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ARBITRARILY POLARIZED BEACON ANTENNA

Filed April 9, 1959

2 Sheets-Sheet 1

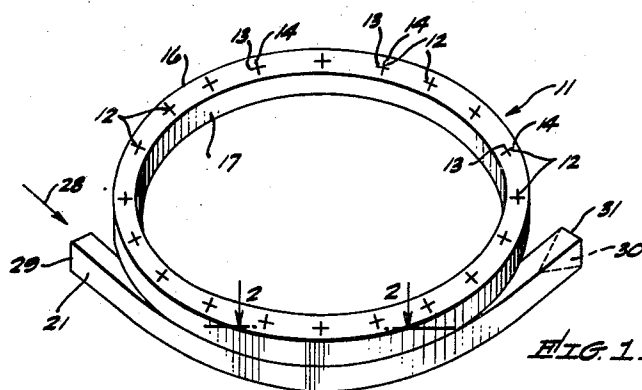


FIG. 1.

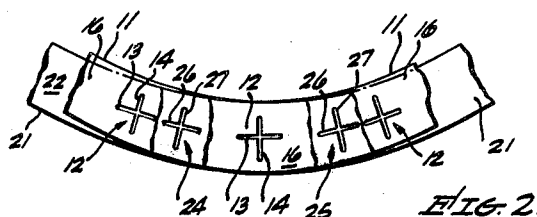


FIG. 2.

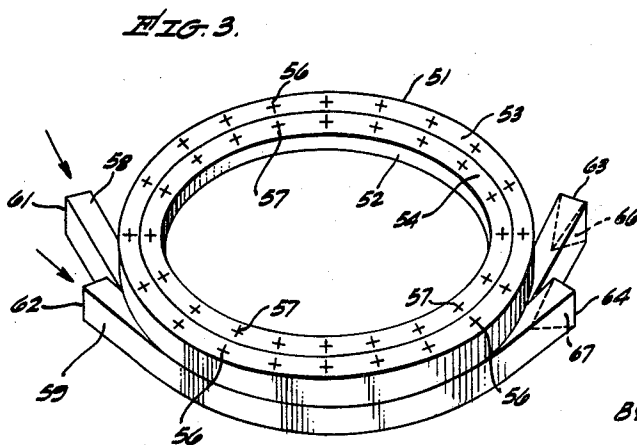


FIG. 3.

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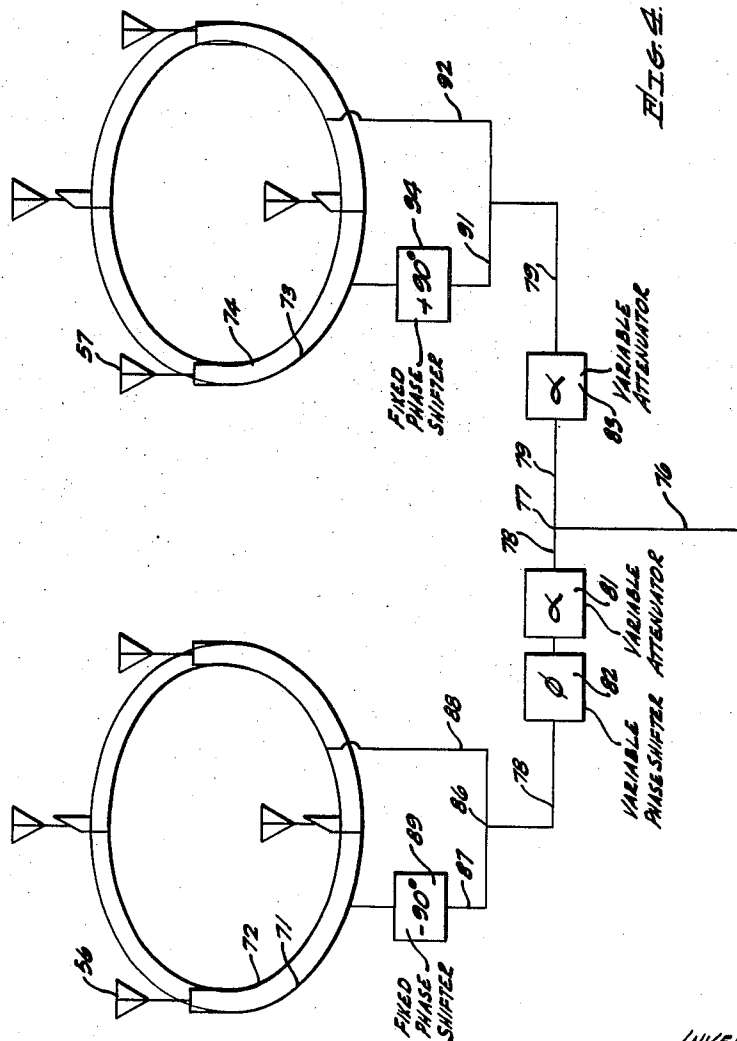
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ARBITRARILY POLARIZED BEACON ANTENNA

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17 Claims. (Cl. 343-756)

The present invention relates to microwave antennas and, more particularly, to a slot-type antenna providing a beacon-type pattern, the far field polarization characteristics of which are variable in an arbitrary manner.

In general, the field pattern of beacon antennas is omni-directional in azimuth to provide as wide a uniform circumferential coverage as possible. In elevation the field pattern has a radial cross-section extending from a minimum at the antenna, then to a maximum at an intermediate distance from the antenna and back to a minimum at the far range. Present day requirements for beacon antennas render substantially obsolete the known types, which provide only linear polarization of one sense or another. In line with such requirements, however, there have been developed low silhouette beacons utilizing corrugated, or dielectric-clad surfaces, supporting the propagation of surface wave modes. While these latter types have been useful because of their flush-type mounting capability, they have proved inherently unsatisfactory in supporting the propagation of the orthogonal modes necessary for arbitrary polarization in a satisfactory manner. Such inherent disadvantage is embodied in the fact that the required different modes of excitation each have different propagation constants, which, in turn, provide radiation patterns differing both in shape and position from each other so that the desired characteristics of a beacon antenna are extremely difficult to obtain.

It is therefore an object of the present invention to provide a new and improved arbitrarily polarized antenna.

Another object is to provide a beacon antenna that has flush-mounting capabilities and transmits or receives radiation of any polarization.

A further object of the invention is to provide a simple planar antenna radiating energy with a far field distribution that is omni-directional in azimuth, end-fire in elevation, and variable in polarization without disturbing the distribution.

Still another object is to provide a simple and easily controlled arbitrarily polarized beacon antenna.

Briefly, in accordance with the present invention at least one ring of square waveguide is provided with a plurality of pairs of symmetrically and perpendicularly crossed slots cut in one planar wall as radiating elements. One slot of each pair lies along the center line of the planar wall with the spacing between pairs of slots being established at substantially one-half the guide wavelength at the frequency of the energy propagated. Also, the circumference of the ring waveguide at the centerline of a planar surface is established to be an integer number of wavelengths at the guide wavelength.

The square waveguide is suitably excited to propagate two independent, but similar, space-orthogonal traveling wave modes of microwave energy having the same frequency. The crossed-slot radiating elements couple to the two modes of the waveguide, in the manner described for a linear antenna array of square waveguide, in co-pending application S. N. 758,021, filed August 29, 1958, and entitled "Arbitrarily Polarized Slot Radiator" by Howard E. Shanks, one of the co-inventors of the present

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invention. Circular polarization of the far-field radiation from the crossed-slot radiators of the ring waveguide is then obtained by controlling the relative phase and amplitude of the two exciting modes.

The foregoing single-ring antenna is made more versatile by concentrically mounting a second similar ring of cross-slotted square waveguide with respect thereto. In this instance one of the rings is excited to radiate energy with a circular polarization of one sense and the second ring is excited to radiate energy with a circular polarization of the opposite sense. These two radiated fields then combine to provide a single pattern having polarization characteristics, which are dependent only on the relative amplitude and phase of the two modes in one ring with respect to the amplitude and phase of the two modes in the second ring. Such dual-ring antenna then provides a far-field energy distribution characteristic of beacon antennas (omni-directional in azimuth, end-fire in elevation) and, additionally, polarization of this energy is variable in an arbitrary manner without affecting the distribution.

Other objects and advantages of the invention will be apparent from the following description and claims considered together with the accompanying drawings, in which:

Figure 1 is a perspective view of a single ring beacon antenna;

Figure 2 is a partially cut away view of a portion of the antenna of Figure 1;

Figure 3 is a perspective view of a double ring beacon antenna; and

Figure 4 is a schematic diagram of a double ring antenna, according to Figure 3, together with the excitation system therefor.

Referring to Figure 1 of the drawings in detail there is illustrated a single ring 11 of square waveguide for the propagation of two space-orthogonal TE_{10} traveling wave modes of microwave energy at the same frequency. A plurality of radiating elements 12, each comprising a pair of symmetrically and perpendicularly cross slots 13 and 14 of narrow and elongated configuration, are provided through one of the two planar walls 16, 17 with the elongated dimension of one slot of each pair lying along the centerline of such one planar wall 16. Each of the radiating elements 12 is disposed substantially one-half wavelength at the waveguide wavelength from adjacent radiating elements 12 and the distance around the ring at the centerline is an integer number of wavelengths at the waveguide wavelength. With the two orthogonal modes present in the ring waveguide 11 one slot 13 of each pair of slots 13 and 14 couples only to one mode and the other slot 14 couples only to the other mode. The phase and amplitude of the radiation from each slot of a pair of slots is, therefore, readily regulated by controlling the phase and amplitude of its exciting mode by means of conventional microwave phase shifters and attenuators (not shown) respectively. Each elemental radiator 12 is then, in turn, made to radiate energy of any ellipticity by suitably controlling the relative phase and amplitude of the two independent and orthogonal modes.

To excite the waveguide 11, a section of square waveguide 21 having a curved portion is mounted with one planar surface 22 in contact with a portion of the planar surface 17 of the ring waveguide, such latter surface 17 being opposite to the slotted planar surface 16. Curved waveguide 21 at the curved portion has the same radius of curvature as that of the ring waveguide 11. Thus, with the curved waveguide 21 and ring waveguide 11 mounted in the foregoing manner, the two waveguides are tangential for a distance with such distance depending upon the length of the curved portion of the waveguide 21.

In accordance with the invention electromagnetic cou-

pling between the ring waveguide 11 and the curved portion of the waveguide 21 is provided to excite two independent orthogonal traveling wave modes in the ring waveguide. As illustrated in Figure 2 at the broken-away portions, this coupling is directional and accomplished by two pairs 24 and 25 of symmetrically and perpendicularly crossed coupling slots 26 and 27, similar to elemental radiators 12, extending through the common wall structure of the two waveguides 11 and 21. A spacing of three-quarters of a wavelength at the waveguide wavelength is provided between the two pairs 24 and 25 of crossed slots 26 and 27 so that energy traveling in one direction, as indicated by arrow 28 at input port 29, in the curved waveguide 21 is coupled into the ring waveguide 11 and propagated in the same direction. Propagation in the opposite direction is prevented by the slot spacing because the phase of the respective energies launched by the pairs of slots 24 and 25 results in cancellation in such opposite direction. Energy of the two orthogonal traveling wave modes in the ring waveguide 11 that is not radiated to space by the elemental radiators 12 during one traversal of the ring waveguide is then coupled back into the curved waveguide 21 by the two coupling pairs 24 and 25 of crossed slots 26 and 27 and propagated in the same direction for suitable dissipation in a conventional absorption-type load 30 mounted at the terminal end 31 of the curved waveguide 21.

With two independent orthogonal modes of microwave energy at the same frequency introduced at input port 29, traveling waves of such modes proceed in the direction of the arrow 28 toward the two pairs 24 and 25 of crossed coupling slots 26 and 27. One slot 26 of each crossed slot pair 24 and 25 couples energy of one of the two modes into the ring waveguide 11 and the other slot 27 of each pair similarly couples energy of the other of the two modes into the ring waveguide. Energy of each mode coupled into the ring waveguide 11 by the first crossed slot pair 24 is additive to the energy of each respective mode coupled into the ring waveguide by the second crossed slot pair 25 in the direction of the arrow 28, because of the three-quarter wavelength spacing. The resultant two modes then have the same relative space-orthogonal relationship, as is present at the input port 29, in proceeding around the ring waveguide 11. Energy of each mode coupled into the ring waveguide 11 by the two crossed slot coupling pairs 24 and 25 that is launched in the opposite direction from that indicated by the arrow 28 is cancelled because of the phase relationship established by the three-quarter wavelength spacing.

As the two orthogonal traveling wave modes traverse the ring waveguide 11 a portion of the energy of each mode is respectively radiated to space by the crossed slots 13 and 14 of the elemental radiators 12. Since one of the slots 13 couples to only one of the two modes and the other slot 14 couples to only the other of the two modes, the individual elemental radiators 12 radiate elliptically polarized energy and this polarization is controlled by the relative phase and amplitude of the two exciting modes. By suitable control of the relative phase and amplitude of the two exciting modes of a multiaperture ring waveguide 51, the polarization of the radiation at the far field is circularly polarized clockwise or counterclockwise in a selective manner.

The spacing between elemental radiators 12 is established at substantially one-half of the waveguide wavelength and the circumference of the ring waveguide 11 at the centerline of one planar face 16, is equal to an integer number of waveguide wavelengths. The far-field distribution of such circularly polarized energy is then omni-directional in azimuth and end-fire in elevation.

Excess energy of the two orthogonal modes, that which is not radiated to space by the elemental radiators 12 in traveling once around the ring waveguide 11, is then coupled out by the two pairs 24 and 25 of crossed coupling slots into the curved waveguide 21. This energy is addi-

tive in the forward direction for each of the two modes, in the same direction as the arrow 28, but cancels in the opposite direction. This action is the same as previously related with respect to the input energy and these coupling slots 24 and 25. The nonreflective absorption-type load 30 at the terminal end 31 of the curved waveguide 21 then removes such excess energy from the system.

To obtain arbitrary polarization with a beacon-type far-field distribution, two similar rings of square waveguide 51 and 52, respectively, are concentrically mounted with planar faces 53 and 54 disposed in the same plane, as shown in Figure 3. The two ring waveguides 51 and 52 are respectively provided with a similar plurality of crossed-slot elemental radiators 56 and 57 along adjacent planar faces, in the manner described with respect to Figure 1, and having the same substantially half-wavelength spacing at the waveguide wavelength. Individually, each of the ring waveguides 51 and 52 supports two independent orthogonal modes of microwave energy at the same frequency, which is radiated to space with circular polarization by the elemental radiators 56 and 57, respectively.

Because one of the rings 51 and 52 necessarily has a different circumference than the other, the smaller ring 52 of the two has a different waveguide wavelength and spacing between adjacent radiator elements 57, which may be readily accomplished in a conventional manner by dielectric loading (not shown) of such smaller waveguide. In this way energy of the same frequency is utilized to excite both ring waveguides 51 and 52 and the radiated energy has the same characteristics from both rings.

Again in the manner described with respect to Figures 1 and 2, sections of square waveguide 58 and 59, having curved portions with the same radii of curvature as those of the ring waveguides 51 and 52 are respectively mounted against the ring waveguides with the curved portions adjacent to planar faces of the ring waveguides, which are disposed opposite to the slotted faces 53 and 54. Also the curved waveguides 58 and 59 have input ends 61 and 62 and are respectively and electromagnetically coupled to the ring waveguides 51 and 52 at the tangential portions by two pairs of crossed coupling slots (not shown) spaced apart three-quarters of a waveguide wavelength, as previously described and detailed for the coupling slots of Figure 2. Additionally, the respective terminal ends 63 and 64 of the curved waveguides 58 and 59 are provided with absorption-type loads 66 and 67 to remove excess energy from the system.

For a better understanding of the operation of the foregoing antenna, reference is made to the schematic feed system shown in Figure 4 for the double ring waveguide antenna of Figure 3, wherein the two ring waveguides 51 and 52 have been separated and illustrated as modal paths rather than as waveguides. Thus, circles 71 and 72, respectively, represent the modal paths of the two orthogonal modes of one ring waveguide 51 and circles 73 and 74, respectively, represent similar modal paths of the other ring waveguide 52.

A conventional source of microwave energy (not shown) is coupled in a single dominant TE_{10} mode to a modal path 76, as by a rectangular waveguide, to a junction 77, such as a conventional waveguide T junction or variable power divider. At the junction 77 the energy divides equally into two primary paths 78 and 79. Conventional variable attenuator 81 and variable phase shifter 82 are serially included in one of the primary paths 78 and a variable attenuator 83 is included in the other primary path 79. These latter elements 81-83 provide means for altering the relative phase and amplitude of the energy propagating along the two primary paths 78 and 79.

One primary path 78 after the variable phase shifter 82 is again divided as at a T junction 86 into two secondary modal paths 87 and 88, one secondary path 87 is established with a space orthogonal relation to the

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other secondary path 88 as by section of rectangular waveguide having a 90 degree twist and with a fixed 90 degree lagging phase shifter 89 included in such path prior to the excitation of the modal path represented by the circle 71. The other secondary path 88 directly excites the modal path represented by the circle 72.

The other primary path 79 is similarly constructed in that after the variable attenuator 83, the energy of this path is divided into two separate secondary paths 91 and 92 with one such secondary path 91 having a space orthogonal relationship with respect to the other such secondary path 92, as by a rectangular waveguide with a 90 degree twist, and with a 90 degree leading phase shifter 94 connected into the path prior to the excitation of the modal path represented by circle 73. Again the remaining secondary path 92 directly excites the modal path represented by circle 74.

In the foregoing reference has been made to certain specific structures of microwave waveguide "plumbing" such as T junctions, power dividers, and twisted sections of rectangular waveguide. These particular structures may be readily assembled to provide the required energy relationships of the present invention, but should not be considered limiting in any respect as various other well-known types of microwave transmission and mode translation elements are well-known and commercially available.

Elemental radiators 56 and 57 are shown schematically in Figure 4 to respectively couple to the two modal paths represented by circles 71, 72 and 73, 74 and for convenience of illustration are reduced in number. By suitable adjustment of the variable phase shifter 81 and the attenuator 82 and 83, the elemental radiators 56 and 57 respectively radiate circularly polarized energy of opposite sense and combine to provide a pattern having polarization characteristics dependent only on the amplitude and phase of the two modes of one modal pair relative to the two modes of the other modal pair. The referenced pattern has a far-field distribution characteristic of beacon antennas, which is omni-directional in azimuth and end-fire in elevation, and, additionally, the polarization of the radiated energy is variable in an arbitrary manner without affecting the distribution.

The elemental radiators 12 and 56, 57 and the crossed pairs of coupling slots 24, 25, as well as those not shown in Figure 4, have been described and illustrated as narrow elongated slots; however, this particular shape of slot is not an absolute requirement because circular apertures will couple to two space-orthogonal modes in much the same manner as the crossed slots. Where circular apertures are utilized, these apertures are centered along the centerline of a planar face and spaced apart as set forth for the referenced crossed slots.

It is to be noted that no structure extends beyond the slotted or apertured planar face, or faces, of the antenna so that flush mounting in a larger planar surface is possible for either ground or airborne installation. Also, it is to be noted that the pattern of radiation distribution in elevation is variable by altering the circumference of the ring waveguides to provide a different integer number of waveguide wavelengths and thereby a different number of elemental radiators spaced one-half waveguide wavelength apart in accordance with the foregoing.

Thus, there has been shown and described in detail a new and improved antenna having flush mounting capabilities. While the description has been made with particular reference to beacon antennas, no limitation is intended thereby as the antenna is useful wherever the distribution pattern characteristics and polarization characteristics permit.

While the salient features of the present invention have been set forth in detail with respect to certain embodiments, it is readily apparent that numerous modifications and changes may be made within the spirit and scope of the invention and it is, therefore, not desired to limit the

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invention to the exact details shown except insofar as they may be set forth in the following claims.

What is claimed is:

1. In a microwave antenna, the combination comprising at least one ring of square waveguide for propagating two independent space-orthogonal modes of microwave energy, a plurality of spaced-apart radiating apertures symmetrically disposed with respect to a circumferential center line in a first planar wall of said ring waveguide, and means electromagnetically coupled to a second planar wall of said ring waveguide for exciting said two independent space-orthogonal modes.

2. In a microwave antenna, the combination comprising at least one ring of square waveguide having a plurality of spaced-apart radiating apertures through a first planar wall symmetrically disposed with respect to the circumferential center line of such wall, said apertures being spaced-apart substantially one-half wavelength at the waveguide wavelength, said circumferential center line being equal to an integer number of waveguide wavelengths, and means electromagnetically coupled to a second planar wall of said ring waveguide for exciting two independent space-orthogonal traveling wave modes variable in phase and amplitude.

3. In a microwave antenna, the combination comprising at least one ring of square waveguide for propagating two independent space-orthogonal modes of microwave energy, a plurality of spaced-apart radiating apertures symmetrically disposed with respect to a circumferential center line in a first planar wall of said ring waveguide, and a section of square waveguide electromagnetically coupled to a second planar wall of said ring waveguide for exciting two independent space-orthogonal traveling wave modes variable in phase and amplitude in said ring waveguide.

4. In a microwave antenna, the combination comprising at least one ring of square waveguide having a plurality of spaced-apart circular radiating apertures through a first planar wall symmetrically disposed with respect to the circumferential center line of such wall, said apertures being spaced-apart substantially one-half wavelength at the waveguide wavelength, said circumferential center line being equal to an integer number of waveguide wavelengths, and a section of square waveguide electromagnetically coupled through a second planar wall of said ring waveguide for exciting two independent space-orthogonal traveling wave modes variable in phase and amplitude.

5. In a microwave antenna, the combination comprising at least one ring of square waveguide having a plurality of spaced-apart radiating elements through a first planar wall, each of said radiating elements including a pair of symmetrically and perpendicularly crossed, narrow, and elongated slots with one slot of each pair being disposed along the circumferential center line of said first planar wall of said ring waveguide, and a section of square waveguide electromagnetically coupled through a second wall of said ring waveguide for exciting two independent space-orthogonal traveling wave modes variable in phase and amplitude.

6. In a microwave antenna, the combination comprising at least one ring of square waveguide for propagating two independent space-orthogonal modes of microwave energy, a plurality of spaced-apart radiating elements symmetrically disposed with respect to a circumferential center line in a first planar wall of said ring waveguide, each of said radiating elements including a pair of symmetrically and perpendicularly crossed, narrow, and elongated slots with one slot of each pair being disposed along the circumferential center line of said first planar wall of said ring waveguide, the spacing between centers of adjacent crossed slot pairs being substantially one-half of a waveguide wavelength, said circumferential center line being equal to an integer number of waveguide wavelengths, and means electromagnetically coupled to a

second planar wall of said ring waveguide for exciting said two independent space-orthogonal modes.

7. In a microwave antenna, the combination comprising at least one ring of square waveguide for propagating two independent space-orthogonal modes of microwave energy, a plurality of spaced-apart radiating elements symmetrically disposed with respect to a circumferential center line in a first planar wall of said ring waveguide, each of said radiating elements including a pair of symmetrically and perpendicularly crossed, narrow, and elongated slots with one slot of each pair being disposed along the circumferential center line of said first planar wall of said ring waveguide, the spacing between centers of adjacent crossed slot pairs being substantially one-half wavelength at the waveguide wavelength, said circumferential center line being equal to an integer number of waveguide wavelengths, and a section of square waveguide electromagnetically coupled through a second wall of said ring waveguide for exciting two independent space-orthogonal traveling wave modes variable in phase and amplitude.

8. The combination of claim 7 wherein said section of square waveguide is characterized as having a curved portion with a radius of curvature equal to that of said ring waveguide.

9. The combination of claim 8 wherein said section of square waveguide is electromagnetically and directionally coupled to said ring waveguide by two coupling apertures symmetrically disposed with respect to the circumferential center line of said second planar wall of said ring waveguide.

10. The combination of claim 9 wherein said two coupling apertures are spaced-apart three-quarters of a wavelength at the waveguide wavelength.

11. In a microwave antenna, the combination comprising a first and second ring of square waveguide for separately propagating two independent space-orthogonal modes of microwave energy, said first and second ring waveguides being disposed concentrically with a first planar wall of each lying in a single plane, each of said first planar walls of said first and second ring waveguides having a similar plurality of spaced-apart radiating apertures symmetrically disposed with respect to a circumferential center line of said first planar walls, means electromagnetically coupled to a second planar wall of said first ring waveguide for exciting two independent space-orthogonal modes of energy radiated to space with a circular polarization of one sense, means electromagnetically coupled to a second planar wall of said second ring waveguide for exciting two independent space-orthogonal modes of energy radiated to space with a circular polarization of an opposite sense, and means for varying the relative phase and amplitude of the two modes of said first ring waveguide with respect to the two modes of said second ring waveguide.

12. In a microwave antenna, the combination comprising a first and second ring of square waveguide for separately propagating two independent space-orthogonal modes of microwave energy at the same frequency, said first and second ring waveguides being disposed concentrically with a first planar wall of each lying in a single plane, said second ring waveguide having a smaller diameter than said first ring waveguide with means included therein to decrease the waveguide wavelengths, each of said first and second ring waveguides having a similar plurality of spaced-apart radiating apertures symmetrically disposed with respect to a circumferential center line of said first planar walls, said apertures of each ring waveguide being spaced-apart substantially one-half wavelength at the waveguide wavelength with said circumferential center line being an integer number of such waveguide wavelengths, means electromagnetically coupled to a second planar wall of said first ring waveguide for exciting two independent space-orthogonal

modes of energy radiated to space with a circular polarization of one sense, means electromagnetically coupled to a second planar wall of said second ring waveguide for exciting two independent space-orthogonal modes of energy radiated to space with a circular polarization of an opposite sense, and means for varying the relative phase and amplitude of the two modes of said first ring waveguide with respect to the two modes of said second ring waveguide.

13. In a microwave antenna, the combination comprising a first and second ring of square waveguide for separately propagating two independent space-orthogonal modes of microwave energy at the same frequency, said first and second ring waveguides having different diameters and being disposed concentrically with a first planar wall of each lying in a single plane, dielectric loading means included in the smaller of said first and second ring waveguides to decrease the waveguide wavelength, each of said first and second ring waveguides having a similar plurality of spaced-apart radiating apertures symmetrically disposed with respect to a circumferential center line of said first planar walls, said apertures of each ring waveguide being spaced-apart substantially one-half wavelength at the waveguide wavelength with said circumferential center line being an integer number of such waveguide wavelengths, a first section of square waveguide electromagnetically coupled to a second planar wall of said first ring waveguide for exciting two independent space-orthogonal modes of energy radiated to space with a circular polarization of one sense, a second section of square waveguide electromagnetically coupled to a second planar wall of said second ring waveguide for exciting two independent space-orthogonal modes of energy radiated to space with a circular polarization of an opposite sense, and means coupled to at least one of said sections of square waveguide for varying the relative phase and amplitude of the two modes of said first ring waveguide with respect to the two modes of said second ring waveguide.

14. In a microwave antenna, the combination comprising a first and second ring of square waveguide for separately propagating two independent space-orthogonal modes of microwave energy at the same frequency, said first and second ring waveguide having different diameters and being disposed concentrically with a first planar wall of each lying in a single plane, dielectric loading means included in the smaller of said first and second ring waveguides to decrease the waveguide wavelength, each of said first planar walls of said first and second ring waveguides having a similar plurality of spaced-apart radiating apertures symmetrically disposed with respect to a circumferential center line of said first planar walls, each of said radiating apertures including a pair of symmetrically and perpendicularly crossed, narrow, and elongated slots with one slot of each pair being disposed along the circumferential center line of said respective first planar wall, a first section of square waveguide electromagnetically coupled to a second planar wall of said first ring waveguide for exciting two independent space-orthogonal modes of energy radiated to space with a circular polarization of one sense, a second section of square waveguide electromagnetically coupled to a second planar wall of said second ring waveguide for exciting two independent space-orthogonal modes of energy radiated to space with a circular polarization of an opposite sense, and means coupled to at least one of said sections of square waveguide for varying the relative phase and amplitude of the two modes of said first ring waveguide with respect to the two modes of said second ring waveguide.

15. The combination of claim 14 wherein said first and second sections of square waveguide are characterized as having respective curved portions with radii of curvature equal to that of said first and second ring waveguides,

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16. The combination of claim 15 wherein said first and second sections of square waveguide are respectively coupled electromagnetically and directionally to said first and second ring waveguides by pairs of coupling apertures spaced-apart along the center line of respective second planar walls. 5

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17. The combination of claim 16 wherein said pairs of coupling apertures are respectively spaced-apart three-quarters of a wavelength at the waveguide wavelength.

No references cited.