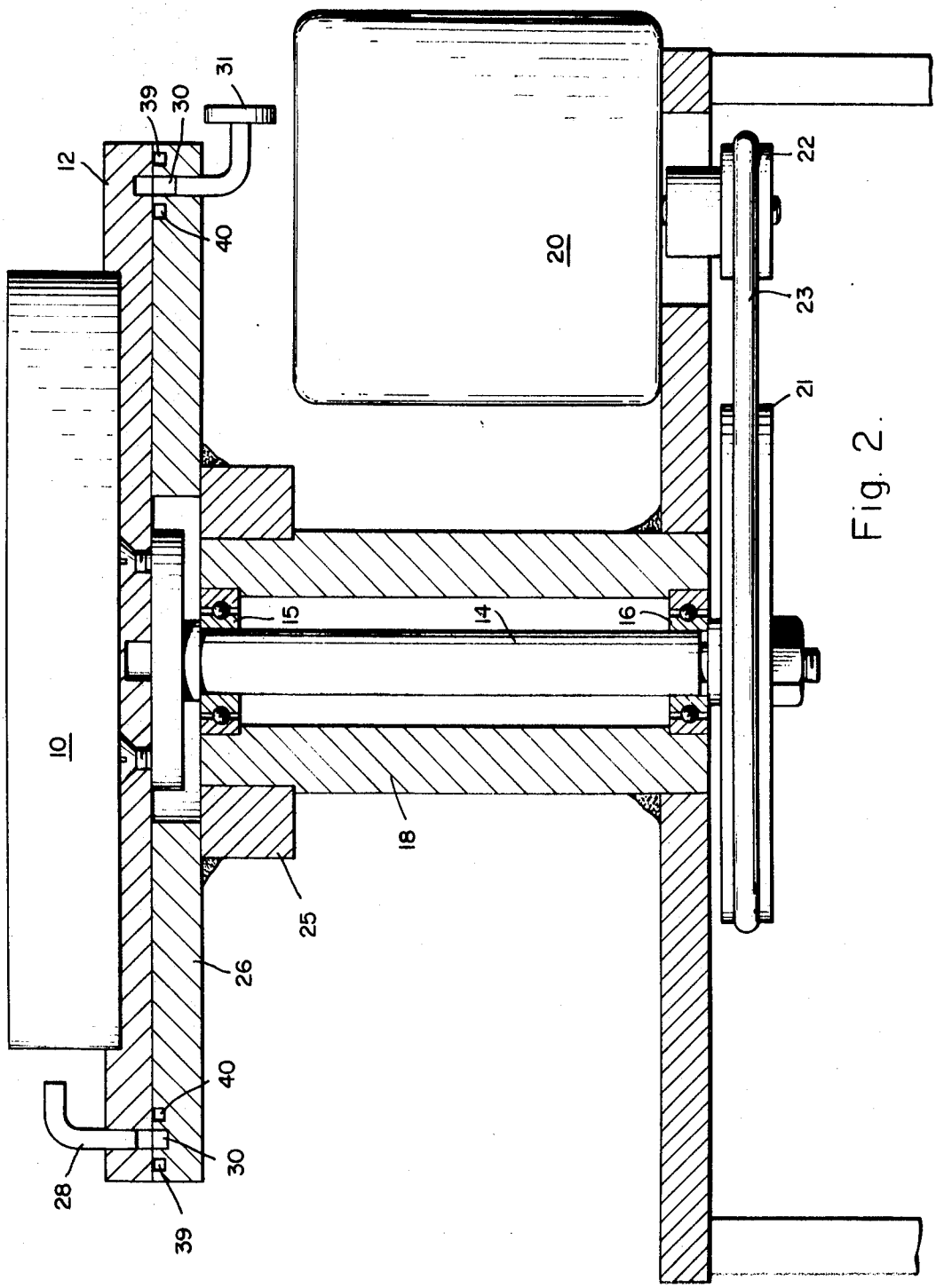


Fig. 2.

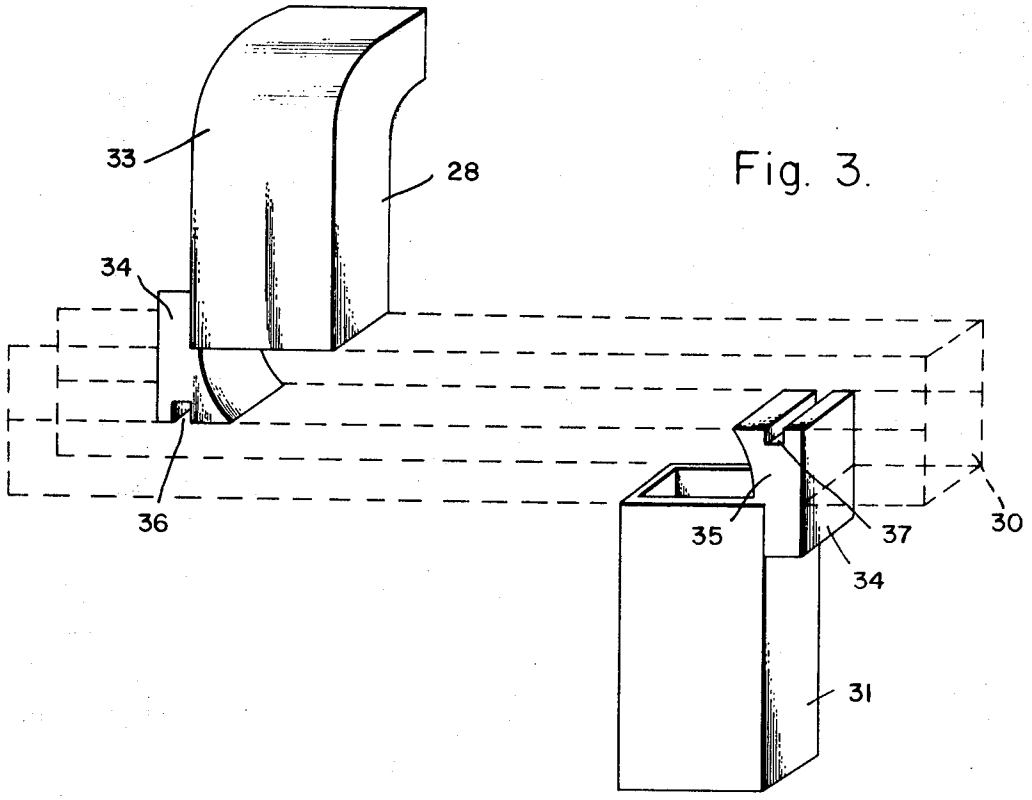


Fig. 3.

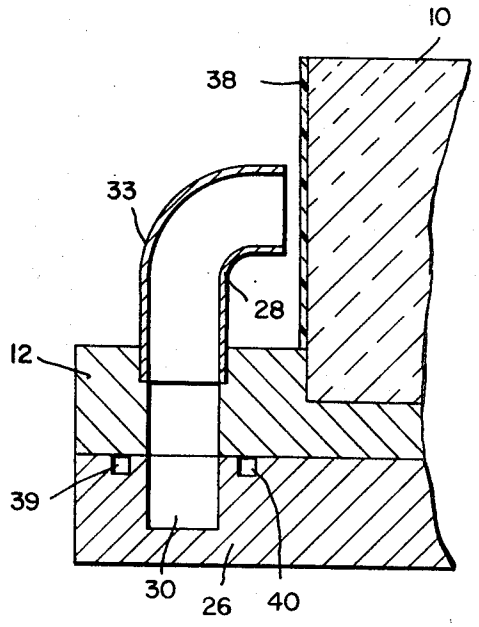


Fig. 4.

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Fig. 6.

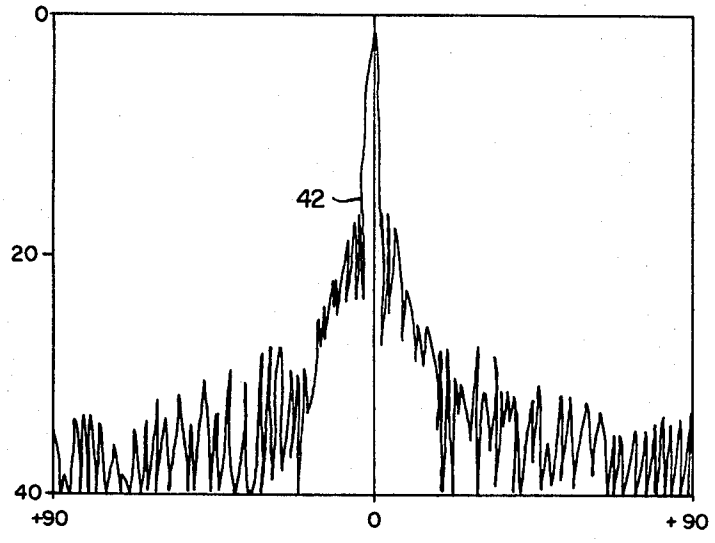
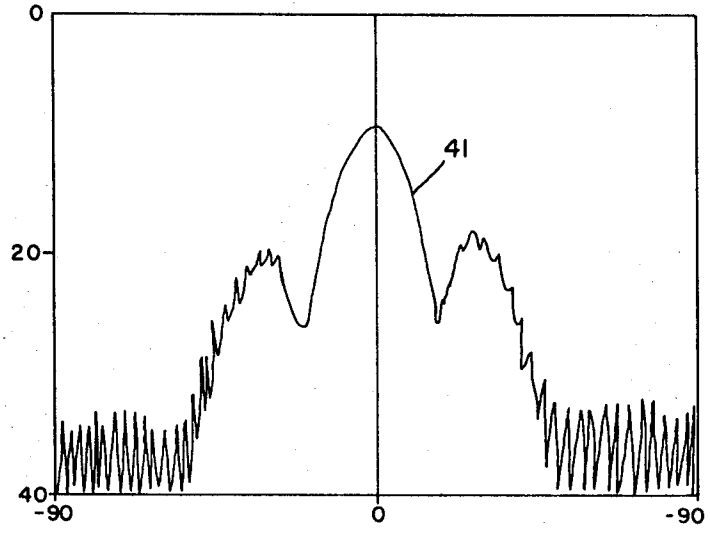


Fig. 5.



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MILLIMETER WAVE-SCANNING LENS ANTENNA

BACKGROUND OF THE INVENTION

Many types of contemporary lenses have been used as microwave antennas to facilitate beam scanning. Chief among these are the spherical Luneberg and the Geodesic or "clamshell" lenses. A Luneberg lens consists of concentric layers of dielectrics that vary from near unity at the surface to higher values at the center. The Geodesic lens, or modified Luneberg, is formed by two parallel curved surfaces (the clamshell) in which the geometry of the curved surfaces focuses an incident plane wave at a point on or close to the periphery.

The interest in homogeneous dielectric spheres as microwave lenses is comparatively recent. The electrical properties of a lens with a spherical shape and a constant dielectric has been measured and reported, but no known attempt has been made to apply these data to scanning antennas, possibly because of the size and weight of a spherical lens.

SUMMARY OF THE INVENTION

In accordance with the present invention, a flat cylindrical quartz lens is combined with a split annular waveguide feed to provide a high-speed scanning system. The flat cylindrical quartz lens can be considered as a slice taken through the center of a spherical lens of a homogeneous dielectric with the edges straightened and aligned parallel to the axis of rotation. The lens thus formed will exhibit a similar combination of focusing and directional properties in the plane of scan as a spherical lens with the same dielectric constant. As in the Luneberg lens, energy is focused by refraction at a point diametrically opposite to the point of entry. The invariant dielectric constant such as in the Geodesic lens eliminates the need for a concentric ring structure whereby such a lens may have high-strength properties, circular symmetry, and greater simplicity of construction than a spherical lens. Scanning achieved by rotating the cylindrical lens together with its feed or rotating the feed alone about an axis of symmetry.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 shows a perspective view of the millimeter wave-scanning lens antenna of the present invention;

FIG. 2 shows a cross-sectional view of the apparatus of FIG. 1;

FIG. 3 shows details of the feed system of the apparatus of FIG. 1;

FIG. 4 shows a cross section of the annular waveguide and feed horn in the apparatus of FIG. 1; and

FIG. 5 and 6 show the H-Plane and E-Plane patterns of the beam generated by the lens antenna of FIG. 1.

DESCRIPTION

Referring now to FIGS. 1 and 2 of the drawings, there is shown a lens-scanning array in accordance with the invention which includes a flat cylindrical dielectric lens 10 mounted on a conductive disc 12. The lens 10 is of the order of 6 inches in diameter and one-half inch thick with polished cylindrical surfaces. In the frequency range of 50–75 gc., the aperture of the lens is 25–35 wavelengths. A shaft 14 supported by bearings 15, 16 within a pedestal 18 is attached to the disc 12 about an axis of rotation and is mechanically coupled to a high-speed motor 20 through pulleys 21, 22 and a belt 23. The pedestal 18 has a collar 25 press fit thereto about the periphery thereof at the extremity adjacent to the lens 10. The collar 25, in turn, supports an annular conductive disc 26 which is coextensive with the disc 12 and spaced 0.004 inches therefrom. The lens 10 is rotated by energizing the high-speed motor 20 and is fed by an open-ended waveguide feed horn 28 located at the focus thereof. The horn 28 is connected to a ring of RG-98/*u* size rectangular waveguide 30 that is split on the broad wall centerline with one-half in the conductive disc 12 and the remaining one-half opposite in the annular disc 26. Output coupling is made by means of a waveguide connection 31 to the bottom of the split waveguide 30. The separation of the two halves of waveguide 30 produces a nonradiating structure similar in electrical characteristics to a slotted-line section.

The waveguide portion 30 constitutes a large rotary joint wherein the top half in disc 12 rotates with the lens 10 and the feed horn 28 while the bottom half remains stationary in the noncontacting disc 26. When the scanner is operated as a receiver, a plane wave incident on the cylindrical surface of lens 10 is focused at a point diametrically opposite. As the lens 10 rotates, the focused energy is picked up by the feed horn 28. The direction of an incoming signal can be represented as a function of the time of the scanner rotation.

A homogeneous lens of suitable dielectric constant has the property of converging a plane wave incident on one surface by refraction to a point diametrically opposed to the direction of propagation. The relationship between dielectric constant and focal length for a spherical lens is expressed in an approximate formula as

$$R'/R = \frac{1}{\sqrt{2}}\,(K/(K-1)) \qquad (1)$$

where

R' is the focal radius of a spherical lens

R is the radius of a spherical lens

K is the dielectric constant.

Equation (1) shows that the focal radius R' varies directly as the radius of a spherical lens. Thus if the focal radius for a given dielectric material is outside the surface of the lens ($R' > R$), an increase in lens diameter will increase the value of R'. For the focus to fall at the periphery of a lens, the dielectric constant would be 3.42. As K approaches unity, the focal point moves toward infinity. Because quartz is a dielectric material that is homogeneous, has a dielectric constant of 3.78 at 25 gc., which is near the ideal of 3.42, has a low loss tangent, tan δ, and is readily available, it was used for the lens 10.

Losses in a 6-inch diameter cylindrical lens 10 at 25 gc., the highest frequency for which the loss tangent in quartz has been measured, can be approximated by the following relationship:

$$\text{Loss in db} = 36\frac{R''}{\lambda}[K^{3/2} - (K-1)^{3/2}] \tan \delta \qquad (2)$$

where

R'' is the radius of lens 10

λ is the wavelength

K is the dielectric constant and

tan δ is the loss tangent.

Equation (2) shows that for a known value of $K = 3.78$ at 25 gc. and tan $\delta = 0.00025$, the energy dissipated in the lens is 0.16db. This loss is comparatively low when it is considered that, at 25 gc., a 6-inch aperture represents nearly 13 wavelengths. At the 56-gc. design frequency, the aperture is some 30λ and the losses can be expected to be higher.

The power varies across the aperture of the lens 10 from a normalized value of unity at a beam angle $\theta = 0$ to a value of zero at $\theta = \theta_c$, where θ_c is the critical angle at which total internal reflections occur and $\sin \theta_c = \frac{1}{\sqrt{K}}$. With an approximate K of 3.8 for quartz, the critical angle θ_c is 31° and the effective aperture of a 6-inch lens is reduced by 11.5 percent to a value of 5.3 inches. It can be shown that the theoretical gain value for a 6-inch lens having an effective aperture 5.3 inches width and 0.400 inch height at 56 gc. is 27.76db.

The feed horn 28 for the lens scanner is an open-ended rectangular waveguide. Microwave energy is coupled into the waveguide section of horn 28 of the scanner through two waveguide bends 33, 34 (FIGS. 3 and 4). Bend 33 is an E-plane bend directly behind and part of the structure of feed horn 28. Bend 34, on the other hand, is an H-plane bend which is part of the top wall or rotating disc 12 of the split annular waveguide 30. The H-plane bend 34 used in coupling energy into the waveguide terminates abruptly at the waveguide 30 centerline in order to pass a similar bend 35 at the output waveguide 37 when the disc 12 is rotated. Although

the bends **34, 35** are only half completed, they serve the purpose of directing energy down the waveguide **30** in one direction. The area of the unfinished part represents a waveguide beyond cutoff and appears as a high impedance to propagation down the waveguide **30** in the reverse direction. Choke joints **36, 37** are additionally included as a part of the reduced bends **34, 35**, respectively, to further improve the impedance match. Bend structure **35** couples energy out of the waveguide **30** at the output point thereof.

Although an open-ended waveguide was used for the feed **28** for the lens scanner, it is within the state of the art to use a pyramidal flare with suitable matching devices such as stub tuners. In addition, a layer **38** over the cylindrical surface of lens **10** one-quarter wavelength in thickness, for example, Teflon with a dielectric constant of 2.08, can be used to reduce surface reflections.

The waveguide **30** portion of the scanner constitutes a large rotary joint. Annular waveguide **30** is approximately 22 inches in circumference, and is split on the broad wall centerline. The top half of the waveguide **30** rotates with the disc **12**, lens **10**, and feed horn **28** while the bottom half in disc **26** is stationary. The waveguide **30** is the standard RG-98/*u* size of 0.074 by 0.148 inch, each half being 0.072 by 0.074 inch with a 0.004-inch gap between. The two halves of the waveguide **30** section are noncontacting and have choke joints **39, 40** (FIGS. **2, 4**) added adjacent to the bottom half of the waveguide **30** in disc **26** as an added precaution against leakage.

E and H plane patterns **41, 42** (FIGS. **5, 6**) show the gain and sidelobe level of the scanner of FIG. **1**. The measured gain figure of 25db. approximates the theoretical gain value of 27.86 from equation (2). The E-plane pattern **41**, FIG. **5**, shows a fan beam of 17.0° at the half-power points for the device of FIG. **1**. A lens **10** with a different thickness would vary the beam dimension in this plane and change the subtended angle.

Optimum spacing of the feed horn **28** from the cylindrical surface of lens **10** is at the focus thereof which varies with the diameter. Spacing for a 2-inch diameter quartz lens is 0.03 inch from the surface; for a 3-inch diameter quartz lens, spacing is 0.05 inch from the surface; and for a 6-inch diameter quartz lens, spacing is 0.10 inch from the surface.

According to equation (1), quartz with a dielectric constant of 3.78 has had a focal radius less than the lens radius. Since for quartz lenses, the focal point falls outside it is an indication that the constant $1/\sqrt{2}$ in the spherical lens equation (1) is not applicable to the case of a cylindrical lens. A new empirical constant of approximately 0.76 calculated from the three focal point measurements above, can be used in equation (1) to predict the optimum spacing of horn **28** from the surface of lens **10** for different diameters thereof.

In operation, scanning is achieved by rotating the horn **28** about the lens **10** which, because of symmetry, may or may not rotate. Location of the scan direction may be obtained by means of an appropriate coupling to disc **12**, not shown. Microwave energy is both transmitted and received through waveguide connection **31** to the bottom half of split waveguide **30**.

What is claimed is:

1. An apparatus for scanning electromagnetic waves at high speed, said apparatus comprising a flat homogeneous dielectric cylinder, said dielectric cylinder having a focal point exterior to the cylindrical surface thereof and an axis of rotation; a first conductive plate of dimensions greater than those of said flat homogeneous cylinder attached to one side thereof, said first plate having a circular groove on the opposite side thereof from and at a radius greater than that of said flat cylinder for providing one-half an annular waveguide; a feed horn mounted on said first plate and coupled to said concentric groove, said feed horn being spaced at said focal point relative to the cylindrical surface of said flat dielectric cylinder; means attached to said first plate for rotating said feed horn and said flat dielectric cylinder about the axis of rotation thereof; a second conductive plate of dimensions greater than those of said circular groove in said first plate disposed adjacent to said first plate, said second plate having a circular groove directly opposite said circular groove in said first plate to provide the remaining half of said annular waveguide; and means coupled to said circular groove in said second plate thereby to provide a rotatable coupled to said feed horn.

2. An apparatus for scanning electromagnetic waves at high speed, said apparatus comprising a flat homogeneous cylinder of radius R and dielectric constant, K, less than 3.78; a first conductive disc of a radius greater than R attached concentrically to one side of said flat cylinder, said first disc having a circular groove disposed concentrically in the remaining side thereof for providing one-half an annular waveguide split through the broadside thereof; a feed horn mounted on said first disc opposite said flat cylinder and coupled to said concentric groove therein, said feed horn being spaced a distance R' from the axis of rotation of said flat cylinder where $R'=0.76RK/(K-1)$; means attached to said first disc for rotating said feed horn and said flat cylinder about said axis of rotation thereof; a second conductive disc of a radius greater than that of said circular groove in said first disc concentrically disposed adjacent to said remaining side of said fist disc, said second disc having a circular groove directly opposite said circular groove in said first disc to provide the remaining half of said annular waveguide; and means coupled to said circular groove in said second disc thereby to provide a rotatable coupling to said feed horn.

3. The apparatus for scanning electromagnetic waves at high speed as defined in claim **2** additionally including first and second choke slots disposed on opposite sides of said annular waveguide, respectively, thereby to minimize radiation therefrom.

4. The apparatus for scanning electromagnetic waves at high speed as defined in claim **2** wherein said feed horn is coupled to said concentric groove in said first disc in a predetermined direction and said last-named means is coupled to said concentric groove in said second disc in a direction opposite to said predetermined direction.

5. A scanning device for electromagnetic waves at high speed, said device comprising a flat homogeneous quartz cylinder with a ¼-wavelength dielectric layer on the cylindrical surface thereof, said quartz cylinder having an axis of rotation and a focal point exterior to said dielectric layer thereof; means for providing a feed horn at said focal point in fixed relation relative to said flat quartz cylinder; means coupled to said cylinder and feed horn for rotating said feed horn about said axis of rotation of said cylinder; and means coupled to said feed horn for transmitting and receiving electromagnetic wave energy therethrough concurrently with the rotation of said feed horn.