Dec. 12, 1961 M. S. WHEELER 3,013,266

BEAM STEERING APPARATUS EMPLOYING FERRITES

Filed April 18, 1957 2 Sheets-Sheet 1

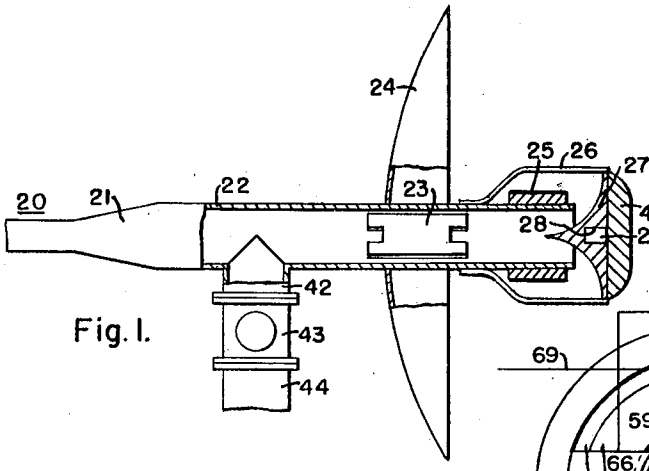



Fig. 1.

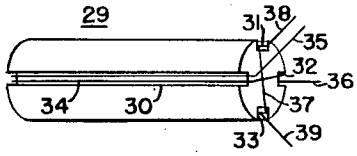



Fig. 2.

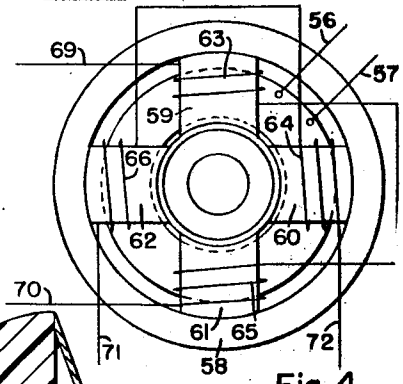



Fig. 4.

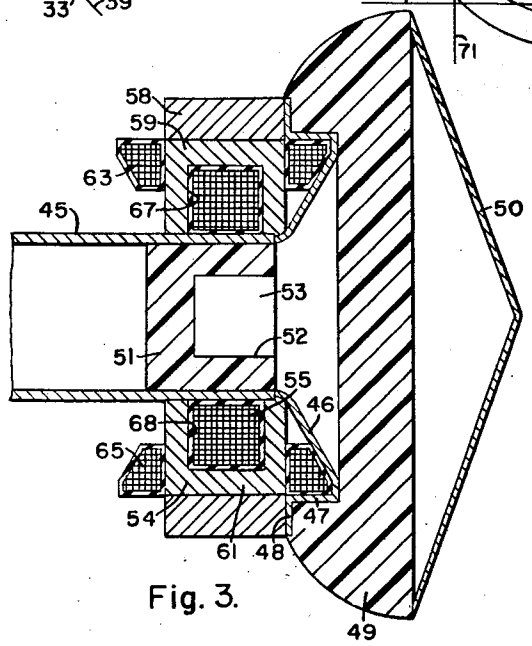



Fig. 3.

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Dec. 12, 1961 M. S. WHEELER 3,013,266

BEAM STEERING APPARATUS EMPLOYING FERRITES

Filed April 18, 1957 2 Sheets-Sheet 2

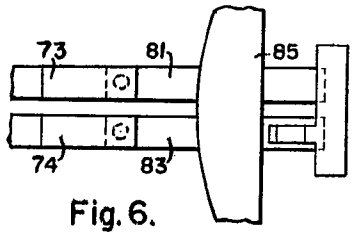


Fig. 6.

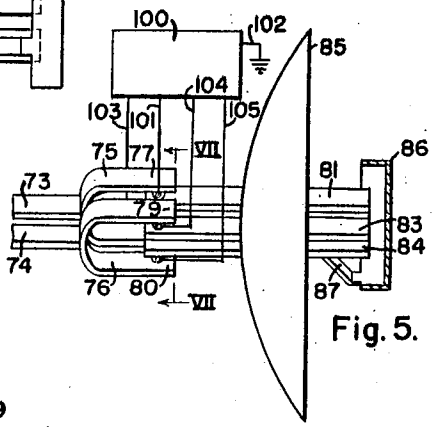


Fig. 5.

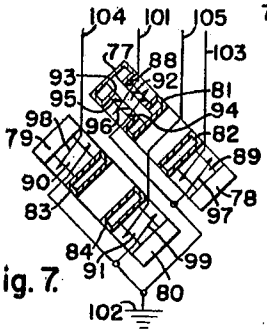


Fig. 7.

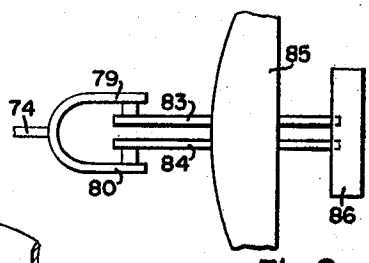


Fig. 8.

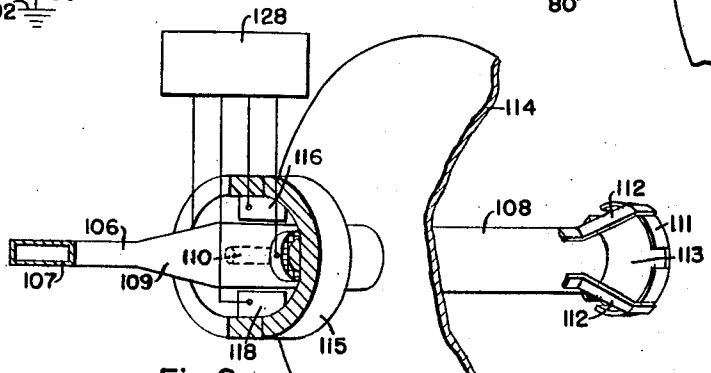


Fig. 9.

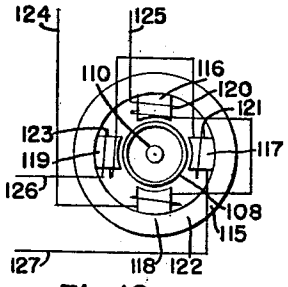


Fig. 10.

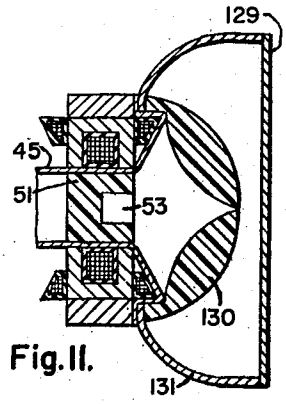


Fig. 11.

United States Patent Office 3,013,266 Patented Dec. 12, 1961



# 3,013,266
# BEAM STEERING APPARATUS EMPLOYING FERRITES

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Filed Apr. 18, 1957, Ser. No. 653,548
28 Claims. (Cl. 343—175)

This invention relates to radiant energy beam steering apparatus, and more particularly to beam steering apparatus employing ferrites for controlling and varying the direction of a beam transmitted from an antenna or other radiating means, and further for assisting in controlling the passage through preselected waveguide paths of energy to be transmitted and received energy reflected from a target.

Prior art antennas or other radiating devices for beam steering, in particular those for beam steering of the conical scanning type, have been characterized by physical motion of at least part of the antenna system. In some cases the physical motion has been motion of a secondary focusing system including a reflector or lens, while in other cases there has been motion of the primary feeding source. Apparatus for accomplishing the necessary physical motion has been complicated mechanically and expensive, and has usually resulted in mechanical vibration, high starting torque at low temperature and short life at high lobing speeds.

The apparatus of the instant invention provides for beam steering, including steering of the type necessary for conical scanning, without the necessity for any physical motion of any part of the antenna system. The subject apparatus employs a ferrite element or elements associated with the radiating apparatus and/or means for conducting energy thereto, and means associated with the ferrite element for producing a magnetic field or fields of such strength and direction with respect to the ferrite element and the energy conducting or radiating apparatus as to produce the desired directional characteristics in the radiated beam. The ferrite element is also used in a duplexing arrangement in some embodiments of the invention.

As will become apparent from the following description, the invention makes use of certain properties of ferrites when employed for conducting microwave energy. One of these is that the permeability of the ferrite may be varied by the application of an external magnetic field. Another property of ferrites employed is their anisotropy; that is to say, the permeability of the ferrite depends upon the orientation of the static magnetic field relative to the alternating magnetic field due to the incident electromagnetic wave. For a given static field strength and direction, there is a preferred polarization of the incident wave for propagation within the ferrite.

Thus, on one hand, the ferrite may be used to concentrate or reject wave energy in a given volume of space containing the ferrite and a suitable magnetic field. Within the ferrite element itself, to some extent, the path of maximum transmission of microwave energy may be controlled by the relatively static magnetic field.

On the other hand, the ferrite may be used to scatter energy in a preferred direction relative to the static magnetic field due to the existence of preferred propagation directions within the ferrite. For example, a small sphere immersed in an infinite plane circular polarized wave and in a static magnetic field will reradiate as a dipole principally along the axis of the magnetic field. The ellipticity of the reradiated energy will depend upon the orientation of the incident wave relative to the static field. In particular, if the incident wave is along the static field, the reradiating dipole is circular and no depolarization is present. As the magnetic field is turned, however, the direction of the principal scattering remains along the magnetic field but it becomes increasingly depolarized.



These effects, singly or combined, may be used to change a beam direction when suitably applied to a radiating system.

In addition to this application of the anisotropic properties of ferrites to beam steering, use is also made in the instant invention of other ferrite applications including their use as phase shifters, polarization rotators, and variable attenuators to produce beam deflection by more indirect methods. For example, a rotating linear polarization is produced in a circular waveguide containing a suitably designed ferrite element by a rotating magnetic field. Using such a polarization rotator with the conical scanner feed commonly referred to as a tri-slot, a deflected beam is produced rotating at three times the rate of rotation of the incident energy.

In another embodiment, a variable attenuator is employed using the magnetic field strength dependence of ferrites. By providing multiple feeds to a radiating system, the beam direction is altered by adjusting the relative power delivered to the separate feeds.

For simplicity, the more direct method of beam deflection may be preferred where the ferrite is used to scatter the incident energy in a preferred direction. In such a device, using circular polarized wave energy, where a ferrite element is disposed in a waveguide carrying circularly polarized wave energy and near the waveguide's opening into space, and is subjected to a transverse magnetic field, the beam or wave is bent by the magnetic field, and the direction of bending reverses when the direction of the magnetic field is reversed. Furthermore, the beam bending direction reverses its sense when the sense of the circular polarization is reversed. In addition, the beam bending direction reverses its sense when the direction of energy transmission is reversed.

It is a primary object of the invention to provide new and improved beam steering apparatus.

Another object is to provide new and improved beam steering apparatus having no moving parts.

Another object is to provide new and improved beam steering apparatus employing ferrites.

A further object is to provide ferrite beam steering apparatus for conical scanning.

Still a further object is to provide new and improved waveguide switching apparatus in which a ferrite element is utilized to assist in controlling the energy which passes through a given channel to a receiver.

Other objects and advantages will become apparent after a perusal of the following specification when studied in connection with the accompanying drawings, in which:

FIGURE 1 is a side elevational view partially in cross section of beam steering and duplexing apparatus constructed according to one embodiment of the invention;

FIG. 2 is a detailed perspective view of a magnetic field producing element of FIG. 1;

FIG. 3 is a cross-sectional view of beam steering apparatus constructed according to the preferred embodiment of the invention;

FIG. 4 is a schematic circuit diagram of the arrangement of coils for producing axial and transverse magnetic field components in the apparatus of FIG. 3;

FIG. 5 is a view in perspective of apparatus for producing a scanning beam by the use of four sequentially energized off-center antenna feeds;

FIG. 6 is a fragmentary detailed plan view of a portion of the apparatus of FIG. 5;

FIG. 7 is a cross-sectional view of a portion of the ap-

paratus of FIG. 5 showing ferrite variable coupling elements in more detail;

FIG. 8 is a side elevational view of the apparatus of FIG. 5 with portions of the beam forming reflector thereof broken away for clarity of illustration;

FIG. 9 is a view in perspective partially broken away and partially in cross section of beam steering apparatus constructed according to another embodiment of the invention;

FIG. 10 is a schematic view of that portion of the apparatus of FIG. 9 for producing a rotating transverse magnetic field; and

FIG. 11 is a view of a modified form of the embodiment of the invention shown in FIG. 3.

Particular reference should be made now to the drawings, in which like reference numerals are used throughout to designate like parts, for a more complete understanding of the invention, and in particular to FIG. 1 thereof, in which a waveguide generally designated by the reference numeral **20** is seen to have a tapered portion **21** which gradually tapers from a rectangular portion to a cylindrical waveguide portion **22**. Rectangular portion **20** is adapted to be connected to transmitting or wave energy generating means, not shown, to obtain therefrom microwave energy of a frequency suitable for transmission by the waveguide. The cylindrical waveguide portion **22** has disposed therein a dielectric member **23** for converting linearly polarized wave energy in the rectangular guide portion into a circularly polarized wave form, in a manner well known to those skilled in the art. A circularly polarized wave form may be desirable because of the symmetry thereof. The wave form in guide portion **22** may be of the $TE_{11}$ mode. Disposed around the outside of the cylindrical waveguide portion **22** is a reflector dish preferably of parabolic contour and generally designated **24**, provided for purposes to be hereinafter more clearly apparent. Disposed around the outside of the cylindrical waveguide portion **22**, as seen in FIG. 1, on the right-hand end thereof is a permanent magnet which may be in the form of a metallic sleeve and designated **25**, the ends of the sleeve **25** being of suitable magnetic polarity, for example, the left-hand end being the north magnetic pole and the right-hand end as seen in FIG. 1 being the south magnetic pole. Mounted on the right-hand end of cylindrical waveguide section **22** is a feedome **26** which is preferably composed of dielectric material. Mounted on the feedome **26** is a shaped member composed of ferrite material and designated by the reference numeral **27**. It will be seen, FIG. 1, that the tapered end of member **27** extends into the adjacent end of the cylindrical waveguide portion **22** a sufficient distance so that the permanent magnet **25** provides a steady component of a magnetic field in the ferrite element, the steady component tending to be along the longitudinal axis of the waveguide portion. The ferrite member **27** has substantially centrally disposed therein a small bore **28** in which there is disposed a cylindrical magnetic field producing element **29**, the element **29** being shown in more detail in FIG. 2 to which particular attention is directed. The member **29**, which may be made of copper plated iron, is seen to have four longitudinally extending grooves at spaced intervals around the periphery thereof, the grooves being designated **30**, **31**, **32** and **33**, respectively. In pairs of these grooves are disposed two windings for generating a magnetic field, one of the windings being designated **34** and having leads **35** and **36**, the other winding being designated **37** and having leads **38** and **39**. Winding **34** is connected by leads **35** and **36** to a suitable source, not shown, of energizing sine wave potential of suitable frequency and amplitude whereas the other winding **37** is connected by leads **38** and **39** to an additional source, not shown, of energizing sine wave potential of the same frequency and amplitude and 90 degrees out of phase with the first-named potential. This arrangement provides for the generation of a rotating magnetic field component, as will be readily understood by those skilled in the art.



Mounted upon the feedome **26** adjacent the ferrite member **27** is a non-magnetic metallic reflector element **40**, commonly referred to as a splash plate.

The cylindrical waveguide portion **22** is seen to be in the form of a T-joint, the T-joint being positioned in a predetermined position in the cylindrical portion, the T or outlet portion **42** being connected to a T-R device generally designated **43** which is connected by a coupled waveguide section **44** to receiving apparatus, not shown, provided for purposes to be made hereinafter more clearly apparent.

In the operation of the apparatus of FIGS. 1 and 2, the permanent magnet **25** provides an axial component of a static field and the small electromagnet **29** recessed into the end of the ferrite element **27** provides a field component rotating at the low frequency scan rate, which corresponds to the frequency of the sine wave voltages hereinbefore mentioned. The resultant field is adjusted in a manner to make the circularly polarized wave in the waveguide follow the resultant low frequency magnetic field and leave the feed or open end of the waveguide portion **22** in a direction controlled by the rotating magnetic field. This direction is off-center to at least a small extent from the longitudinal axis of the waveguide and the wave reflected from the metal reflector **40** is off-set with respect to the antenna center line. It is reflected back to the aforementioned reflector element **24**, where it is reflected out into space at a small angle with respect to the longitudinal axis of the waveguide section and the focal axis or reflection axis of the reflector element **24**. As the field in element **29** rotates, the beam of radiant energy rotates about the reflector axis and provides for a conical scanning beam.

The polarization changer **23** may be omitted, if desired, taking suitable design precautions in the feed to produce a uniformly nutating beam in spite of the asymmetry of the incoming wave.

Should it be desired to use the same antenna apparatus for receiving, as is ordinarily the case in radar apparatus, the aforementioned T-joint **42** is provided which passes received energy through the T-R tube **43** and the adjacent waveguide section **44** to receiving apparatus, not shown. By suitable arrangement of dimensions, certain advantages are derived, as will be made hereinafter more clearly apparent.

Reference is made now to FIGS. 3 and 4 in which the preferred embodiment of the invention is illustrated. A cylindrical waveguide **45** has a portion thereof broken away for clarity of illustration and is adapted to be connected to microwave energy generating means which generates wave energy of a frequency suitable for transmission by the waveguide. At the right-hand end of waveguide **45** as seen in FIG.3 there is an outwardly flaring portion **46** with an annular lip portion **47** and an annular flange portion **48**. The aforementioned flaring flange **48** and lip portion **47** may be formed integrally with the waveguide or may be formed separately if desired. The cylindrical waveguide **45** contains preferably circularly polarized energy to be radiated, the circular polarization having been obtained by any convenient means, as will be readily understood by those skilled in the art. Mounted upon the flaring end of the waveguide is a dome support member designated **49** which may be composed of plastic or other suitable material. Mounted upon the dome **49** is a conical splash plate **50**. Disposed within the end of the circular or cylindrical waveguide **45** is a dielectric supporting member **51** having a bore **52** therein for receiving a preferalby cylindrical ferrite member **53**. Disposed around the outside of the waveguide **45** adjacent the aforementioned member **51** is a ring shaped channel member **54**, composed of any suitable non-magnetic material, which may have a substantially square cross section having disposed therein a coil **55**

having leads 56 and 57, FIG. 4, for connecting the coil 55 to a suitable source of direct current potential, not shown, for energizing the coil and setting up a magnetic field component which passes axially through the ferrite member 53. Mounted upon an annular ring supporting member 58 are four pole pieces 59, 60, 61 and 62, having disposed thereon windings 63, 64, 65 and 66, respectively. Windings 63 and 65 are connected in series and are connected by way of leads 69 and 70 to a first source, not shown, of suitable sine wave energizing potential. Windings 64 and 66 are connected in series and are connected by way of leads 71 and 72 to a second source, not shown, of sine wave energizing potential, the first and second sources of energizing potential being of the same frequency and amplitude and 90° out of phase with each other whereby a rotating transverse magnetic field component is set up. The steady axial and rotating transverse magnetic field components provide a rotating resultant field.

In the operation of the apparatus of FIGS. 3 and 4, the reflecting splash plate 50 with its generally concave surface has the effect of converting the angular variations in the path of travel of the wave energy produced by the ansotropic ferrite in the waveguide into a virtual off-center source of radiation, to provide for a conical scanning beam radiated from a parabolic secondary reflector, not shown, which it is understood is located around the outside of the waveguide to the left of the magnetic field producing means, as seen in FIG. 3.

Particular attention should be paid now to FIG. 11, in which a modification of the embodiment of FIG. 3 is shown. In FIG. 11, the conical splash plate 50 of FIG. 3 has been replaced by a flat reflector 129, and a dielectric lens 130 added in feedome 131, the lens having a suitable shape such as that shown in FIG. 11, the dielectric lens 130 and reflector 129 providing for a displaced center of radiation.

Particular reference should be made now to FIGS. 5, 6, 7 and 8 in which another embodiment of the apparatus is illustrated. A pair of similar rectangular waveguides 73 and 74 have a pair of U-shaped waveguide portions 75 and 76, respectively, the U-shaped portion 75 having ends 77 and 78, and portion 76 having end portions 79 and 80. Waveguides 73 and 74 are both connected to receive preferably equal amounts of energy from generating means, of suitable frequency for transmission by the waveguides. Disposed near the aforementioned end portions 77, 78, 79 and 80 are four waveguide or antenna feed portions 81, 82, 83 and 84, respectively. Disposed around the outside of the antenna feed elements 81, 82, 83 and 84 is a first beam-forming reflector 85, and disposed adjacent the right-hand ends of the feeder elements, as seen in FIG. 5, is a second reflector 86 mounted by any suitable means such as arm 87, reflector element 86 reflecting energy leaving the feeds back to the parabolic reflector 85 for transmission into space. Reflector element 86 may have a dielectric feedome portion if desired.

Disposed between each of the waveguide end portions 77, 78, 79 and 80 and the adjoining portions of the feeder elements 81, 82, 83 and 84, respectively, are four variable coupling elements, FIG. 7, each of the coupling elements being seen to include a ferrite rod which extends between the waveguide and the antenna feed element, the coupling elements being generally designated 88, 89, 90 and 91, respectively. The coupling element 88 is seen to include the ferrite rod 92, the ends of which extend through bores 93 and 94 in the walls of the adjacent waveguide and feeder element, respectively. Ferrite rod 92 is surrounded over a portion of its length by member 95 which may be composed of dielectric material and a conducting outer wall forming a type of coaxial waveguide. The member 95 has therearound a coil 96 for producing a magnetic field. The aforementioned coupling elements 89, 90 and 91 are constructed in a manner similar to coupling element 88 and are seen to have coils 97, 98 and 99, respectively, therearound. Coil 96 has one terminal thereof connected to a source of energizing potential 100 by way of lead 101 and the other terminal thereof connected to ground 102. Coil 97 has one terminal thereof connected to ground 102 and the other terminal thereof conected by lead 103 to the aforementioned source of potential 100. Coil 98 has one terminal thereof connected to ground 102 and the other terminal thereof connected by lead 104 to source of potential 100. Coil 99 has one terminal thereof connected to ground 102 and the other terminal thereof connected by lead 105 to the aforementioned source of potential 100. The source of potential 100 is constructed and arranged to sequentially vary the energization of the coils 96, 97, 98 and 99 to thereby sequentially vary the strengths of the magnetic fields produced by the coils in their respective ferrite elements, such for example as ferrite element 92, to thereby vary the coupling between the ends of the waveguide and the associated ends of the antenna feeder elements. An arrangement is thereby provided whereby the off-center antenna feeder elements are sequentially energized in greater and thereafter lesser amounts to provide a periodically varying beam of radiation from reflector 85. By suitable choice of component parts and adjustment of voltages, a substantially conical scanning meam may be obtained, if desired. In FIG. 8 there is shown a side elevational view of the apparatus shown in perspective in FIG. 5, whereas in FIG. 6 a plan view, partially broken away, is shown.

Particular reference should be made now to FIGS. 9 and 10 in which an additional embodiment of beam steering apparatus is shown. A waveguide generally designated 106 has a rectangular portion 107 and a cylindrical portion 108 connected by a tapered portion 109. The rectangular portion is adapted to be connected to transmitting means or other source of linearly polarized wave energy, not shown, suitable for transmission by the waveguide. Disposed within the cylindrical portion 108 is a cylindrical ferrite member 110, having its longitudinal axis in substantial alignment with the longitudinal axis of the cylindrical waveguide portion 108. Attached near the open end of portion 108 is a tri-slot reflector plate or element 111 which may be mounted by any suitable means such as the arms 112 and spaced from the end of the waveguide by a dielectric feedome 113. Disposed around the waveguide portion 108 is a beam forming dish or reflector 114 which may be of parabolic contour. Disposed around the outside of the waveguide section 108 adjacent the aforementioned ferrite member 110 and spaced from the outer surface of the waveguide section is a soft iron ring or core member 115 which provides a return path for the substantially transverse magnetic field generated by four electromagnets mounted on the inside of the ring member 115 at equally spaced intervals around the periphery thereof. Four magnetic pole pieces 116, 117, 118 and 119 have windings 120, 121, 122 and 123, respectively. Oppositely disposed windings are connected in series to form pairs, and the pairs of windings are connected by leads 124, 125, 126 and 127 to a source of potential 128, FIG. 9, which energizes the pairs of windings with substantially sinusoidal voltages of the same frequency and amplitude displaced in phase 90° from each other to provide for a rotating magnetic field component transverse to the longitudinal axis of the ferrite element 110 and which rotates about the longitudinal axis thereof. The rotating transverse magnetic field on ferrite element 110 causes energy leaving the open end of cylindrical waveguide portion 108 and striking reflector 111 to be electrically offset from the antenna center line and to thereby be reflected to reflector 114 in such a manner as to provide a beam which is off-center from the radiation or reflection axis ot reflector 114. This beam rotates in a conical pattern in accordance with the rotation of the transverse magnetic field on ferrite element 110. The polarization of the

microwave output to the tri-slot may rotate at twice the speed of the rotating magnetic field. The direction of polarization of the transmitted beam may rotate at three times the rotation rate of the polarization of the output or six times the frequency of the driving field.

Particular reference should be made now again to FIG. 1 for a description of certain duplexing aspects of the invention not heretofore described in detail. It is known in the art that where a wave of a certain polarization is transmitted, return signals from certain targets, for example, aircraft may be depolarized to a large extent, or, if for example left-hand circular polarization is used in transmission, half of the return signal may be right-hand circularly polarized. In some applications, it may be desirable to pass to the receiver only energy oppositely polarized to the transmitted energy.

In the instant embodiment, the transmitter and receiver lines may be in space quadrature with one another and provision made for transmission of one sense of circular polarization and the reception of the reverse sense of circular polarization. Assume by way of example that the entrance to T-R member 43 is spaced a predetermined distance, for example, ¼ wavelength, from the adjacent end of the cylindrical waveguide section, and that the energy received by section 20 is vertically polarized, while the T-R device 43 is adapted to receive or pass only horizontally polarized wave energy. The vertically polarized energy to be transmitted is changed into, for example, left-hand circularly polarized energy by circular polarizer 23, and is radiated from the open end of the waveguide at an angle with respect to the longitudinal waveguide axis in accordance with the instantaneous direction of the resultant transverse magnetic field. Assume by way of example that this direction is in the plane of the cross section at an angle of, for example 10 degrees with respect to the longitudinal axis of the waveguide. A portion of the received reflected energy will be right-hand circularly polarized, and will enter the open end of the waveguide at substantially the same angle with respect to the longitudinal axis. In accordance with hereinbefore described principles, this received right-hand circularly polarized wave energy will be changed by member 23 into horizontally polarized wave energy which will be passed by T-R device 43 and coupling means 44 to suitable receiving apparatus, not shown.

In the above described apparatus, by suitable choice and arrangement of dimensions, the receiver may be decoupled from the transmitter by approximately 30 db by virtue of their space quadrature coupling. This reduces the incident power on the T-R in the receiver line, and may provide for the elimination of an additional T-R switch device.

The above described duplexing feature of the invention illustrated in connection with the embodiment of FIG. 1 may also be used with other embodiments of the invention, and is particularly suitable for use with the preferred embodiment of FIG. 3.

Whereas reflector means have been shown employed with the invention, in some embodiments reflector means could be omitted, if desired, and a conical scanning pattern obtained from radiation leaving the open end of the waveguide.

It should be understood in all cases that the waveguides are composed of material having high electrical conductivity but having no characteristics which would substantially interfere with the magnetic fields set up for controlling or varying the permeability of the ferrite members.

Preferably the anisotropic ferrite members are symmetric and of uniform characteristics throughout.

Whereas the apparatus has been illustrated and described with reference to elements having certain relative dimensions, it should be understood that any suitable dimensions or arrangement of parts could be employed if desired.

Certain modifications may be made without departing from the scope of the invention. For example, the transverse magnetic field producing means of FIG. 3 might have substituted therefor a field producing element such as element 29, disposed in a suitable bore provided centrally located in ferrite element 53.



I claim as my invention:

1. Beam steering apparatus comprising, in combination, waveguide means adapted to be operatively connected to a source of microwave energy, one end of said waveguide means being open to provide for the radiation of energy therefrom, ferrite means disposed in said waveguide means adjacent said end, and variable magnetic field producing means associated with said ferrite means, said ferrite means and magnetic field producing means being constructed and arranged to cause energy to leave said end at a predetermined angle with respect to the longitudinal axis of the waveguide means in accordance with the strength and direction of the magnetic field produced by said magnetic field producing means, said angle being rotatable through 360 degrees about said longitudinal axis.

2. Beam steering apparatus for producing a beam which moves in a conical scanning pattern comprising, in combination, waveguide means adapted to be operatively connected to a source of microwave energy, at least one ferrite element associated with said waveguide means, variable magnetic field producing means associated with said ferrite element for varying the energy transmission characteristics of the ferrite element in accordance with variations in the magnetic field, and means including a lens and primary reflector cooperating with said waveguide means for utilizing the energy passing therethrough after variation by the ferrite element for producing a secondary conical scanning beam of radiation.

3. Beam steering apparatus comprising, in combination, energy transmission means adapted to receive microwave energy for radiation into space in the form of a steered beam, ferrite means disposed within said transmission means adjacent the transmitting end thereof, and magnetic field producing means for producing a plurality of angularly disposed magnetic fields through said ferrite means, said ferrite means and magnetic field producing means providing for energy being radiated in a predetermined beam direction under the control of the magnetic field, said magnetic field producing means including means for varying the magnetic fields produced thereby periodically to thereby periodically change the direction of said beam.

4. Beam steering apparatus comprising, in combination, first reflector means, waveguide means adapted to be operatively connected to a source of microwave energy, said waveguide means having one end thereof open for the passage of energy therethrough, second reflector means adapted to reflect energy leaving said end back to said first reflector means for reflection therefrom into space, and direction control means associated with said waveguide means for causing energy to leave said waveguide means at an angle with respect to the longitudinal axis of the waveguide means to thereby provide for radiation of a beam at an angle with respect to the radiation axis of the first reflector means, said direction control means including ferrite means disposed in predetermined position with respect to said waveguide means whereby at least a portion of the energy in the waveguide means is required to pass through at least a portion of said ferrite means and means operatively associated with said ferrite means for producing a magnetic field within said ferrite means, said magnetic field causing the transmission of energy through said ferrite means to vary in such a manner as to cause the energy leaving the waveguide means to leave at an angle with respect to the longitudinal axis thereof.

5. Beam steering apparatus comprising, in combination, waveguide means adapted to transmit in a preselected mode circularly polarized wave energy, said wave-

guide means having one end thereof open, first reflector means disposed outside of said waveguide means, ferrite member means mounted near said end, means operatively associated with said ferrite member means for subjecting said ferrite member means to a substantially constant magnetic field substantially along the longitudinal axis of the waveguide means, means mounted in said ferrite member means for generating a rotating magnetic field transverse to the longitudinal axis of the waveguide means, and second reflector means mounted adjacent said ferrite member means, said means for producing a rotating transverse magnetic field causing circularly polarized wave energy in said waveguide means to leave said waveguide means at a predetermined angle with respect to the longitudinal axis thereof, said last named energy being reflected by said second reflector means to said first reflector means, said first reflector means reflecting said last named energy into space in the form of a beam, said rotating magnetic field causing said beam to follow a conical scanning pattern.

6. Beam steering apparatus comprising, in combination, waveguide means constructed and arranged to transmit in a preselected mode circularly polarized wave energy, said waveguide means having one end thereof open, ferrite means disposed adjacent said end, means for subjecting said ferrite means to a substantially constant magnetic field substantially along the longitudinal axis of the waveguide means, and transverse magnetic field producing means for subjecting said ferrite means to a transverse magnetic field which varies in direction, said varying transverse magnetic field causing wave energy to leave the open end of said waveguide means at an angle with respect to the longitudinal axis thereof which varies in accordance with variations in the direction of the transverse magnetic field to thereby provide a beam of radiant energy under the control of said transverse magnetic field producing means.

7. Beam steering apparatus comprising, in combination, waveguide means adapted to transmit polarized wave energy, one end of said waveguide means being open to provide for the radiation of said energy into space, ferrite means disposed in predetermined relation to said end, magnetic field producing means including transverse magnetic field producing means operatively disposed in predetermined relation to said ferrite means, means operatively connected to said transverse field producing means for causing the transverse field to rotate about the longitudinal axis of the waveguide means, and reflector means for reflecting the energy leaving said waveguide means into a conical scanning pattern of radiation.

8. Beam steering apparatus comprising, in combination, waveguide means adapted to be operatively connected to means for generating microwave energy, one end of said waveguide means being open to provide for the radiation of energy therefrom, ferrite means disposed in predetermined spaced relation to said end, and magnetic field producing means including means disposed in predetermined position with respect to said ferrite means, said magnetic field producing means being constructed and arranged to produce a magnetic field component lying substantially along the longitudinal axis of the waveguide means and a rotating magnetic field component lying substantially transverse to said longitudinal axis, said magnetic field producing means causing energy leaving said end to leave at an angle with respect to the longitudinal axis of said waveguide means, said angle rotating with said rotating magnetic field.

9. Beam steering apparatus comprising, in combination, waveguide means adapted to be operatively connected to a source of microwave energy, one end of said waveguide means being open to provide for the radiation of energy therefrom, ferrite means disposed in predetermined position with respect to said end, and means mounted adjacent the ferrite means for subjecting said ferrite means to a rotating transverse magnetic field, said last named means including two pairs of windings, the windings of each pair being oppositely disposed with respect to each other, said pairs being disposed at a 90° angle with respect to each other, and means for energizing said pairs by a pair of substantially sine wave voltages, said pair of voltages being of substantially the same frequency and amplitude and 90° out of phase with respect to each other, said rotating transverse magnetic field causing energy to leave said end at an angle which varies in accordance with variations in the instant direction of said transverse magnetic field.

10. Beam steering apparatus comprising, in combination, waveguide means adapted to be connected to a source of electromagnetic wave energy, said waveguide means having one end thereof open for the radiation of energy therefrom, dielectric means mounted in the waveguide means at said end, said dielectric means having a bore substantially centrally disposed thereof, a ferrite member mounted in said bore, and magnetic field producing means operatively associated with said waveguide means for subjecting said ferrite member to a magnetic field component along the longitudinal axis of the waveguide means and a transverse magnetic field component, said magnetic field producing means including means for causing said transverse magnetic field component to rotate about the longitudinal axis of the waveguide means, the resultant magnetic field causing energy to leave said waveguide means at an angle with respect to the longitudinal axis thereof, said angle being under the instantaneous control of said transverse magnetic field component and varying with variations in the direction of said transverse magnetic field component as it rotates to provide a conical scanning pattern of radiation.

11. Beam steering apparatus comprising, in combination, waveguide means adapted to transmit circularly polarized wave energy, first reflector means disposed adjacent said waveguide means, said first reflector means having a reflecting surface substantially in the form of a parabola, one end of said waveguide means adjacent said first reflector means being open to provide for the passage of energy therethrough, ferrite means disposed in a predetermined position with respect to said end, magnetic field producing means operatively associated with said ferrite means, said magnetic field producing means being constructed and arranged to produce in said ferrite means a magnetic field component lying along the longitudinal axis of said waveguide means and a transverse magnetic field component, said transverse magnetic field component rotating about the longitudinal axis of said waveguide means, and second reflector means disposed in a predetermined position with respect to said ferrite means, said ferrite means and magnetic field producing means causing energy to leave said waveguide means at an angle with respect to the longitudinal axis thereof, said angle varying with variations in the instant direction of said transverse magnetic field component, said energy being reflected from said second reflector means to the reflecting surface of said first reflector means and thence being radiated into space in the form of a conical scanning beam of radiation.

12. Beam steering apparatus comprising, in combination, waveguide means, said waveguide means having a cylindrical portion and a rectangular portion connected by a tapering portion, said rectangular portion being adapted to be connected to a source of microwave energy having a linearly polarized wave form, means disposed in said waveguide means for changing the energy therein into a circularly polarized wave form, the end of said cylindrical portion being open to permit the passage of energy therefrom, ferrite means disposed in a predetermined position with respect to said end, magnetic field producing means disposed in predetermined position with respect to said ferrite means and including means for producing a magnetic field in said ferrite means transverse to the longitudinal axis of the waveguide means,

and reflector beam forming means adapted to receive energy from the open end of the waveguide means and reflect said last named energy into space, said last named energy leaving said waveguide means at an angle under the control of said transverse magnetic field to thereby provide for steering the beam of radiation.

13. Beam steering apparatus comprising, in combination, waveguide means adapted to be connected to a source of microwave energy and to transmit said energy, beam forming reflector means, four similar feeder means disposed at equally spaced intervals peripherally around the reflection axis of said beam forming reflector means, other reflector means adapted to receive the outputs of said feeder means and reflect said outputs to said beam forming reflector means for radiation thereby, and means including four ferrite variable coupling elements coupling said waveguide means to said four feeder means respectively for sequentially varying the energization of said feeder means to thereby produce a beam of radiation which continually varies in predetermined directions from the radiation axis of said beam forming reflector means.

14. Beam steering apparatus comprising, in combination, waveguide means adapted to receive and transmit microwave energy, beam forming antenna reflector means, four antenna feeder elements equally spaced from the reflection axis of said antenna reflector means and peripherally spaced at equal intervals around said axis, other reflector means adapted to reflect energy from said feeder elements to said antenna reflector means, and four variable coupling means coupling said four feeder elements respectively to said waveguide means, each of said coupling means including a ferrite rod and magnetic field producing means disposed in predetermined spaced relation to the ferrite rod for subjecting the rod to a varying magnetic field to thereby vary the transmission of microwave energy through the ferrite rod, and means for varying the energization of the magnetic field producing means of all the variable coupling means sequentially to vary the energy conducted from the waveguide means to the feeder elements sequentially to thereby provide for the generation of a beam of radiation which periodically varies in a predetermined manner with respect to the radiation axis of the antenna reflector means.

15. Beam steering apparatus for producing a beam which provides a conical scanning pattern of radiation, comprising, in combination, waveguide means adapted to transmit circularly polarized wave energy, first reflector means disposed around said waveguide means and having a parabolic contour for the reflecting surface thereof, one end of said waveguide means adjacent said first reflector means being open for the passage of energy therethrough, a ferrite member disposed in predetermined position with respect to said end, first magnetic field producing means including means disposed in predetermined position with respect to said ferrite member and creating a magnetic field component in said ferrite member which extends substantially along the longitudinal axis of the waveguide means, second magnetic field producing means including means disposed in predetermined position with respect to said ferrite member for creating a magnetic field component transverse to said longitudinal axis, said transverse magnetic field component rotating about said longitudinal axis at a predetermined period of rotation, the resultant magnetic field causing energy to leave said end at an angle with respect to the longitudinal axis of the waveguide means, said angle rotating about said longitudinal axis at a period corresponding to the rotation of the transverse magnetic field component, and second reflector means for reflecting said last named energy to the reflecting surface of the first reflector means to thereby be reflected into space in a beam forming a conical scanning pattern.

16. Beam steering apparatus for producing a beam for conical scanning comprising, in combination, first reflector means, waveguide means adapted to receive and transmit circularly polarized wave energy, one end of said waveguide means being open to permit the passage of energy therethrough, a ferrite member disposed in predetermined position with respect to said end, first magnetic field producing means including means disposed in predetermined position with respect to said end for creating a magnetic field lying substantially along the longitudinal axes of said waveguide means and said ferrite member, second magnetic field producing means including means disposed in predetermined position with respect to said ferrite member, said second magnetic field producing means comprising a substantially cylindrical metallic member having four longitudinal grooves in the sides thereof, said four longitudinal grooves being equally spaced around the periphery thereof, a pair of coils disposed in said grooves, said coils lying in planes that intersect each other at substantially 90°, means for energizing a first one of said coils with a first sine wave alternating current voltage, means for energizing the second of said coils with a second sine wave voltage of the same frequency and amplitude 90° out of phase with said first voltage to thereby produce a transverse magnetic field which rotates in a plane substantially transverse to the longitudinal axis of the waveguide means, and second reflector means, the energy leaving said waveguide means leaving at an angle with respect to the longitudinal axis thereof under the control of said transverse magnetic field, said last named energy being reflected from said second reflector means to said first reflector means and therefrom into space to form a steered beam of energy for producing a conical scanning pattern.

17. Beam steering apparatus comprising, in combination, four substantially similar waveguide means adapted to be energized by substantially equal amounts of wave energy, four antenna feeder means, reflector means, said antenna feeder means being equally spaced from the radiation axis of the reflector means and equally spaced around the periphery of said axis, and four variable coupling devices coupling said waveguide means to said feeder means respectively, each of said variable coupling devices including a ferrite element extending into the waveguide means and into the adjacent feeder means and a magnetic field producing coil disposed around the ferrite element, a source of potential, and means connecting said source of potential to all said magnetic field producing coils, said source of potential being adapted to sequentially vary the energizations of said coils to vary the magnetic fields produced thereby and thereby vary the energy transferred by the ferrite elements between the associated waveguide means and the associated feeder means, the sequential variation in the amounts of energy coupled to said feeder means providing for the radiation of a steered beam from said reflector means having a pattern of radiation which varies at a period corresponding to the period of energization of said magnetic field producing coils.

18. Beam steering apparatus comprising, in combination, waveguide means having a rectangular portion and a cylindrical portion connected by a tapering portion, said rectangular portion being adapted to receive energy in a suitable wave form for transmission by said waveguide means, a cylindrical ferrite member disposed within the cylindrical portion of the waveguide means, the longitudinal axis of the ferrite member corresponding to the longitudinal axis of the cylindrical waveguide portion, means disposed external to the cylindrical waveguide portion for subjecting said ferrite member to a steady magnetic field extending substantially along the longitudinal axis of the ferrite member, means disposed in predetermined position with respect to said ferrite member for subjecting said ferrite member to a magnetic field transverse to the longitudinal axis of the ferrite member, said transverse field rotating at a predetermined rate about said longitudinal axis, first reflector means disposed

around the outside of said cylindrical portion, the end of said cylindrical portion being open for the passage of energy therethrough, and second reflector means disposed in predetermined position near said end, said second reflector means reflecting energy leaving said end back to said first reflector means for reflecting therefrom into space, said ferrite member and said magnetic fields providing for energy leaving said end in a direction off-center from the longitudinal axis of said cylindrical waveguide portion to thereby provide for energy leaving the first reflecting means in a direction at a varying angle with respect to the radiation axis of the first reflector means to thereby provide for a conical scanning beam.

19. Beam steering apparatus comprising, in combination, waveguide means adapted to transmit in a preselected mode circularly polarized wave energy, said waveguide means having one end thereof open, ferrite member means mounted at said end, means operatively associated with said ferrite member means for subjecting said ferrite member means to a substantially constant magnetic field component substantially along the longitudinal axis of the waveguide means, and means mounted in said ferrite member means for generating a rotating magnetic field component transverse to the longitudinal axis of the waveguide means, said means for generating a rotating transverse magnetic field component causing circularly polarized wave energy in said waveguide means to leave said end of the waveguide means at a predetermined angle with respect to the longitudinal axis thereof, said rotating transverse magnetic field component producing a conical scanning beam of radiation.

20. In apparatus of the character disclosed, in combination, waveguide means, said waveguide means having a rectangular portion, a cylindrical portion, and a tapering portion connecting the rectangular and cylindrical portions, said rectangular portion being adapted to receive and conduct vertically polarized wave energy of a predetermined frequency, said circular portion having an outlet in the side thereof, said outlet being disposed in predetermined spaced relation to said rectangular portion and said tapering portion, said outlet being adapted to pass in substantial amounts only horizontally polarized wave energy of said frequency, one end of said circular portion being open to permit the passage of energy therethrough, means mounted in predetermined spaced position with respect to said open end to provide for wave energy leaving said end at a preselected angle with respect to the longitudinal axis of the circular portion, said last named means also causing energy received from said angle to be conducted by the circular portion of the waveguide means, and polarizing means disposed in said circular portion between the open end thereof and said outlet, said polarizing means changing the vertically polarized wave energy into left-hand circularly polarized wave energy for transmission through the open end, said polarizing means changing right-hand circularly polarized received energy into horizontally polarized energy for passage through said outlet.

21. In apparatus of the character disclosed, in combination, waveguide means adapted to be operatively connected to both generating means and receiving means, said waveguide means having an open end for the passage of energy therethrough, said waveguide means including means disposed in predetermined spaced relation to said end for bending wave energy leaving and entering said end, and means disposed in said waveguide means for changing the polarization of wave energy therein, said waveguide means and polarization changing means being constructed and arranged whereby the waveguide means is adapted to obtain from the generating means linearly polarized wave energy and to transmit said last named energy as circularly polarized wave energy at a predetermined angle with respect to the longitudinal axis of the waveguide means, said waveguide means and polarization changing means being also constructed and arranged to receive other energy arriving from said angle and having a circular polarization opposite to the circular polarization of the transmitted wave energy and to pass said received energy to said receiving means as linearly polarized wave energy having a plane of polarization substantially perpendicular to the plane of polarization of the energy obtained from the generating means.

22. In beam steering apparatus of the character disclosed, in combination, waveguide means adapted to be operatively connected to both generating means and receiving means, said waveguide means having one end thereof open, polarization changing means located in said waveguide means near said end, ferrite means disposed in predetermined position with respect to said end, and magnetic field producing means operatively associated with said ferrite means, said waveguide means, polarization changing means, ferrite means, and magnetic field producing means providing for the passage of linearly polarized wave energy obtained from the generating means and the radiation of said last named energy as circularly polarized wave energy radiated at a predetermined angle with respect to the longitudinal axis of the waveguide means, said waveguide means, polarization changing means, ferrite means and magnetic field producing means also providing for the reception from said angle of circularly polarized wave energy circularly polarized in a direction opposite to that of the transmitted wave energy and for passage of the received energy to the receiving means as linearly polarized wave energy having a direction of polarization substantially perpendicular to the direction of polarization of the wave energy supplied by the generating means.

23. In beam steering apparatus of the character disclosed, in combination, waveguide means adapted to be operatively connected to both generating means and receiving means, said waveguide means having one end thereof open for the passage of energy therethrough, polarization changing means disposed in said waveguide means, ferrite means mounted in predetermined spaced relation to said end, means mounted on the end of said waveguide means for subjecting said ferrite means to a steady component of a magnetic field lying along the longitudinal axis of the waveguide means, and magnetic field producing means including means centrally disposed of said ferrite means, said magnetic field producing means subjecting the ferrite means to a magnetic field component rotating about the longitudinal axis of the waveguide means, the rotating resultant field causing energy to leave said waveguide means at an angle with respect to the longitudinal axis thereof and causing energy approaching the end of said waveguide means from said angle to be received and conducted by the waveguide means, said waveguide means and polarization changing means being constructed and arranged to obtain linearly polarized wave energy from the generating means and to transmit said linearly polarized wave energy as circularly polarized wave energy having a first direction of circular polarization, said waveguide means and polarization changing means being adapted to conduct to the receiving means received circularly polarized wave energy polarized in a second direction of circular polarization opposite to the first direction, the energy conducted to the receiving means being linearly polarized in a direction substantially perpendicular to the direction of polarization of the linearly polarized energy obtained from the generating means.

24. In beam steering apparatus, in combination, waveguide means adapted to be operatively connected to both generating means and receiving means, said waveguide means having one end thereof open for the passage of energy out of and into the waveguide means, and polarization changing means associated with said waveguide means, said waveguide means and polarization changing means being constructed and arranged whereby linearly polarized wave energy having a preselected direction of polarization is obtained from the generating means and

is transmitted as circularly polarized wave energy having a preselected direction of polarization, and received wave energy circularly polarized in a direction opposite to the direction of polarization of the transmitted wave energy is conducted to the receiving means as linearly polarized wave energy having a direction of polarization substantially perpendicular to the direction of polarization of the linearly polarized wave energy obtained from the generating means.

25. In beam steering apparatus, in combination, waveguide means including polarization changing means and adapted to be operatively connected to both generating means and receiving means, said waveguide means having one end thereof open for the passage of energy from the waveguide means and into the waveguide means, and ferrite wave bending means disposed in predetermined spaced relation to said end, linearly polarized wave energy obtained from the generating means being transmitted at an angle to the longitudinal axis of the waveguide means as circularly polarized wave energy, and received energy received from said angle as circularly polarized wave energy having a direction of polarization opposite to that of the transmitted wave energy being conducted to the receiving means as linearly polarized wave energy having a direction of polarization substantially perpendicular to the direction of polarization of the energy obtained from the generating means.

26. In beam steering apparatus, in combination, waveguide means adapted to be operatively connected to both generating means and receiving means, polarization changing means disposed in said waveguide means, one end of said waveguide means being open for the passage of energy therethrough, ferrite means disposed in predetermined spaced relation to said end, and magnetic field producing means including means disposed in predetermined position with respect to said ferrite means, said magnetic field producing means including a magnetizable cylindrical member having a pair of coils disposed longitudinally thereof at right angles with respect to each other and means for energizing said pair of coils by a pair of sine wave voltages of substantially the same frequency and amplitude and 90° out of phase with each other whereby a rotating magnetic field is produced, said rotating magnetic field causing energy leaving said end to form a conical scanning pattern of radiation, said polarization changing means providing for changing linearly polarized wave energy obtained from the generating means into circularly polarized wave energy, said polarization changing means providing for changing circularly polarized received energy having a direction of polarization opposite to that of the transmitted energy into linearly polarized energy for passage to the receiving means, said last named energy having a direction of polarization substantially perpendicular to the direction of polarization of the energy obtained from the generating means.

27. Beam steering apparatus comprising, in combination, waveguide means adapted to be operatively connected to both generating means and receiving means, said waveguide means being adapted to obtain from the generating means linearly polarized wave energy and to conduct to the receiving means linearly polarized wave energy having a direction of polarization substantially perpendicular to the direction of polarization of the energy obtained from the generating means, said waveguide means having one end thereof open for the passage of energy to and from the waveguide means, ferrite means disposed in predetermined spaced relation to said end, and magnetic field producing means including means disposed in predetermined position with respect to said ferrite means for bending wave energy leaving and entering said end.

28. In beam steering apparatus, in combination, energy transmitting means adapted to be connected to generating means and receiving means, said energy transmitting means including quadrature type duplexing means wherein the generating means and receiving means couple to mutually perpendicular circular waveguide modes, ferrite means associated with said transmitting means for deflecting the direction of transmission of the wave energy, and means associated with said transmitting means for utilizing the deflected energy to provide a virtual source of radiation.

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