Aug. 11, 1970 N. G. SAKIOTIS ET AL 3,524,192

SCANNING APPARATUS FOR ANTENNA ARRAYS

Filed Dec. 9, 1963 2 Sheets-Sheet 1

Fig. 1

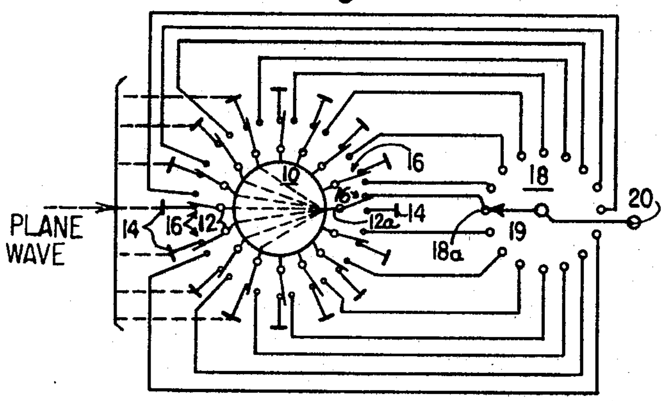


Fig. 2

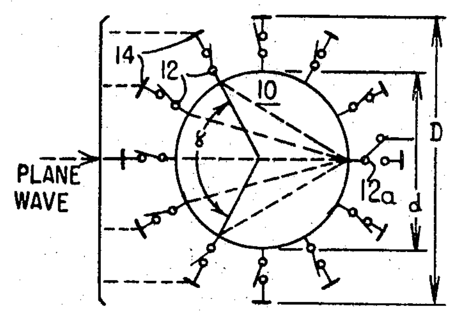


Fig. 3

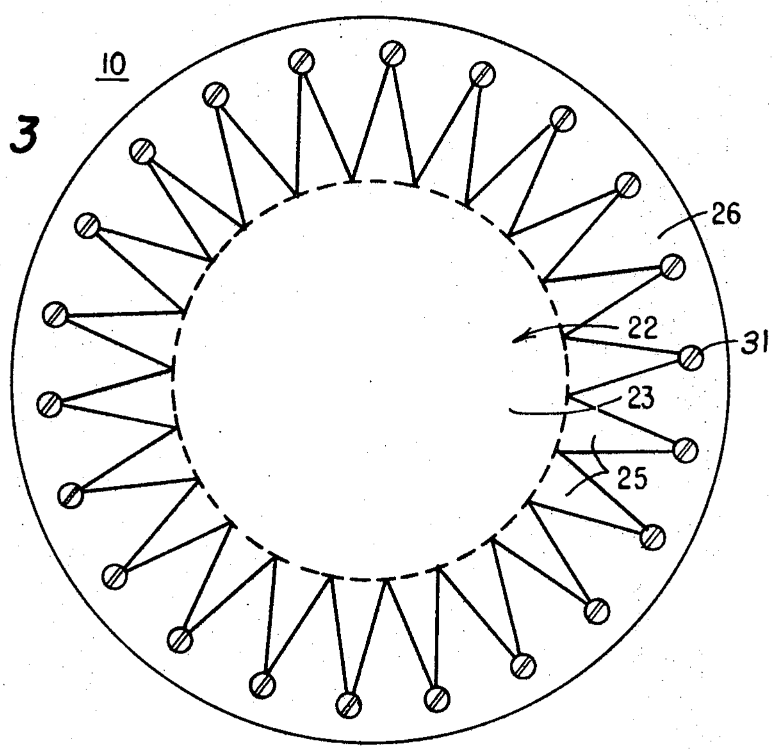
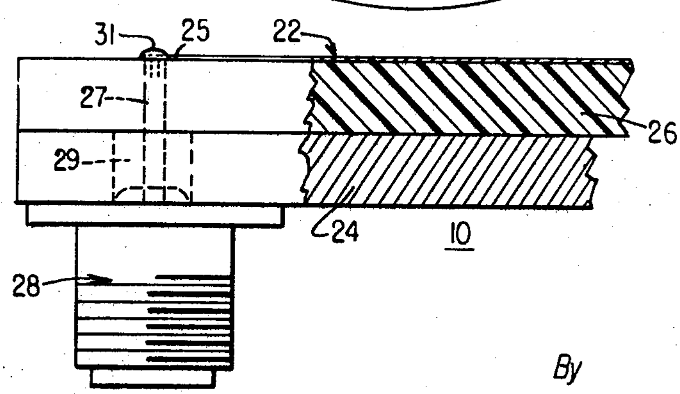


Fig. 4



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SCANNING APPARATUS FOR ANTENNA ARRAYS

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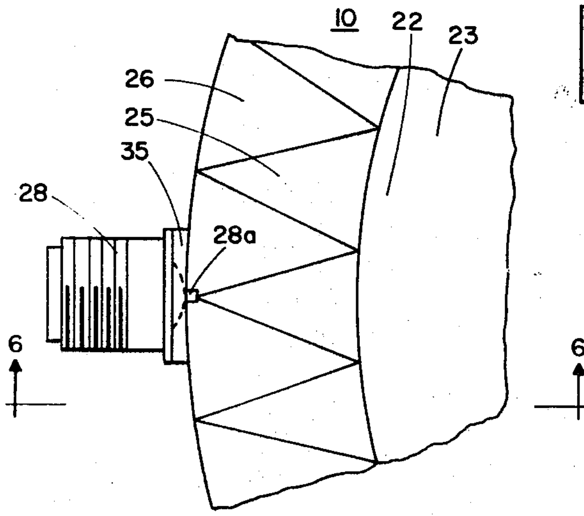

Fig.5

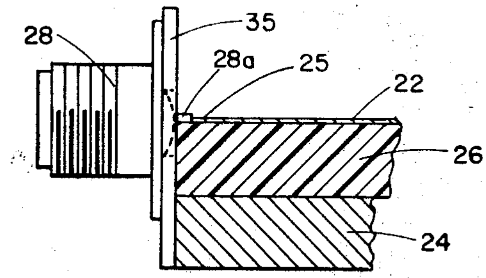

Fig.6

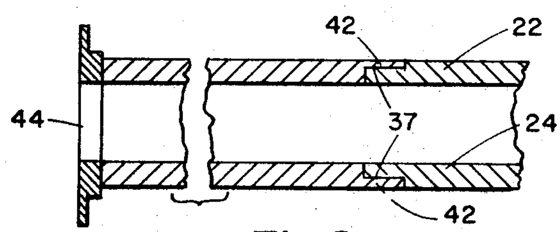

Fig.8

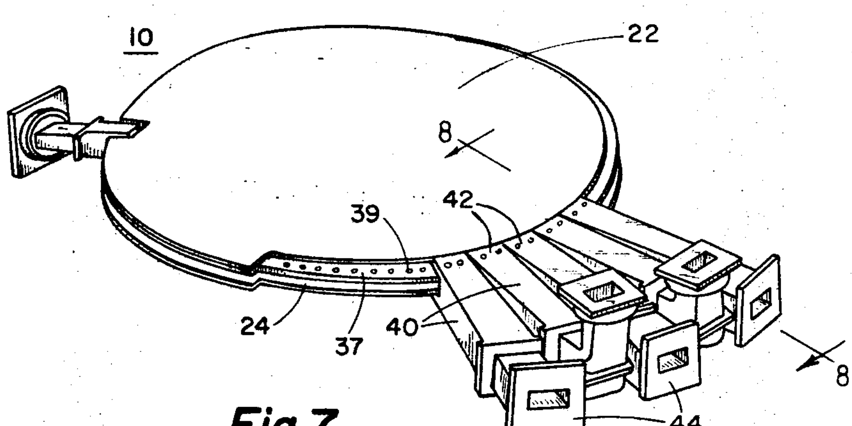

Fig.7

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United States Patent Office

3,524,192

Patented Aug. 11, 1970

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3,524,192
SCANNING APPARATUS FOR ANTENNA ARRAYS

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Filed Dec. 9, 1963, Ser. No. 328,868
Int. Cl. H01q 3/24
U.S. Cl. 343—854 12 Claims

ABSTRACT OF THE DISCLOSURE

A scanning system having a circular array of antennas and a coupling network comprising a two dimensional microwave lens with a plurality of feed points about its periphery, and a switching network to selectively connect a predetermined number of antennas to corresponding feed points. The wave energy is focused at a single diagonally opposite feed point that acts as the output port.

This invention relates generally to antenna scanning systems and more particularly to a phasing lens and associated circuitry to provide electronic scanning of circular antenna arrays.

Electronic scanning of fixed antenna arrays offers many advantages over mechanical scanning arrangements wherein the radiating structure is rotated. An attractive method for electronically steering the beam of a fixed antenna array is by use of an electromagnetic energy feed system which provides a multiplicity of independent overlapping beams, each of which utilizes the full array aperture. The beam is then steered in discrete steps by sequentially selecting independent feed points for each of the beams.

In some antenna arrays electronic scanning is achieved by utilizing multiport couplers to feed a limited number of array elements. This approach, however, is inherently narrow band and becomes complex for arrays having a large number of elements. Electronically controlled phase-shifters and multipole switches may be incorporated into the system to expand the number of array elements utilized, but such an application becomes expensive and complex for a large number of array elements.

It has been proposed, in conjunction with circular symmetric antenna arrays, to use a two-dimensional microwave lens wherein energy appearing about a given arc of its periphery is collimated into a beam diametrically opposite the wave front of a received plane wave of electromagnetic energy. However, known lenses of this type are provided with an index of refraction (dielectric constant) that varies as a function of lens radius. In addition, scanning systems usually employed with this type of lens require a single feed point, with scanning achieved by causing relative rotation between the antenna array and the lens or by causing rotation of the single feed point relative to the lens. The moment of inertia of the rotating structure and the inherent problems resulting from using mechanically moving parts at high frequencies has placed definite limitations on scanning speed and overall system utility of arrangements of this type. Consequently, it is desirable to provide an energy collimating lens which may be readily incorporated with a multi-element circular antenna array for electronic scanning about a desired azimuth without the use of mechanically moving parts and with a minimum of system complexity.

It is therefore among the objects of this invention to provide an improved antenna scanning system.

Another object is to provide an improved microwave lens construction for simplified electronic scanning of circular symmetric antenna arrays.

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A further object of the invention is to provide a two-dimensional circular-symmetric constant-index of refraction microwave lens particularly suited for enabling simplified electronic scanning of circular antenna arrays.

A feature of the invention is the provision of a homogeneous cylinder of dielectric material clad with metal on both faces thereof to form a parallel plate transmission region. A plurality of arbitrary feedpoints are located about the periphery of the cylinder so that electro-magnetic energy introduced at a selected number of adjacent feedpoints focuses at a single diagonally opposite feedpoint, and a simple electronic switching arrangement is used to cause scanning of a circular symmetric planar antenna array, by changing the location of the focal point about the periphery of the lens.

A further feature is the provision of a two-dimensional circular-symmetric microwave lens having the region between two conducting plates filled with a dielectric material of uniform dielectric constant. A number of feedpoints are equally spaced about its circumference, and angular displacement of the beam produced by an associated circular antenna array is achieved by electronically switching the focal point of the lens about its circumference.

A more specific feature of the invention is the provision, in an electromagnetic energy focusing lens of the above described type, of a low-loss high dielectric constant material disposed between conducting plates to provide a cylindrical transmission region, with the conducting plates spaced for propagation in the TEM mode. This produces a simple and compact construction for broadband operation that has low absorption loss.

Other objects, features and attending advantages of the invention will become apparent from the following description when taken in conjunction with the accompanying drawings, in which:

FIG. 1 is a schematic diagram of an electronically scanned antenna array utilizing a circular symmetric lens having a focal point on its circumference;

FIG. 2 is a schematic diagram illustrating the manner in which energy is focused by the lens;

FIG. 3 is a plane view of a particular embodiment of a microwave lens according to the invention;

FIG. 4 is an enlarged side view, partially in section, of a portion of the lens of FIG. 3;

FIG. 5 is a partial plane view of another embodiment of the lens;

FIG. 6 is a cross-section of the lens taken along lines 6—6;

FIG. 7 is a portion of a perspective view of another form of the lens; and

FIG. 8 is a cross-section of FIG. 7 taken along lines 8—8.

The invention includes a microwave lens that focuses energy introduced at a number of adjacent feedpoints on its periphery at one feedpoint. The lens is circular symmetric, having N feedpoints equally spaced around its periphery, with each feedpoint adapted to be connected either to an associated element of a circular symmetric planar antenna array or to utilization means of the overall system by electronic switching means. All feedpoints but one are connected to antenna array elements, with the remaining feedpoint serving as a focal point for electromagnetic energy introduced at the other feedpoints. Scanning of the array elements is achieved by changing the selected focal point on the periphery of the lens.

Structurally, the lens consists of two conducting plates parallely disposed, with a dielectric medium therebetween forming a cylindrical transmission region having an index of refraction (or dielectric constant) that is constant throughout. Located symmetrically about the periphery of the transmission region are an arbitrary number of energy feedpoints, each having an associated energy coupling port. It is to be understood that the principle of reciprocity applies so that the feedpoints may function to introduce electromagnetic energy to or to collect electromagnetic energy from the transmission region, depending whether the lens is utilized with a receiving or transmitting antenna array. The energy so introduced (or collected) is then collimated at selected focal points corresponding to the feedpoints positioned around the lens periphery.

Referring now to FIG. 1, the circular symmetric antenna system illustrated includes lens **10** having a multiplicity of N coupling ports **12** representing N possible feedpoints equally spaced around its periphery. Each coupling port is connected by an equal length line to a corresponding array elements **14** of a circular symmetric planar antenna array. A single pole double throw switch **16** is interposed between each coupling port and its associated array element **14**, with one leg of each switch connected to a leg or input port of single pole N-throw communtator switch **18**. Switch **16** may be biased diode microwave switches or where feasible from the standpoint of system complexity and cost may be a ferrite circulator. Switch **18** is a multi-throw diode switch which conveniently may be of the type described in the copending application of Philip C. Clar, Ser. No. 308,286, filed Sept. 11, 1963, now Pat. No. 3,223,947 and assigned to the assignee of this application.

The above described switching arrangement enables a selected Nth port of lens **10** to be connected to a selected input port of commutator switch **18**, while the remaining ports are connected to N–1 elements of the antenna array. Switches **16** and **18** are actuated by a suitable control circuit (not shown), as for example, a selectively triggered DC biasing arrangement when diode switches are used. Scanning is achieved by successively connecting a different single coupling port **12** and hence its associated feedpoint on the periphery of lens **10** to a corresponding input port of commutator switch **18**, and then to the common or output port of commutator switch **18** by appropriate control of switches **16** and **18**.

Thus, as shown in FIG. 1, N–1 coupling ports or feedpoints **12** on the periphery of lens **10** are coupled to array elements **14** by SPDT switches **16**, with the Nth feedpoint **12***a* coupled to a delated Nth port **18***a* of commutator switch **18**. A common port **19** of switch **18** in turn connects the selected Nth port **18***a* to the output port **20** of the overall system. Accordingly, an incoming plane wave of electromagnetic energy, as shown in dotted lines in FIGS. 1 and 2, is received by an arbitrary number of array elements. The angle between the first and the last array element which receives the incoming plane wave of electromagnetic energy may be considered the array aperture angle. It can be seen that within this array aperture angle a discrete number of individual array elements are provided.

Referring now to FIG. 2, the direction of propagation of the incoming plane wave (or alternately of an outgoing plane wave) is parallel to a diameter of lens **10** taken through its focal point associated with the Nth port **12***a*. The energy introduced at the remaining N–1 feedpoints or coupling ports **12** is propagated through lens **10** and focuses at its Nth feedpoint **12***a* to be subsequently fed to the system output port **20** via switches **16** and **18**. It can be seen from the foregoing that by successively switching other feedpoints **12** to provide other focal points **12***a* on the periphery of lens **10**, the propagation path of a received plane wave is made successively parallel to a diameter of the lens taken through different points about its periphery. This in turn results in steering the antenna array in discrete steps about 360° azimuth.

Lens **10**, a two-dimensional circular symmetric constant index lens, is comprised of parallel conductive plates defining a cylindrical transmission region filled with a material of uniform dielectric constant. One form, utilizing strip-line techniques and adapted to be utilized in a coaxial line system, is shown in FIGS. 3 and 4. Conducting plate **22**, having a generally circular body portion **23** and a scalloped periphery forming horns or tapers **25**, is separated from a metallic base plate **24** by dielectric medium **26**. A pin or conductor **27** extends through dielectric medium **26** and through an aperture **29** in base plate **24**, and is connected to the apex of tapers **25** by a screw **31**. Pin **27** terminates such that it is co-extensive with the center conductor of coaxial connector **28**, secured to base plate **24**. Connector **28** may be a type-N or other suitable coaxial connector. The ratio of the diameter of aperture **29** to pin **27** is preferably chosen to provide the same characteristic impedance of the interconnecting coaxial cable with switches **16** and **18**, typically 50 ohms. It is to be understood that a number of pins **27** and coaxial connectors **28** are disposed equally around the periphery of lens **10** to provide a connection with the apex of each of tapers **25**. Each connector **28** provides a coupling port for lens **10**, with tapers or horns **25** providing a transition for the feedpoints or focal points of energy propagated in the dielectric medium between conductive plate **22** and base plate **24**. The taper is utilized to produce a gradual transition to minimize mismatch and hence losses by radiation spillover. Energy supplied to coaxial conductors **28** and thereby introduced at an arbitrary number of points around the periphery of the lens will be directed to a focal point located on a diameter parallel to the direction of propagation of a plane wave, as illustrated in FIG. 2.

Conducting plate **22**, including body portion **23** and tapers **25**, may be of copper, silver, or the like, and may be deposited or plated on dielectric medium **26** by known techniques. Its thickness need only be sufficient to minimize skin losses at the frequencies of interest, in the order of a few thousandths of an inch. Base plate **24** may be copper or brass, and has no critical electrical dimensions. It should be of sufficient thickness to provide convenient mounting for connectors **28** and to impart mechanical rigidity to dielectric material **26**.

Dielectric medium **26** is preferably a material having a high relative dielectric constant and a low loss-tangent. A low loss-tangent will minimize insertion loss of lens **10** in the overall system, while a high dielectric constant reduces physical dimensions to provide a compact unit. Commercially available high alumina ceramics have a relative dielectric constant in the order of 100 or greater, and a loss-tangent of less than 1×10^{-3}. Ceramic materials, in addition, are machinable to form a desired configuration and a metallic plate **22** may be readily painted, plated or deposited thereon. One such suitable material, having a loss-tangent of .0007 and a relative dielectric constant of 130 is ceramic N1400T110, supplied by the American Lava Corp. Other materials such as strontium titanate (loss-tangent .001, relative dielectric 300) and dielectric materials supplied under the trade names of "Eccoceram" and "Stycast" may also be used, and under certain circumstances, hereinafter discussed, air may be used as the dielectric material.

To minimize losses and to provide for losses that are substantially constant over a wide frequency range, it is desirable that the energy be propagated between plates **22** and **24** in the TEM mode. This mode is also advantageous where coaxial cable is used to interconnect array elements **14** and switches **16**, **18** in an overall system, as is conventional at UHF and the lower microwave portions of the frequency spectrum. The TEM mode of propagation is readily achieved by making the spacing between conducting plates **22** and **24** less than $\lambda/2\sqrt{\epsilon}$ (where ϵ is the relative dielectric constant for dielectric material **26**) for the highest frequency of interest. This effectively results in a low pass filter having a cutoff frequency determined by the spacing between plates **22** and **24**. And it can be shown that the ratio of lends diameter d to array element diameter D (see FIG. 2) is:

$$\frac{d}{D}=\frac{1+\cos\theta_0}{\sqrt{\epsilon}}$$

where θ_0 is a constant chosen to minimize phase error over a given aperture angle α and ϵ is the effective dielectric constant of the lens. Thus it is apparent that an extremely small and compact lens for a given array diameter may be realized by using a dielectric material having a large dielectric constant ϵ.

It is to be noted that the system of FIG. 1 utilizes a 1:1 correspondence lens, that is one having a number of feedpoints equal to the number of antenna array elements. Angular displacement of the focal point results in an equal angular displacement of the array beam and accordingly the antenna array can be steered 360° in azimuth by a complete revolution of the focal point on the lens circumference. Alternately a 2:1 correspondence lens may be utilized, with the number of feedpoints equal to one-half of the array elements. In this instance an additional set of single pole double throw switches are used to connect each port and its associated feedpoint to either one of two diametrically opposite array elements. In this instance, angular displacement of the focal point on the periphery of the lens results in one-half as much angular displacement of the array beam, and accordingly a complete revolution of the focal point on the lens circumference steers the beam 180° in azimuth.

A modification of lens **10** of FIGS. 3 and 4 is shown in FIGS. 5 and 6, and provides an in-line rather than a perpendicular coaxial to strip line transition. Conducting plate **22**, including body portion **23** and tapers **25**, is plated or depositioned on dielectric material **26** in the manner previously discussed. Dielectric material **26** is made circular in shape and has a diameter approximately equal to the spacing between the apexes of two diametrically opposite tapers **25**. Thus the apex of each taper **25** terminates at the periphery of dielectric material **26**. Base plate **24** is also circular and has the same diameter as dielectric material **26**. A plurality of mounting brackets **35** are secured to the annular edge of circular base plate **25**, and extend perpendicularly across the annular edge of circular dielectric material **26**, mounted coaxial with base plate **24**. Connectors **28** are in turn mounted on brackets **35** and positioned so that their center conductors **28a** rest on the top surface of dielectric material **26** and at the apexes of tapers **25**. Each connector **28** may be a standard coaxial type-N connector with its center pin shortened so that it just contacts the apex of a taper **25**, and an electrical connection such as soldering made at that point.

A still further modification wherein waveguide feed is provided for lens **10** is shown in FIGS. 7 and 8. This modification is particularly useful at X-band and higher microwave frequencies where coaxial interconnections of the overall system becomes undesirable. In this modification plates **22** and **24** both identical in structure, are made circular in configuration. A groove **37** is provided around the outer periphery each of plates **22** and **24**, and a plurality of holes **39**, parallel to the major axes of the lens **10**, are provided in grooves **37**.

A number of hollow rectangular members **40**, taking the form of short sections of waveguide, are disposed around the periphery of plates **22** and **24**. One end of the top and bottom walls of hollow members **40** are provided with lands **42** which mate with grooves **37**. Lands **42** are in turn bolted or screwed to the holes **39** in grooves **37** to maintain plates **22** and **24** in a fixed spaced relationship. As before, the spacing between the plates **22** and **24** is maintained less than $\lambda/2\sqrt{\epsilon}$ to provide propagation in the TEM mode. The other end of hollow members **40** are provided with a flange **44**, which may be a standard waveguide flange for mating with interconnecting waveguide of the overall system.

The lens periphery is at the outer periphery of circular plates **22** and **24**, and a feedpoint is provided at points about this periphery equidistant between the side walls of hollow members **40**. The space between the plates may be air filled, or may be filled with a suitable dielectric material as discussed. The dielectric reduces the physical size of the lens structure while air dielectric reduces losses which may be troublesome at higher microwave frequencies.

Because of the simplified construction of the above described focusing lens and of the simplified associated switching circuitry used therewith, circular antenna arrays having 100 or more elements may be conveniently scanned in discrete steps about a 360° azimuth by providing a lens with a multiplicity of focal points on its periphery. By utilizing microwave diode switches controlled by bistable multivibrator circuits connected as a ring counter and synchronized by a clock pulse, scanning rates between 200 r.p.s. and 20,000 r.p.s. are possible. A large number of array elements provides a high resolution so that angular separation of the two beam widths for individual array elements is readily distinguishable.

The invention provides, therefore, an improved antenna scanning system utilizing a simple and compact two-dimensional focusing lens. Electronic scanning of circular symmetric antenna arrays is readily achieved with a minimum of circuit complexity. The lens is readily adaptable to systems having a large number of independent array elements by use of a simple switching arrangement. Use of a high dielectric low loss material having a constant index of refraction for the lens simplifies construction and ensures reliable low loss operation over a wide band of frequencies in the UHF and microwave regions.

We claim:

1. A system for scanning a circular array of antenna elements including in combination, electromagnetic energy focusing means comprising a homogeneous cylinder of dielectric material having conductive boundary surfaces for electromagnetic energy disposed on the opposite ends thereof, a plurality of electromagnetic energy feedpoints spaced at discrete points around the periphery of said cylinder, with a selected one of said feedpoints providing a focal point for a plane wave of electromagnetic energy having a direction of propagation parallel to a diameter of said cylinder taken through said selected feedpoint, and circuit means for selectively coupling said one feedpoint to a common terminal while coupling the other feedpoints to elements of said antenna array, said circuit means operable to sequentially couple a different selected feedpoint to said common terminal to rotate said focal point around the periphery of said cylinder, thereby causing scanning of said antenna array elements.

2. A system for scanning a circular array of antenna elements including in combination, focusing means for electromagnetic energy comprising a pair of spaced apart conductive plates with a dielectric material of constant index of refraction disposed therebetween to provide a cylindrical transmission region for said electromagnetic energy, a plurality of electromagnetic energy feedpoints equally spaced at discrete points around the periphery of said cylindrical transmission region, with a selected one of said feedpoints providing a focal point for a plane wave of electromagnetic energy having a direction of propagation parallel to a diameter of said cylindrical region taken through said selected feedpoint, and switching means operable to sequentially select different focal points while coupling remaining feedpoints to said array elements, thereby providing scanning of said array elements.

3. A system for scanning a circular array of antenna elements including in combination, a microwave lens comprising a pair of spaced apart conductive plates with a dielectric material of constant index of refraction disposed therebetween to provide a cylindrical transmission region for high frequency electromagnetic energy, a plurality of electromagnetic energy coupling ports, a plurality of transitions connected to said coupling ports to provide energy feedpoints about the periphery of said cylindrical transmission region, single-pole multi-throw switching means having a common port and a plurality of further ports, and a plurality of single-pole double-throw switching means for connecting one of said electromagnetic energy coupling ports to said further ports while at the same time connecting the remaining ones of said electromagnetic coupling ports to elements of said antenna array, said single-pole multi-throw switching means and said single-pole double-throw switching means operable to rotate the energy feedpoints of said cylindrical transmission region about its periphery to thereby cause scanning of said antenna array elements.

4. A focusing lens for electromagnetic energy comprising a homogeneous cylinder of dielectric material, conductive surfaces on each end of said cylinder defining a transmission region within said cylinder, and a plurality of energy coupling means spaced at discrete points around the periphery of said cylinder, with a selected one of said energy coupling means providing a focal point for a plane wave of electromagnetic energy having a direction of propagation parallel to a diameter of said cylinder taken through said selected energy coupling means.

5. A microwave lens including in combination, first and second conductive plates with a dielectric medium of uniform dielectric constant disposed therebetween, said plates and said dielectric medium providing a cylindrical transmission region having a constant index of refraction, and a plurality of feedpoints for electromagnetic energy disposed at discrete points around the periphery of said cylindrical transmission region, with a selected one of said feedpoints providing a focal point for a plane wave of electromagnetic energy appearing at the other feedpoints and having a direction of propagation parallel to a diameter of said cylinder taken through said selected feedpoint.

6. The lens of claim **5** wherein the spacing of said conductive plates is less than one-half of the effective wavelength of the electromagnetic energy propagated in said cylindrical transmission region.

7. A microwave lens including in combination, a body of dielectric material having first and second parallel major surfaces and having a constant index of refraction throughout, first and second conductive members disposed on said major surfaces, at least one said conductive member having a circular body portion to thereby define a cylindrical transmission region within said dielectric material, a plurality of electromagnetic energy coupling ports, and a plurality of electromagnetic energy transitions equally spaced about the periphery of the circular

body portion of said one conductive member, each said transition connected between the periphery of the circular body portion of said one conductive member and one of said coupling ports to thereby provide a plurality of equally spaced energy feedpoints about the periphery of said cylindrical transmission region, with each said feedpoint providing a focal point for a plane wave of electromagnetic energy having a direction of propagation parallel to a diameter of said cylindrical transmission region taken through such feedpoint.

8. The microwave lens of claim **7** wherein said dielectric material has a relative dielectric constant substantially greater than unity.

9. The microwave lens of claim **7** in which said coupling ports are coaxial transmission line connectors and said transitions are comprised of generally triangular conductive members having an apex connected to the center conductor of said coaxial connector and a base contiguous with the periphery of the circular body portion of said one conductive member.

10. A microwave lens including in combination, first and second disc shaped metallic plates, said metallic plates coaxial with one another and spaced apart to provide a cylindrical transmission region therebetween, and a plurality of wave guide transition elements disposed around the periphery of said cylindrical transmission region, said transition elements providing a plurality of feedpoints for electromagnetic energy around the periphery of said cylindrical transmission region, with individual ones of said feedpoints providing a focal point for a plane wave of electromagnetic energy having a directional propagation parallel to a diameter of said cylindrical transmission region taken through such feedpoint.

11. The microwave lens of claim **10** wherein said cylindrical transmission region has a relative dielectric constant of unity and has a constant index of refraction throughout.

12. A microwave lens of claim **10** wherein said cylindrical transmission region has a relative dielectric constant substantially greater than unity and has a constant index of refraction throughout.

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R. E. BERGER, Assistant Examiner

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