

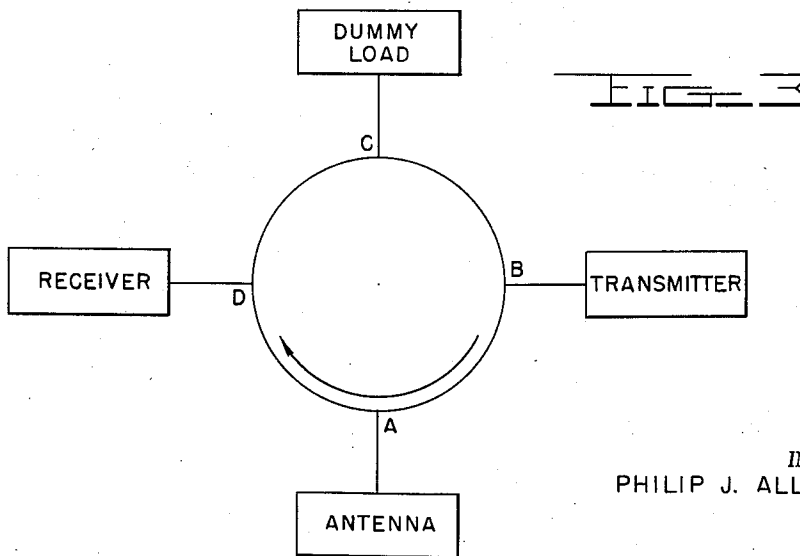
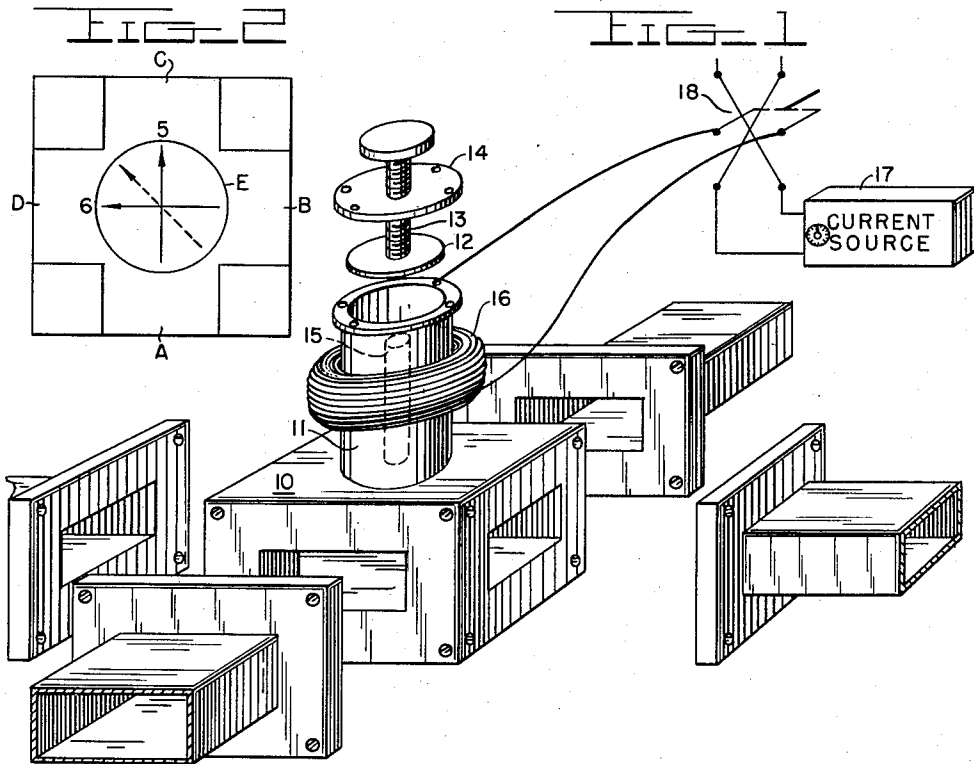
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MICROWAVE CIRCULATOR

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1

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MICROWAVE CIRCULATOR

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The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

This invention relates in general to waveguide directional coupling means and in particular to a microwave circulator employing a single hybrid junction.

The term "microwave circulator" is descriptive of non-reciprocal or "one-way" multiport coupling networks which generally employ a gyrator, such as a Faraday rotator, for shifting the plane of polarization of the propagated wave, and at least two hybrid junctions for coupling the network to the waveguide system. An informative dissertation on the basic operation of microwave circulators is to be found in the article by C. L. Hogan, Reviews of Modern Physics, vol. 25, No. 1.

While a variety of microwave circulators are available, the majority of these multiport devices are extremely complex. Whereas all of the heretofore known circulators have required at least two hybrid junctions it will be appreciated that they have been quite cumbersome, as well as expensive to construct. It is readily apparent that a simplified and relatively inexpensive microwave circulator is needed and would be welcomed as a highly desirable advancement of the art.

Accordingly:

It is an object of this invention to provide an improved microwave circulator employing a turnstile type hybrid junction.

It is another object of this invention to provide a compact single junction microwave circulator which is relatively economical to construct.

It is still another object of this invention to provide a single junction non-reciprocal coupling means having a convenient terminal arrangement adaptable to a variety of circulator applications.

Other objects of the invention will become apparent upon a more comprehensive understanding of the invention for which reference is had to the following specification and drawings.

Wherein:

Fig. 1 is an expanded pictorial showing of one embodiment of the invention.

Fig. 2 is a topside diagrammatic showing of wave polarizations in the embodiment of Fig. 1.

Fig. 3 is a symbolic showing of the device of this invention as incorporated in an operating system.

Briefly, the device of this invention is a simplified microwave circulator incorporating a single hybrid junction of the turnstile variety, and a 45° Faraday rotator in a new and novel combination. In the invention the symmetrical properties of the turnstile junction and the non-reciprocal properties of the Faraday rotator are utilized, in combination, to achieve a compact and relatively inexpensive low-loss device for the directional coupling of wave energy.

Referring now to the drawings:

An exemplary and preferred embodiment of the device of this invention is shown in Fig. 1. This embodiment incorporates a turnstile junction 10 for interconnecting two cross arms of rectangular waveguide intersecting at right angles and for connecting a circular waveguide directly above the intersection thereof such that the axis of

2

the circular waveguide is in perpendicular relation to the plane formed by the axes of the cross arms and meets the intersection of the axes. For purposes of this application, the point at which the axes intersect is termed the "common central point" of the turnstile junction.

As is conventional in hybrid junctions of the turnstile variety, a graduated cylindrical structure, not shown, is suitably disposed for matching purposes directly below the circular waveguide and in the center of the junction. It will be seen that the hybrid junction structure generally described above is a typical turnstile junction. For a more detailed description of a turnstile structure of the type described above, reference is had to U. S. Patent No. 2,686,901 to R. H. Dicke, which issued August 17, 1954.

A waveguide section 11 is shown connected as the circular waveguide arm of the turnstile junction 10. For reasons which will become apparent hereinafter, the waveguide section 11 is terminated by a shorting means. It will be noted that in the depicted embodiment the shorting means is adjustable, constituting a metal disc 12, of substantially the same diameter as the inner diameter of the waveguide section 11, which is variably mounted by means of the screw 13 and the threaded end plate 14. While this adjustable feature is desirable in that it increases the general utility of the device, it should be understood, that it is not essential to the invention that the shorting means be adjustable and that the shorting means may be permanently fixed in position if desired. In addition, it is understood that any suitable waveguide shorting means may be substituted for the shorting means shown.

Within the waveguide section 11, a means for effecting a rotation of the plane of polarization of an entrant wave is interposed between the shorting means and the turnstile junction. It is essential to this invention that this rotator means be capable of providing a non-reciprocal rotation of the plane of polarization of the wave energy passing therethrough. In other words, the rotator means must be capable of providing a rotation of the plane of polarization wherein the direction of rotation, as considered from one end, clockwise or counterclockwise, is independent of the direction of propagation of the wave through the rotator means. In the embodiment of Fig. 1 a basic Faraday rotator comprising the ferrite rod 15 centrally extended within the waveguide section and the electromagnet winding 16 which encompasses the ferrite containing portion of the waveguide section 11 has been exemplarily shown. In this particular Faraday rotator, the degree of rotation is determined by the field strength of the electromagnet 16 as well as the composition and configuration of the ferrite rod 15 and the frequency of the propagated wave. In this embodiment, the direction of rotation, clockwise or counterclockwise, is determined by the polarity of the magnetic field applied. Thus, by adjustment of the magnitude of the current supplied to the electromagnet winding 16 by the current source 17, the Faraday rotator will provide the desired degree of rotation, in this invention 45 degrees. Likewise, it will be seen that the direction of rotation of the plane of polarization may be controlled by the position of the DPDT switch 18 which connects the current source 17 to the electromagnet 16. While a simple Faraday rotator has been exemplarily shown in the embodiment of Fig. 1 it is understood, of course, that it is within the purview of this invention to employ any type of wave polarization means capable of providing the requisite non-reciprocal rotation of the plane of polarization of the principal mode of a propagated wave. For example, where an untended constant rotation over a relatively wide band of frequencies would be desirable, a ridged ferrite device of the type disclosed in the application No. 502,257 filed

April 18, 1955, by Herman Chait et al., might be directly substituted for the rotator shown in Fig. 1.

Fig. 2 is illustrative of the basic operation of the device of this invention.

In a conventional turnstile junction of the type employed in this invention, with the signal entering port A, the signal will divide into two modes of equal power at the junction to excite the arms connected to ports B and D equally and in phase with a linear TE_{10} mode and to excite the circular arm which is connected to the two mode port E with a linear TE_{11} mode which is electrically polarized in the plane of arrow 5 in Fig. 2. In reiteration, $\frac{1}{4}$ of the power input (or $\frac{1}{2}$ the voltage input) to port A excites each of the ports B and D while $\frac{1}{2}$ the power input to port A excites the port E. Since opposing ports are isolated from one another in a properly matched hybrid junction of this type, it will be seen that none of the signal entering port A is coupled out port C.

As previously described above, the wave circulator of the present invention incorporates a shorted waveguide section containing a Faraday rotator which is connected to the circular port of the turnstile junction. Thus, in the device of this invention, the portion of the wave signal which excites the circular port E passes through the rotator, which provides a first 45 degree rotation of the plane of polarization of the wave, to the shorting means whereupon the wave energy is totally reflected back through the rotator to re-enter the turnstile junction. Since the direction of rotation of the plane of polarization is independent of the direction of the propagated wave, the second traversal of the Faraday rotator provides another 45 degree rotation of the plane of polarization in the same direction as provided by the first traversal. Thus the re-entrant signal is polarized in the plane of arrow 6 in Fig. 2, at right angles to polarization of the wave which entered the port E. This re-entrant wave, with its new polarization, excites the ports B and D, equally but out of phase, and is isolated from ports A and C. Assuming a lossless rotator, it can be shown that the voltage with which the re-entrant wave excites each of the ports B and D is equal to $\frac{1}{2}$ the input voltage to port A.

By adjustment of the position of the shorting means in the waveguide section such that the differential path length of the direct and reflected waves is $n\lambda/2$ at the operating frequency, where n is an odd integer and λ is the wavelength within the waveguide, the re-entrant wave can be so phased at the junction that the direct and reflected wave voltages cancel at port D and add at port B. The resultant being that all energy entering port A leaves the junction via port B and both ports C and D are isolated from port A.

In like manner, by adjustment of the position of the shorting means in the waveguide section such that the differential path length between the direct and reflected waves is $n\lambda/2$ at the operating frequency, where n is an even integer and λ is the wavelength within the waveguide, the re-entrant wave can be so phased at the junction that the direct and reflected wave voltages cancel at port B and add at port D. The resultant then being that all energy entering port A leaves the junction via port D and both ports B and C are isolated from port A.

It will be seen that the differential path length between the direct and reflected wave may be reasonably approximated as twice the distance from the shorting means to the common central point of the turnstile junction.

The direction of "circulation," either to the left or to the right of the input port, may be controlled by reversing the switch 18 which reverses the direction of current flow to change the polarity of the applied magnetic field, or by moving the shorting means in the waveguide section 11 one quarter of the wavelength at the operating frequency, which alters the differential path length by one-half the wavelength.

While the wave circulator of the present invention provides the highest isolation with the lowest insertion loss

at the operating frequency for which it is designed, it is understood that the device of this invention is operable over a band of frequencies in applications where the highest isolation with the lowest insertion loss is not a critical requirement. Fundamentally, it is the differential path length in the waveguide section which determines the frequency sensitivity of the device. Obviously, the shorter the waveguide section, the less the differential in path length between the direct and reflected wave, and the greater the bandwidth obtainable. It will be seen that in this invention it is the physical length of the 45° Faraday rotator which determines the minimum length of the waveguide section and thus presents a practical limitation to the bandwidth.

An operating model of the embodiment shown in Fig. 1 has been constructed. In this operating model, which was designed for use at 9375 mc. a circular waveguide having an inside diameter of $1\frac{3}{16}$ inch and a length of 4λ at the design center frequency was used as the waveguide section 11. The Faraday rotator incorporated a rod of commercially available ferrite, Ferramic 1331, about one inch long and $\frac{7}{32}$ inch in diameter with polystyrene plugs on both ends of the rod for impedance matching purposes. The length of the rotator element, including the polystyrene plugs, was approximately two inches overall. The ferrite rod and polystyrene plugs were supported within the waveguide by a styrofoam cylinder having the same outer diameter as the inner diameter of the waveguide section.

With optimum adjustment of the circulator at the design center frequency, 9375 mc., the maximum cross isolation, i. e., isolation between opposing ports, such as between A and C or between B and D, was 46 db and the maximum reverse isolation, i. e., isolation between successive ports in the direction opposite the intended direction of coupling, such as between A and B or B and C with coupling intended between ports A and D, was also 46 db. With bandwidths of 5 mc., 18 mc., and 57 mc., the measured reverse isolation was 40 db, 30 db and 20 db, respectively. In this operating model, circulator insertion loss was measured as 0.15 db, and the input VSWR was under 1.05:1 at the design center frequency. It will be noted that in the constructed model the waveguide section 11 was slightly longer than necessary to accommodate the Faraday rotator. It will be appreciated that even greater bandwidth might reasonably be expected employing a waveguide section of minimum length.

Fig. 3 depicts the wave circulator of this invention in conventional symbolic form. In Fig. 3 the circulator is connected as a duplexer in a radar application with the antenna connected to the port A and the transmitter and receiver connected to the ports B and D, respectively. A dummy load is connected to port C for the purpose of dissipating any reflected energy from the receiver and to absorb leakage power from B to C. In this utilization, of course, port B serves as the input port on transmission and port A serves as the input port on reception. The high cross isolation characteristic of the device is particularly valuable in this duplexer utilization. It will be appreciated, of course, that the invention has other circulator utility than in a duplexer arrangement as has been exemplarily shown in Fig. 3. For example, considering its high reverse isolation characteristic, the device is readily adaptable to antenna lobe switching and a variety of other microwave switching applications, as well. In addition it will be seen that by varying the position of the shorting means in the waveguide section 11, as permitted in the embodiment of Fig. 1, the device of this invention may be utilized for power distribution purposes in a microwave system.

With further reference to the exemplary embodiment of Fig. 1 it should be understood that it is not essential to the invention that the waveguide section 11 have a circular cross section. Any waveguide capable of supporting two orthogonal dominant modes of a propagated

wave might be substituted for the circular waveguide shown. For example a square waveguide could be substituted, if desired.

Finally, it is understood that the invention is to be limited only by the scope of the claims appended hereto.

What is claimed is:

1. A microwave circulator for use in a waveguide system comprising a turnstile junction having a plurality of coplanar ports capable of supporting a single dominant mode of a propagated wave equidispersed with respect to each other about a common central point with an additional port capable of supporting two orthogonally disposed dominant modes disposed directly above said common central point; a waveguide section capable of supporting two orthogonally disposed dominant modes of a propagated wave connected to said additional port; means for reflecting back a propagated wave within said waveguide section, and means for rotating the plane of polarization of the principal mode of a propagated wave, the direction of rotation in said means for rotating the plane of polarization being independent of the direction of propagation of the wave therethrough; said rotating means being interposed between said reflecting means and said common central point and operative to rotate the plane of polarization of a propagated wave an odd multiple of 45 degrees with each traversal thereof.

2. A microwave circulator for use in a waveguide system comprising a turnstile junction having a plurality of coplanar ports capable of supporting a single dominant mode of a propagated wave equidispersed with respect to each other about a common central point with an additional port capable of supporting two orthogonally disposed dominant modes disposed directly above said common central point; a waveguide section capable of supporting two orthogonally disposed dominant modes of a propagated wave connected to said additional port; means disposed within said waveguide section for reflecting back a propagated wave, said reflecting means being disposed at a point $n\lambda/4$ from said common central point, where n is an integer and λ is the wavelength in the waveguide section at the central operating frequency of the waveguide system; and means for rotating the plane of polarization of the principal mode of a propagated wave, the direction of rotation in said means for rotating the plane of polarization being independent of the direction of propagation of the wave therethrough; said rotating means being interposed between said reflecting means and said common central point and operative to rotate the plane of polarization of a propagated wave an odd multiple of 45 degrees with each traversal thereof.

3. A microwave circulator for use in a waveguide system comprising a turnstile junction having a plurality of coplanar ports capable of supporting a single dominant mode of a propagated wave equidispersed with respect to each other about a common central point with an additional port capable of supporting two orthogonally disposed dominant modes disposed directly above said common central point; a circular waveguide section capable of supporting two orthogonally disposed dominant modes of a propagated wave connected to said additional port; shorting means within said waveguide section for reflecting back a propagated wave, said shorting means being disposed at a point $n\lambda/4$ from said common central point where n is an integer and λ is the wavelength in the waveguide section at the central operating frequency of the waveguide system; and Faraday rotator means for rotating the plane of polarization of the principal mode of a propagated wave wherein the direction of rotation is independent of the direction of propagation of the wave therethrough; said Faraday rotator being interposed between said shorting means and said common central point and operative to rotate the plane of polarization of a propagated wave an odd multiple of 45 degrees with each traversal thereof.

4. A microwave circulator for use in a waveguide system comprising a turnstile junction having a plurality of

coplanar ports capable of supporting a single dominant mode of a propagated wave equidispersed with respect to each other about a common central point with an additional port capable of supporting two orthogonally disposed dominant modes disposed directly above said common central point; a circular waveguide section capable of supporting two orthogonally disposed dominant modes of a propagated wave connected to said additional port; means for reflecting back a propagated wave within said waveguide section, said reflecting means being disposed at a point $n\lambda/4$ from said common point, where n is an integer and λ is the wavelength at the central operating frequency of the waveguide system; Faraday rotator means for rotating the plane of polarization of the principal mode of a propagated wave wherein the direction of rotation is independent of the direction of propagation of the wave therethrough; said Faraday rotator means being interposed between said reflecting means and said common central point; and control means connected to said rotator means operative to control the rotation of the plane of polarization of a wave being propagated therethrough.

5. A microwave circulator for use in a waveguide system comprising a turnstile junction having a plurality of coplanar ports capable of supporting a single dominant mode of a propagated wave equidispersed with respect to each other about a common central point with an additional port capable of supporting two orthogonally disposed dominant modes disposed directly above said central point; a circular waveguide section capable of supporting two orthogonally disposed dominant modes of a propagated wave connected to said additional port; means disposed within said waveguide section for reflecting back a propagated wave; said reflecting means being disposed at a point $n\lambda/4$ from said common central point where n is an integer and λ is the wavelength in the waveguide section at the central operating frequency of the waveguide system; Faraday rotator means for rotating the plane of polarization of the principal mode of a propagated wave wherein the direction of rotation is independent of the direction of propagation of the wave therethrough, said Faraday rotator means being interposed between said reflecting means and said common central point; and control means connected to said rotator means operative to control the rotation of the plane of polarization of a wave being propagated therethrough.

6. A microwave circulator for use in a waveguide system comprising a turnstile junction having a plurality of coplanar ports capable of supporting a single dominant mode of a propagated wave equidispersed with respect to each other about a common central point with an additional port capable of supporting two orthogonally disposed dominant modes disposed directly above said common central point; a circular waveguide section capable of supporting two orthogonally disposed dominant modes of a propagated wave connected to said additional port; means disposed within said waveguide section for reflecting back a propagated wave; said reflecting means being disposed at a point $n\lambda/4$ from said common central point where n is an integer and λ is the wavelength in the waveguide section at the central operating frequency of the waveguide system; Faraday rotator means for rotating the plane of polarization of the principal mode of a propagated wave wherein the direction of rotation is independent of the direction of propagation of the wave therethrough; said Faraday rotator means being interposed between said reflecting means and said common central point; and control means connected to said rotator means operative to control the direction of rotation of the plane of polarization of a wave being propagated therethrough.

7. A microwave circulator for use in a waveguide system comprising a turnstile junction having a plurality of coplanar ports capable of supporting a single dominant mode of a propagated wave equidispersed with respect to

each other about a common central point with an additional port capable of supporting two orthogonally disposed dominant modes disposed directly above said common central point; a circular waveguide section capable of supporting two orthogonally disposed dominant modes of a propagated wave connected to said additional port; means disposed within said waveguide system for reflecting back a propagated wave, said reflecting means being disposed at a point $n\lambda/4$ from said common central point where n is an integer and λ is the wavelength in the waveguide section at the central operating frequency of the waveguide system; Faraday rotator means for rotating the plane of polarization of the principal mode of a propagated wave wherein the direction of rotation is independent of the direction of propagation of the wave therethrough, said Faraday rotator means being interposed between said reflecting means and said common central point; first control means connected to said rotator means operative to control the degree of rotation of the plane of polarization of a wave being propagated therethrough, and second control means connected to said rotator means operative to control the direction of rotation of said plane of polarization.

8. A microwave circulator for use in a waveguide system comprising a turnstile junction having a plurality of coplanar ports capable of supporting a single dominant mode of a propagated wave equidispersed with respect to each other about a common central point with an additional port capable of supporting two orthogonally disposed dominant modes disposed directly above said common central point; a waveguide section capable of supporting two orthogonally disposed dominant modes of a propagated wave connected to said additional port; means disposed within said waveguide section for reflecting back a propagated wave; means for rotating the plane of polarization of the principal mode of a propagated wave, the direction of rotation in said means for rotating the plane of polarization being independent of the direction of propagation of the wave therethrough; said rotating means being interposed between said reflecting means and said common central point and operative to rotate the plane of polarization of a propagated wave an odd multiple of 45 degrees with each traversal thereof.

9. A microwave circulator for use in a waveguide system comprising a turnstile junction having a plurality of coplanar ports capable of supporting a single dominant mode of a propagated wave equidispersed with respect to each other about a common central point with an additional port capable of supporting two orthogonally disposed dominant modes disposed directly above said common central point; a waveguide section capable of supporting two orthogonally disposed dominant modes of a propagated wave connected to said additional port; means disposed within said waveguide section for reflecting back a propagated wave; means for varying the position of said reflecting means with respect to said common point; means for rotating the plane of polarization of the principal mode of a propagated wave, the direction of rotation in said means for rotating the plane of polarization being independent of the direction of propagation of the wave therethrough; said rotating means being interposed between said reflecting means and said common central point and operative to rotate the plane of polarization of a propagated wave an odd multiple of 45 degrees with each traversal thereof.

10. A microwave circulator for use in a waveguide system comprising a turnstile junction having a plurality of coplanar ports capable of supporting a single dominant mode of a propagated wave equidispersed with respect to each other about a common central point with an additional port capable of supporting two orthogonally disposed dominant modes disposed directly above said common central point; a circular waveguide section capable of supporting two orthogonally disposed dominant modes of a propagated wave connected to said

additional port; means disposed within said waveguide section for reflecting back a propagated wave; means for varying the position of said reflecting means with respect to said common central point; Faraday rotator means for rotating the plane of polarization of the principal mode of a propagated wave wherein the direction of rotation is independent of the direction of propagation of the wave therethrough; said Faraday rotator means being interposed between said reflecting means and said common central point; and control means connected to said rotator means operative to control the rotation of the plane of polarization of a wave being propagated therethrough.

11. A microwave circulator for use in a waveguide system comprising a turnstile junction having a plurality of coplanar ports capable of supporting a single dominant mode of a propagated wave equidispersed with respect to each other about a common central point with an additional port capable of supporting two orthogonally disposed dominant modes disposed directly above said common central point; a circular waveguide section capable of supporting two orthogonally disposed dominant modes of a propagated wave connected to said additional port; means disposed within said waveguide section for reflecting back a propagated wave; means for varying the position of said reflecting means with respect to said common central point; Faraday rotator means for rotating the plane of polarization of the principal mode of a propagated wave wherein the direction of rotation is independent of the direction of propagation of the wave therethrough; said Faraday rotator means being interposed between said reflecting means and said common central point; and control means connected to said rotator means operative to control the direction of rotation of the plane of polarization of a wave being propagated therethrough.

12. A microwave circulator for use in a waveguide system comprising a turnstile junction having a plurality of coplanar ports capable of supporting a single dominant mode of a propagated wave equidispersed with respect to each other about a common central point with an additional port capable of supporting two orthogonally disposed dominant modes disposed directly above said common central point; a circular waveguide section capable of supporting two orthogonally disposed dominant modes of a propagated wave connected to said additional port; means disposed within said waveguide system for reflecting back a propagated wave; means for varying the position of said reflecting means with respect to said common central point; Faraday rotator means for rotating the plane of polarization of the principal mode of a propagated wave wherein the direction of rotation is independent of the direction of propagation of the wave therethrough; said Faraday rotator means being interposed said reflecting means and said common central point; first control means connected to said rotator means operative to control the degree of rotation of the plane of polarization of a wave being propagated therethrough; and second control means connected to said rotator means operative to control the direction of rotation of said plane of polarization.

References Cited in the file of this patent

UNITED STATES PATENTS

2,686,901	Dicke	Aug. 17, 1954
2,748,352	Miller	May 29, 1956
2,748,353	Hogan	May 29, 1956
2,760,166	Fox	Aug. 21, 1956
2,767,379	Mumford	Oct. 16, 1956
2,817,812	Fox	Dec. 24, 1957

OTHER REFERENCES

Fox et al.: Bell System Technical Journal, vol. 34, No. 1, January 1955, pages 5-103. (Copy in Scientific Library.)