June 8, 1948. H. A. IAMS 2,442,951

SYSTEM FOR FOCUSING AND FOR DIRECTING RADIO FREQUENCY ENERGY

Filed May 27, 1944 4 Sheets-Sheet 1

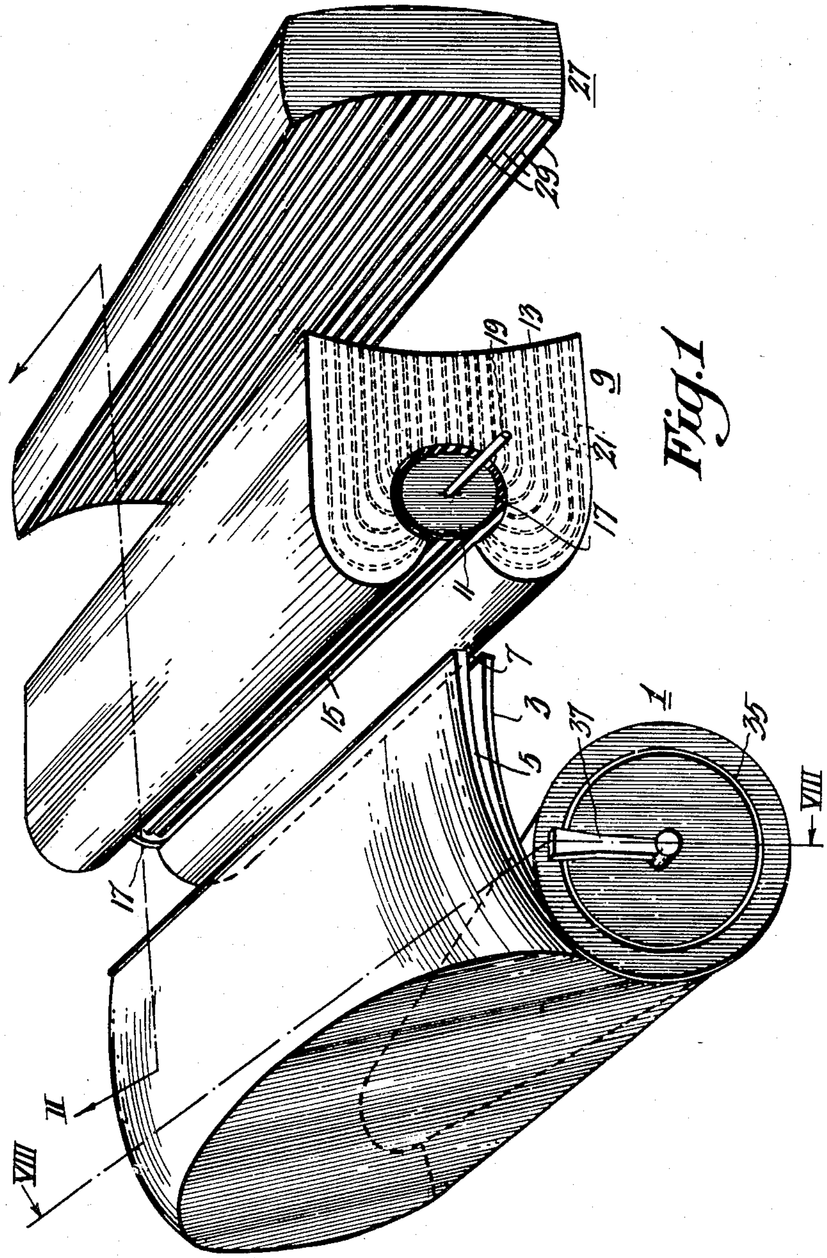


Fig. 1

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June 8, 1948. H. A. IAMS 2,442,951

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Filed May 27, 1944 4 Sheets-Sheet 2

Fig. 2.

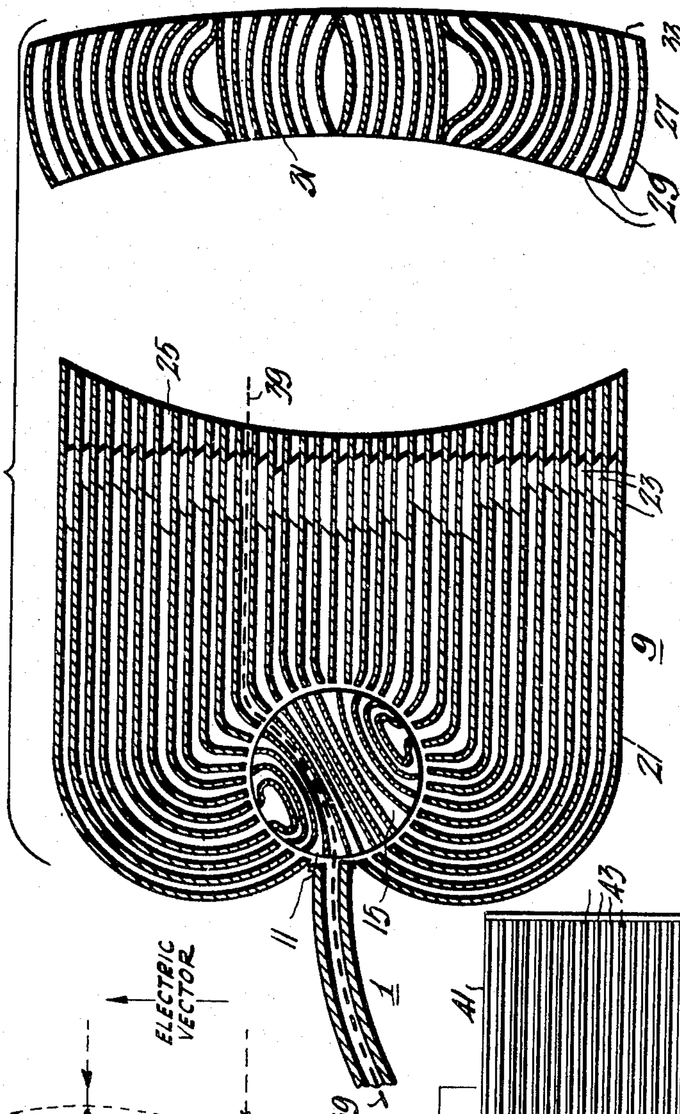


Fig. 3.

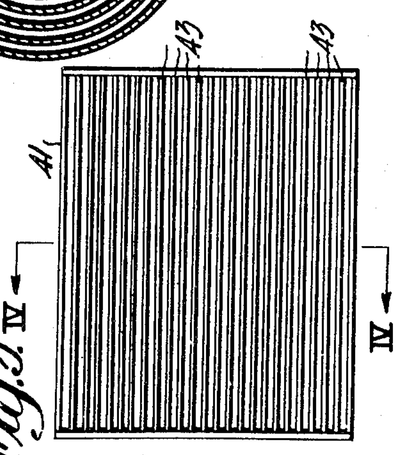
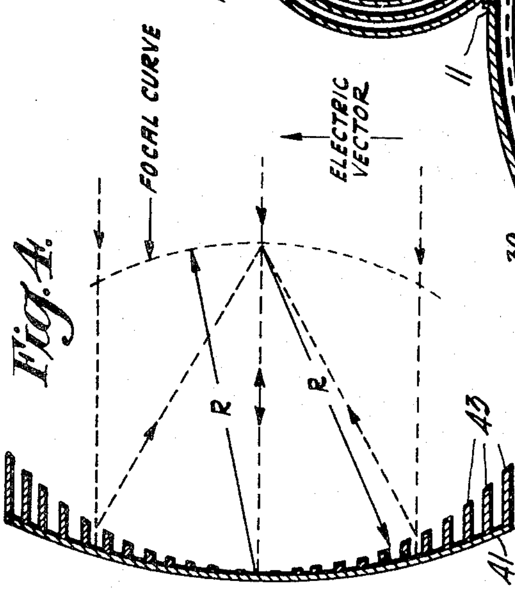


Fig. 4.

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4 Sheets-Sheet 3

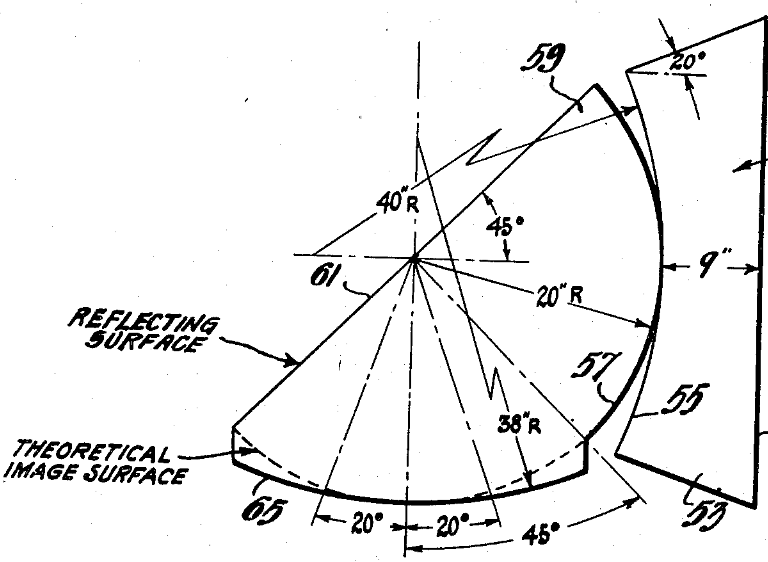


Fig.5.

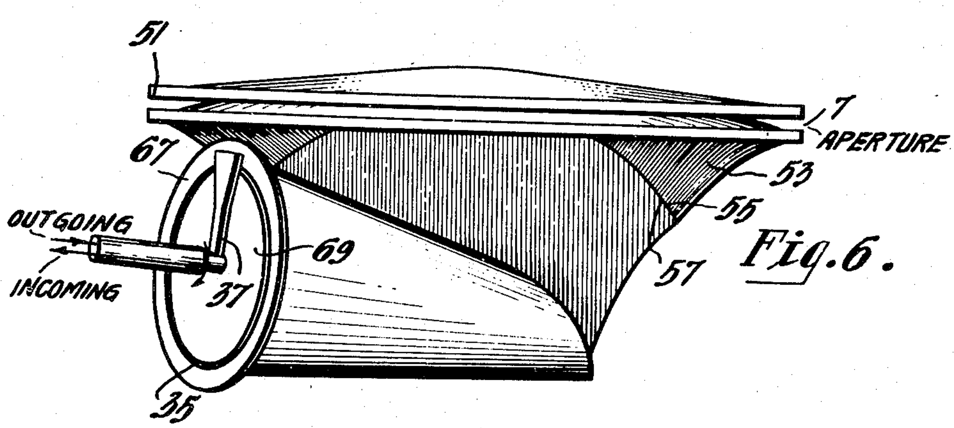


Fig.6.

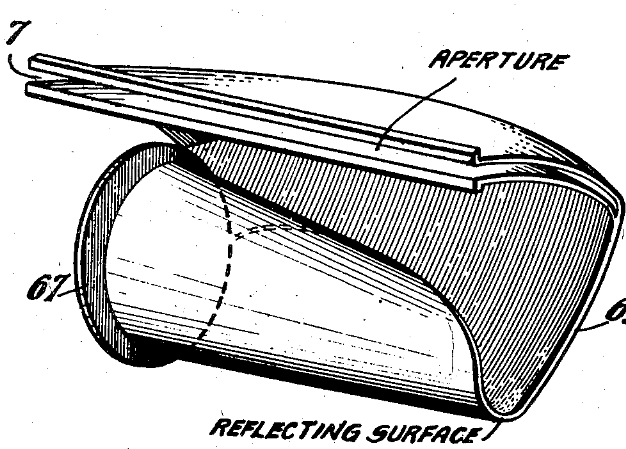


Fig.7.

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June 8, 1948. H. A. IAMS 2,442,951

SYSTEM FOR FOCUSING AND FOR DIRECTING RADIO FREQUENCY ENERGY

Filed May 27, 1944

4 Sheets-Sheet 4

Fig. 8.

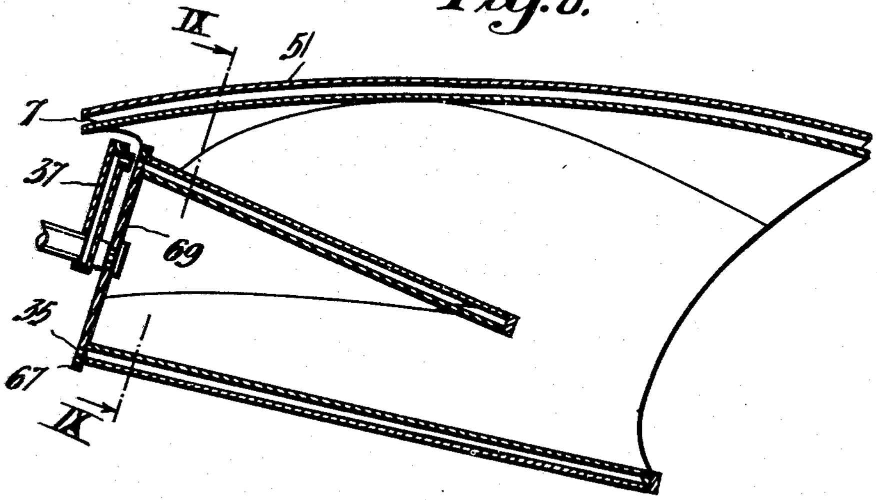
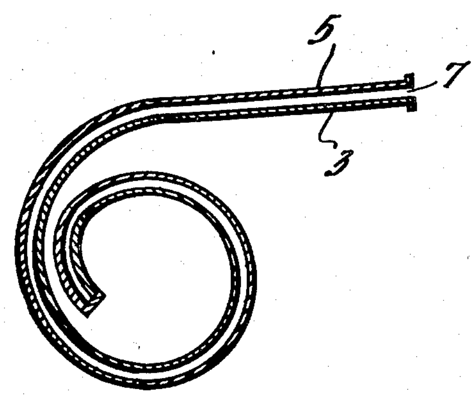



Fig. 9.

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# UNITED STATES PATENT OFFICE

2,442,951

## SYSTEM FOR FOCUSING AND FOR DIRECTING RADIO-FREQUENCY ENERGY

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Application May 27, 1944, Serial No. 537,624

21 Claims. (Cl. 250—33.63)

1

This invention relates to a system for focusing and for directing radio frequency energy, and more especially to a system for scanning with radio-frequency waves a scene to be viewed. In radio vision, it is desirable to scan the scene to be viewed by radiating directively a narrow beam of radio-frequency energy which is reflected, converted into electrical signals at the receiver, and finally converted into optical indications corresponding to the reflected energy.

Numerous scanning devices have been proposed. One such scanning device is described and claimed in applicant's copending application Serial No. 533,311, filed April 29, 1944, for Radio wave devices. In the system disclosed in the copending application, means are provided for establishing a narrow beam of radio-frequency energy. The narrow beam may be directed along one dimension of the scene to be viewed. The beam is directed along a second dimension of the scene by means of a reflector which is rocked back and forth to secure the necessary scanning along the second dimension.

While such means are usually effective from an electrical viewpoint, the rocking reflector has mechanical disadvantages. One means for eliminating the rocking reflector has been proposed by Richard L. Burtner. The Burtner device, which is more completely described in copending application Serial No. 536,161, filed May 18, 1944, for Radio frequency devices, employs a pair of scanning means of the type disclosed in the Iams application and a device for rotating the plane of polarization of the outgoing or incoming waves. While the Burtner device eliminates the mechanical difficulties, it does so slightly at the expense of the electrical characteristics of the system.

According to the present invention, continuously rotatable parts are employed to direct the radio scanning beam toward the scene to be viewed. The scanning beam is directed along one dimension of the scene to be viewed by means of the device claimed in applicant's hereinbefore mentioned application. The beam, which is established and directed, say, in the horizontal dimension, moves through an angle of approximately 40 degrees. The thus directed beam is applied to a continuously rotatable element which distributes the beam to a selected group of wave guiding elements whereby the beam is moved along the other dimension of the scene to be viewed.

Since the last mentioned wave guiding means produces waves having a cylindrical front, it is

2

necessary for vertical focusing to interpose, between the wave guiding means and the scene, a lens or focusing device for converting the waves having a cylindrical wavefront into waves having a plane wavefront. In place of the converting and focusing device, a novel wave reflector may be employed.

One of the objects of the invention is to provide an improved radio vision scanning system. Another object of the invention is to provide an improved radio scanning system in which continuously rotating parts are employed. Another object of the invention is to provide a novel wave focusing and directing system in which aberrations are minimized. An additional object is to provide an improved radio frequency lens. A further object is to provide an improved wave reflecting and focusing device.

The invention will be described by referring to the accompanying drawings, in which Figure 1 is a perspective view of one embodiment of the invention; Figure 2 is a sectional view taken along the line II—II of Fig. 1; Figure 3 is an elevational view of the wave reflector of the invention; Figure 4 is a sectional view taken along the line IV—IV of Fig. 3; Figure 5 is a plan view of one of the sheets which are formed into the wave guide device 1 of Fig. 1; Figures 6 and 7 are respectively a front view and a perspective view of the wave guide device; Figure 8 is a sectional view taken along the line VIII—VIII of the scanner of Fig. 1; and Figure 9 is a sectional view taken along the line IX—IX of Fig. 8 of the scanner of Fig. 1. Similar reference characters indicate similar elements in the drawings.

Referring to Fig. 1, a wave guiding device 1, including a pair of wave guiding members 3, 5, is disposed so that its rectangular aperture 7 is positioned near the rectangular opening of a second wave guiding device 9. The second device includes a continuously rotatable assembly 11, consisting of a plurality of wave guiding members, and a stator assembly 13 of several wave guiding members.

The second wave guiding device 9 may be best understood by referring to Fig. 2. The rotatable assembly 11 includes a plurality of wave guiding members or channels 15 which are preferably formed by conductors having the same effective path length. These conductors are disposed symmetrically with respect to a selected diameter of the rotor and are arranged so that one aperture of each wave guiding member is disposed parallel to the rectangular opening of the focusing device 1. The several wave guiding members are formed by suitably bending the conductors so that paths in the channels have the same effective length. The several members may be soldered or otherwise secured to circular end plates 17, which are in turn fastened to a shaft 19 which is connected to a motor and to a sweep generator (not shown). The rotatable assembly 11 forms a cylinder which is disposed within the cylindrical opening of the stator 9.

The stator also consists of a plurality of wave guiding elements 21, which are disposed parallel to each other and are spaced one-half wave length or less of the applied wave length to form channels. It is preferable to have the lengths of the wave guiding elements of the stator equal to $L+K\lambda$, where L is a predetermined length of one of said guiding elements, K is any integer, and $\lambda$ is the length of the applied waves. From inspection, it will be seen that the wave guiding elements terminate at one end in a cylindrical surface which surrounds the rotor and at the other end in a cylindrical surface which has a predetermined radius corresponding to that of the image surface of the focusing element 27.

It is difficult to arrange the several wave guiding elements so that they are (*a*) symmetrically disposed about the center of the stator 9, (*b*) terminated at the cylindrical surface of the rotor, and (*c*) terminated at the second cylindrical surface without introduction of slight irregularities in effective lengths. Therefore, it is preferable to employ phase correcting means such as the insulation blocks 23. These insulation blocks have a dielectric constant other than unity, whereby the effective path length of each of the several wave guiding channels may be adjusted. In order to minimize reflections from the dielectric, the blocks may be tapered as shown.

The waves emerging from the opening 25 of the stator 9 have a cylindrical wavefront which is converted into a plane wavefront by means of the focusing device 27. The focusing device 27 consists of a plurality of conducting vanes 29, with parallel edges. Both edges of a given fin are the same distance from the axis, measured along the cylindrical surfaces. The spacing between edges of any two adjacent fins is preferably, but not necessarily the same. The vanes are spaced from each other by one-half wave length or less, so that waves polarized normal to the surface of the vanes pass through the guiding portions with negligible attenuation. The several path lengths are made equal to $L+K\lambda$, where L is the length of one of the vanes as measured in the sectional view, K is any integer, and $\lambda$ is the length of the applied wave. The wave guiding members are symmetrically arranged on either side of the center line. The wave guiding members terminate openly along predetermined geometrical surfaces. By way of example, the surface 31 is in the form of a cylinder having a radius $r$, while the surface 33 is in the form of a cylinder having a radius $2r$. The focusing device 27 is disposed so that the center of curvature of the surface 31 coincides with the center of curvature of the stator surface 25.

While this "lens" has many of the properties of a cylindrical lens, it has the advantage that the absorption and reflection of the usual refracting material is avoided, and aberration can be made low for all parts of the image.

The operation of the shutter "lens" is as follows: Suppose that a plane wavefront, polarized with its electric vector perpendicular to the edges of the shutters, arrives on the side with the larger radius of curvature. Any two adjacent fins slice off a section of the wavefront having a height less than one-half wave length and a length as great as the length of the fins. As the wave passes between the two fins, motion in a horizontal direction is not altered; the vertical component of motion is guided by the attachment of the electric field to the conducting fins. Since the path length between any of the sets of fins is the same (or different by an integral number of wave lengths), the phase delay for all parts of the wavefront is the same. However, the shape of the entrance and exit sides of the device is different. The electric fields emerging from adjacent channels therefore join hands to form a new wavefront which has a shape different from that on the entrance side. For the proportions given, a plane wavefront is converted into a cylindrical wavefront which focuses at a distance from the emergent side equal to twice the radius of that side.

The foregoing description is for a shutter "lens" which best fits the present purpose. However, the "lens" is not limited to the proportions mentioned. The surfaces joined by the equal-width fins might be a plane, and a circular cylinder of radius $r$, for example. In this case a plane wavefront incident in the same phase at all parts of the plane surface will, after passing over a multitude of paths of equal phase delay, emerge at the cylindrical surface with all parts of the wavefront in phase. The emerging cylindrical wavefront then comes to a focus on the axis of the cylinder. Radiation which is incident at some angle other than the one mentioned is also focused, though the focus is not equally good for all angles (as is substantially true for the preferred design).

For certain applications, such as the correction of aberration of other optical systems, the principles outlined above may be used without making a device which is itself a focusing element. Thus, when there is a wavefront of one shape which should be converted to another shape, the conversion may be made by connecting radiators on a surface of the first shape to radiators on a surface of the second shape by means of a multiplicity of wave-guiding elements having equal phase delay.

One of the sheets 3 is illustrated in Fig. 5. In this view the sheet 5 is shown flat. One edge of the aperture 7 of Figs. 1, 6 and 7 is defined by the edge 51 of the sheet 53, which is formed so that its curved portion 55 may be joined by soldering or the like to the curved portion 57 of the second sheet 59. The second sheet includes a straight portion 61 to which, after the sheet 59 is curved, is secured a reflecting surface 63. The second sheet 59 is curved into a hollow conical form in which the curved line 65 becomes the base and one boundary of the annular portion or opening 35.

The combination of the sheets 53 and 59 thus described is duplicated and the two sheets are held in spaced relation by suitable spacers to form the wave guide device illustrated in Figs. 1, 6 and 7. The base of the device may include an annular plate 67 and a central disc 69. The focal region of the device is the annular region between the curved portions 65 of duplicate sheets 61. A wave guide member 37 with an opening adjacent the annular region 35 is arranged to rotate so that outgoing radio frequency energy may be successively applied to portions of the annular region or so that incoming radio frequency energy may be applied from successive portions of the annular region to the receiver which is not shown.

In the operation of the wave guide means 1, any plane wave applied to the aperture 7 will be focused at a point or small region in the annular focal region 35. As the angle between the plane wave front and the aperture changes, the focal point will change. In a similar manner as the outgoing energy is applied to different portions of the focal region, the angle between the wave front and the aperture will change. The effect of the change corresponds to sweeping the outgoing beam back and forth through the line to be scanned.

In the thus described scanning system, the waveguiding device 1 includes an annular opening 35 and a rotatable waveguide 37. Energy supplied through the waveguide 37 from a radio frequency generator (not shown) and through the annular opening 35 is guided through the device so that the beam of energy is focused and directed through the rectangular aperture 7, and deflected in synchronism with the rotations of the rotating waveguide 37. In other words the radio frequency energy emerging from the aperture 7 is continuously changing in phase along the length of the aperture in synchronism with the rotations of the waveguide member 37 so that the beam is directed through the scanning angle. By way of example, a beam 1° in width may be moved through an angle of 40° which subtends one dimension of the scene to be scanned. While in Fig. 1 the rectangular aperture has been spaced from the rotor 11 to make the illustration clear, it should be understood that in practice the rectangular opening is disposed close to the rotor as shown in Fig. 2.

The rotor 11, acting as a commutator or switching device, selectively applies the energy from the first waveguiding means 1 to the several channels of the stator 9. By way of example, the broken line 39 shows how the wave energy is directed through one of the wave guiding channels of the stator. Because of the symmetrical arrangement of the rotor, the energy will be directed from the uppermost channel through the several channels to the lowermost channel (or vice versa, depending on direction of rotation) twice per revolution of the rotor. If the rate of rotation of the rotor 11 is made substantially less than the rate of rotation of the rotating waveguide member 37, the beam of energy may make a complete horizontal sweep while the vertical deflection is from one channel to the next. The two rotatable elements 11 and 37 are preferably connected together through suitable gearing (not shown). The energy thus emerging from the cylindrical surface 25 will be focused by the shutter-like lens 27 on the scene to be viewed, the elevation of the beam depending upon the position of emergence of the energy from surface 25.

It should be understood that, while the foregoing description has been limited to the application of radio frequency energy which is radiated directively toward the scene to be viewed, the same device is capable of receiving selectively the reflected energy from the scene. Thus the device may be used for transmitting or for receiving or, by applying discrete pulses of energy and by using a TR box, the device may be used for both transmitting and receiving.

While the system has been described for the transmission type of lens 27, it should be understood that the energy may instead be reflected by the cylindrical reflector illustrated in Figs. 3 and 4. If the reflector is employed, it should be disposed so that its center line forms a suitable angle (for example 45°) with the center line of the waveguiding device 9, whereby the reflector will not be shadowed by the device 9 but will apply thereto the radio frequency energy reflected from the scene to be viewed. The reflector consists of a cylindrical member 41, on whose surface are secured a number of wave guiding elements 43. The wave guiding elements are disposed along the flat dimension of the cylindrical surface 31 and extend generally toward the source of waves to be reflected. The space between the waveguiding elements 43 is preferably not over one-half wave length of the applied energy. It will be seen that the depths (measured from the surface 41) of the waveguiding elements 43 progressively increase as the distance from the center line increases. Moreover, the surfaces of the several wave guiding elements terminate in a cylindrical surface whose radius is equal to $r$. The thus arranged reflector focuses the radio frequency energy in a focal region defined by a cylinder having a radius equal to $r$ and having a center coinciding with the center of the reflecting surface.

The cylindrical reflector of Figs. 3 and 4 has the property of focusing, with small aberration, a wavefront moving parallel with the axis or at any moderate angle to the axis. (With the well-known parabolic reflector the focus is perfect on the axis, but it deteriorates rapidly for increasing off-axis angles.) The design of the preferred reflector is as follows: A circle having a radius $r$ equal to the desired focal length is drawn with its center on the axis. An ellipse with its minor axis extending from the center of the circle to the intersection of the circle with the axis is drawn, with its major axis equal to 2R. Then conducting fins, spaced $\lambda/2$ or less, are placed between a portion of the circle and a portion of the ellipse; the fins are parallel to the axis. The elliptical surface 41 is made of a conducting or reflecting material. For a cylindrical reflector, the structure should be extended perpendicular to the paper as far as desired.

In operation, a plane wavefront incident on the mirror is sliced into strips by the fins extending out from the elliptical surface. The strips of wavefront are guided by the fins to the reflecting surface, and back out to the aperture through which they came. It has been found analytically and experimentally that the phase delay between adjacent channels is such that the emerging wavefront (formed by the joining of the multiplicity of strip wavefronts) is of such form as to focus at a distance $r$ from the mirror, and that the focus remains good when the radiation is incident at considerable angles off axis.

Thus the invention has been described as an improved radio scanning system by means of which a narrow beam of radio frequency energy may be established, focused, and directed so that it scans the scene to be viewed along two dimensions. The system includes a "shutter" lens or a vane type reflector, both of which have other uses.

I claim as my invention:

1. A radio vision scanning system including in combination, wave guiding means for forming a narrow beam of radio wave energy, means for directing said beam through an angle subtending one dimension of a scene to be viewed, and sup-

plementary means including a continuously rotatable element interposed between said wave guiding means and said scene for directing said narrow beam of radio wave energy through an angle subtending another dimension of said scene.

2. A radio vision scanning system including in combination, wave guiding means for forming a narrow beam of radio wave energy, means for directing said beam through an angle subtending one dimension of a scene to be viewed, and supplementary means including a continuously rotatable element interposed between said wave guiding means and said scene for directing said narrow beam of radio wave energy through an angle subtending a dimension disposed at right angles to the first mentioned dimension.

3. A radio vision scanning system including in combination, wave guiding means for forming a narrow beam of radio wave energy, means for directing said beam through an angle subtending one dimension of a scene to be viewed, supplementary means including a continuously rotatable element interposed between said wave guiding means and said scene for directing said narrow beam of radio wave energy through an angle subtending another dimension of said scene, said supplementary means having an effective length such that the radio waves emerging therefrom have a substantially cylindrical wavefront, and means for converting said waves having a cylindrical wavefront into waves having a plane wavefront.

4. A radio vision scanning system including in combination, wave guiding means for forming a narrow beam of radio wave energy, means for directing said beam through an angle subtending one dimension of a scene to be viewed, supplementary means including a continuously rotatable element interposed between said wave guiding means and said scene for directing said narrow beam of radio wave energy through an angle subtending a dimension disposed at right angles to the first mentioned dimension, said supplementary means having an effective length such that the radio waves emerging therefrom have a substantially cylindrical wavefront, and means for converting said waves having a cylindrical wavefront into waves having a plane wavefront.

5. A radio vision scanning system including in combination, wave guiding means for forming a narrow beam of radio wave energy, means for directing said beam through an angle disposed in a predetermined plane, and supplementary means including a continuously rotatable element for directing said beam through an angle in a second plane normal to said predetermined plane, said supplementary means including a plurality of wave guiding elements having effective lengths equal to $L+K\lambda$, where L is a predetermined length of one of said wave guiding elements, K is any integer and $\lambda$ is the length of said waves.

6. A system according to claim 5, in which the wave guiding elements of said supplementary means include materials having dielectric constants, other than unity, for adjusting the effective lengths of said wave guiding elements.

7. A system for focusing and for directing radio frequency energy including a first focusing device having conjugate points substantially at infinity and along one portion of the circumference of a cylinder of predetermined radius, a wave guiding device consisting of a plurality of juxtaposed wave guiding members having the same effective length and terminating, respectively, in an aperture disposed on another portion of the circumference of said cylinder and in a second cylindrical surface, and a rotatable assembly of wave guiding members for extending, successively, certain of said wave guiding members to a region bounded by a rectangle and including a portion of said second cylindrical surface.

8. A system for focusing and for directing radio frequency energy including a first focusing device having conjugate points substantially at infinity and along one portion of the circumference of a cylinder of predetermined radius, a wave guiding device consisting of a plurality of juxtaposed wave guiding members having the same effective length and terminating, respectively, in an aperture disposed on another portion of the circumference of said cylinder and in a second cylindrical surface, and a rotatable assembly of wave guiding members for extending, successively, certain of said wave guiding members to a region bounded by a rectangle and including a portion of said second cylindrical surface, each of the wave guiding members of said rotatable assembly having the same effective length.

9. A system for focusing and for directing radio frequency energy including a first focusing device having conjugate points substantially at infinity and along one portion of the circumference of a cylinder of predetermined radius, a wave distributing device consisting of a plurality of juxtaposed wave guiding members having the same effective length and terminating, respectively, in an aperture disposed on another portion of the circumference of said cylinder and in a second cylindrical surface, a rotatable assembly of wave guiding means for extending selectively certain of said wave guiding members to a region bounded by a rectangle and including a portion of said second cylindrical surface, and a second focusing means having an aperture substantially coinciding with said rectangle.

10. A system for focusing and for directing radio frequency energy including a focusing device having conjugate points substantially at infinity and along one portion of the circumference of a cylinder of predetermined radius, a wave guiding device consisting of a plurality of juxtaposed wave guiding members having the same effective length and terminating, respectively, in an aperture disposed on another portion of the circumference of said cylinder and in a second cylindrical surface, a rotatable assembly of wave guiding members for extending selectively certain of said first mentioned wave guiding members to a region bounded by a rectangle and including a portion of said second cylindrical surface, and a utilization means having an aperture substantially coinciding with said rectangle, and having a focal region disposed within an annular opening.

11. A system for focusing and for directing radio frequency energy including a first focusing device having conjugate points substantially at infinity and along one portion of the circumference of a cylinder of predetermined radius, a wave guiding device consisting of a plurality of juxtaposed wave guiding members having the same effective length and terminating, respectively, in an aperture disposed on another portion of the circumference of said cylinder and in a second cylindrical surface, a rotatable assembly of wave guiding members for extending selectively certain of said first mentioned wave guiding members to a region bounded by a rectangle and including a portion of said second

cylindrical surface, a second focusing means having an aperture substantially coinciding with said rectangle and having a focal region disposed within an annular opening, and rotating means for scanning said annular opening.

12. A device for focusing and for directing radio waves including a plurality of spaced vanes for guiding said waves, each of said vanes having an effective path length equal to $L+K\lambda$ where L is a predetermined length of one vane, K is any integer and $\lambda$ is the length of the waves, said vanes being spaced to permit passage of waves polarized substantially normal to the surfaces of said vanes, and terminating openly along the surfaces of predetermined geometrical forms.

13. A device for focusing and for directing radio waves including a plurality of spaced vanes having parallel edges for guiding said waves, each of said vanes having an effective path length equal to $L+K\lambda$ where L is a predetermined length of one vane, K is any integer and $\lambda$ is the length of the waves, said vanes being spaced $\lambda/2$ or less to permit passage of waves polarized substantially normal to the surfaces of said vanes and terminating openly along the surfaces of predetermined geometrical forms.

14. A device for focusing and for directing radio waves including a plurality of spaced vanes having parallel edges for guiding said waves, each of said vanes having an effective path length equal to $L+K\lambda$ where L is a predetermined length of one vane, K is any integer and $\lambda$ is the length of the waves, said vanes being spaced $\lambda/2$ or less to permit passage of waves polarized substantially normal to the surfaces of said vanes and terminating openly along the surfaces of predetermined geometrical forms, at least one of said surfaces being a cylinder of predetermined radius.

15. A device for focusing radio waves in a predetermined focal region including in combination a wave reflecting member having a surface curving along one dimension and flat along another dimension and a plurality of wave guiding elements mounted on said curved surface parallel to its flat dimension, said wave guiding elements being arrayed in parallel and spaced one-half wave length or less and being of increasing depth according to their spacing from the center to the edges of said curved surface.



16. A radio wave switching device including a plurality of wave guiding members having the same effective length arranged in the form of a cylinder.

17. A radio wave switching device including a plurality of wave guiding members having the same effective length arranged in the form of a cylinder, and means for applying energy to said wave guiding members.

18. A radio wave switching device including a plurality of wave guiding members having the same effective length arranged in the form of a cylinder, means for applying energy to said wave guiding members, means for applying, and means for removing energy.

19. A radio wave switching and distributing device including a plurality of wave guiding members terminating in a circular cylindrical surface, and a plurality of wave guiding members rotatable within said circular cylindrical surface.

20. A device for focusing and for directing radio waves including a plurality of spaced vanes terminating openly along surfaces of cylindrical form, the length of said cylindrical form being parallel to the longer dimension of the space between said vanes.

21. A device for focusing and for directing radio waves including a plurality of spaced vanes terminating openly along surfaces of cylindrical form, the length of said cylindrical form being parallel to the longer dimension of the space between said vanes, and in which the two surfaces of cylindrical form are defined respectively by radii $r$ and $2r$.

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