May 7, 1963 H. N. CHAIT ETAL 3,089,101

FIELD DISPLACEMENT CIRCULATOR

Filed Feb. 27, 1959

FIG. 2

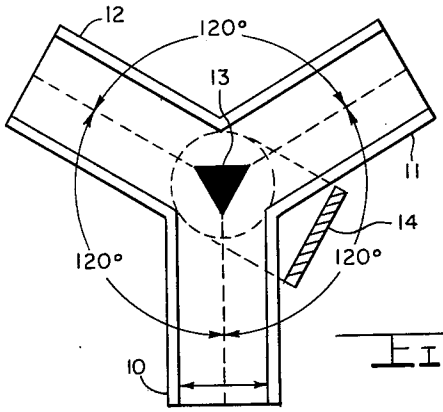


FIG. 3

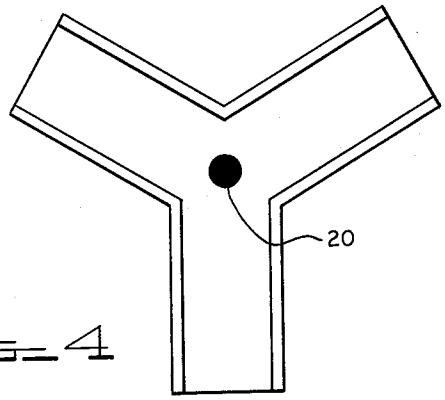


FIG. 4

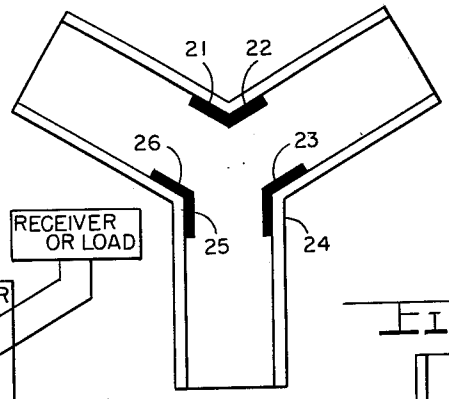


FIG. 1

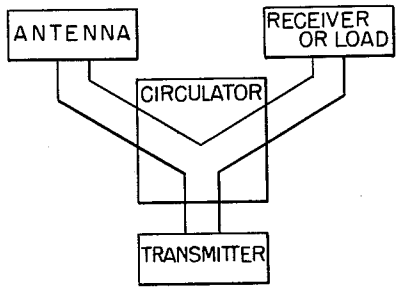
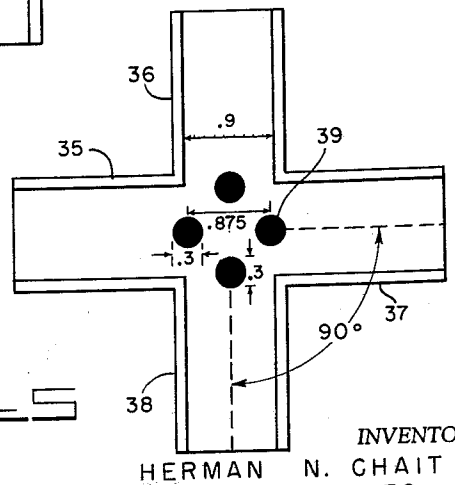


FIG. 6



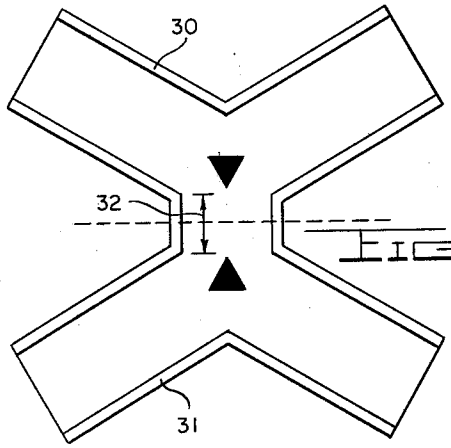


FIG. 5

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FIELD DISPLACEMENT CIRCULATOR

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(Granted under Title 35, U.S. Code (1952), sec. 266)

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 to electromagnetic transmission systems known as circulators and more particularly to circulators using only rectangular waveguides.

In many situations involving the use and distribution of radio frequency energy, particularly the transmission or distribution of such energy by hollow circular or rectangular piping classified as waveguide, there exists the need for such an elementary appearing device as a switch, by means of which energy may be sent through selected pipes out of a group. In radar devices, the familiar T—R box is an example of such a switch where a single antenna is connected alternately to a transmitter and a receiver as indicated in FIG. 1.

Such switching of radio frequency energy is not a simple matter because the rapidity with which such switching occurs normally rules out any apparatus which involves mechanical motion. In addition, efficient power transfer and avoidance of spurious signals requires careful attention to impedance matching even during the instant switching action occurs.

A further application of waveguide switches to radio systems such as radar is the elimination of adverse effects of return energy on the trnasmitter. It is well known that radar energy reflected by nearby objects or by a mismatched antenna can return to the radar transmitter while it is operating, causing undesirable variable loading thereof. Thus it would be advantageous to use an additional waveguide switch between the transmitter and the antenna which will deliver transmitter energy to the antenna and at the same time deliver energy returned by the antenna to a load device where it can be absorbed harmlessly to prevent its undesirable effect upon the transmitter.

Thus two typical applications of waveguide switches have been set forth, the first being simpler in principle than the latter because the latter is required to be operative to channel energy simultaneously through several paths.

A class of devices capable of fulfilling the more difficult latter requirements has been labeled circulator, which in the past has consisted of one or more sections of waveguide containing gyromagnetic material in combination with several mode transducers. Such circulators have been of a first type which relies for its operation upon the rotation of the plane of polarization of the propagated energy, or of a second type, the differential phase shift type, which depends upon the nonreciprocal phase shift of a slab of ferrite in a rectangular waveguide. For the first type, to secure rotation of the plane of polarization, it has been customary to use circular waveguide whereas in most microwave transmission systems rectangular waveguide is primarily used. Thus initially in use of this type of polarization circulator, an impedance matching problem is encountered due to the difference in impedance of circular and rectangular waveguide. In the differential phase shift type of circulator two hybrid junctions are required in addition to the ferrite loaded waveguide thereby increasing the size, weight and cost of the overall circulator.

It is therefore a first object of this invention to provide a circulator using only rectangular waveguide.

A further object is to provide a passive duplexer.

A further object of this invention is to provide a circulator wherein the phase of the transmitted electromagnetic energy is shifted with no change in its plane of polarization.

A further object of this invention is to provide a microwave circulator using only rectangular waveguide sections and a transverse magnetic field.

A further object of the present invention is to provide a circulator requiring no transitional devices.

It is a further object of the present invention to provide a microwave circulator which does not require any magic T's or hybrid junctions.

It is a further object of the present invention to provide a microwave circulator of reduced size, weight and cost.

Other and further objects and features of the present invention will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in connection with the accompanying drawings wherein:

FIG. 1 shows a typical arrangement of apparatus embodying the features of the present invention.

FIGS. 2–6 show various embodiments of the circulator constructed in accordance with the teachings of the present invention.

In accordance with the basic features of the present invention, utilization is made of the principle that the field distribution in a rectangular waveguide containing a ferrite subjected to a magnetic field can be assymetrical even though the physical configuration is symmetrical. By properly selecting the ferrite and its proportions it is possible to concentrate the energy on one side of the waveguide. Reversing the field or changing the direction of propagation will cause the energy to concentrate on the other side of the wave guide. Using the principles of the present invention this phenomenon has been utilized to construct a new type of circulator. Typically ferrite material is placed at the region of the junction of n rectangular waveguides which intersect at $360/n$ degrees.

The placement of the ferrite can be either in the immediate region of the junction which is common to all the waveguide, or it can be disposed in the waveguide in sufficient proximity to the junction or common region so as to affect the distribution of energy in the junction. The magnetic field is applied normal to the broad dimension of the waveguide. The basic apparatus of the present invention can also be employed as a waveguide switch by using a reversible magnetic field instead of a static magnetic field.

As used in connection with the present invention the term circulator is applied to a passive device of "n" ports that may be used interchangeably for input or output of electromagnetic energy, the device having the peculiar property that energy going into a first port will come out from an adjacent (second) port while energy entering the second port will not come out at the first port but instead will come out at a subsequent adjacent (third) port, etc., with energy from the nth port finally returning to the adjacent (first) port.

With reference now to FIG. 2 of the drawing the typical apparatus indicated therein embodies the features of the present invention as applied to a three port circulator with one broad wall thereof being removed to show inside arrangements. It is to be understood of course that the principles of the invention are also applicable to circulators having a different number of ports. Apparatus of FIG. 2 makes use of propagational characteristics of a rectangular waveguide loaded by ferrite wherein an asymmetrical radio frequency field distribution is obtained even though the distribution of the ferrite material itself is symmetrical. This asymmetrical field distribution is a consequence of the radio frequency magnetic field being

elliptically polarized in planes parallel to the broad walls of the guide and is of opposite sense on either side of the guide. Since the effective permeability of the magnetized ferrite depends on the sense of polarization it is seen that the sides of the ferrite loaded guide are electrically dissimilar. Thus the apparatus effectively displaces the field of the energy being transmitted through a waveguide to one side of the guide or the other in such a way that substantially all the power being transmitted through the guide can be diverted into one adjacent waveguide in the junction region and prevented from entering other waveguides. As shown in FIG. 2, three rectangular waveguides **10**, **11** and **12** intersect at angles of 120 degrees in the plane of the broad dimension. In the region of intersection which is common to all the waveguides, is disposed a ferrite member **13** having three-fold symmetry. A permanent magnet field producing device of suitable structure indicated by numeral **14** is provided to apply a magnetic field to the ferrite material **13** perpendicular to the plane of FIG. 2. It is to be understood of course that in applications wherein a static field is suitable, the ferrite material **13** could be permanently magnetized or a permanent magnet could be contained within the ferrite material itself thereby eliminating the requirement for an external magnet **14**. Additionally the magnet **14** could be an electromagnet rather than a permanent magnet to provide somewhat more flexible control of the operation of the device. Also the generic term ferrite is used to define materials having gyromagnetic properties, which may be typically ferrites having spinel structure and garnet structure.

In typical S band equipment operating at approximately 3,000 megacycles, a magnetization field intensity of 38 oersteds is sufficient which may easily be provided by a small permanent magnet located either external or internal relative to the waveguide. As further detail of a specific structure employed, the ferrite material as shown in FIG. 2 in the form of an equilateral triangle assembly has a dimension on the side of 1.2 inches and extends between the broad walls.

With reference now to FIG. 3 of the drawing, the apparatus indicated therein is similar to that of FIG. 2 differing in the specific configuration of the ferrite member. In this particular illustration the ferrite member is a cylinder **20** placed at the 120° junction of the three rectangular waveguides. Typical cylinder diameters for *x*-band range from .125 inch to .500 inch. The best results appeared to be obtained with a diameter of .350 inch filling the .400 inch thick guide in height. With such a ferrite configuration the insertion loss of the apparatus was less than ½ db and the isolation and reflection greater than 30 db over a frequency band of about 50 megacycles.

FIG. 4 shows a third form of ferrite loading which also has the desired three-fold symmetry. In this apparatus as intended for use at the typical X band, six slabs **21**, **22**, **23**, **24**, **25**, and **26** were disposed along the narrow walls of the waveguides in the region of the intersection, the slabs being of .500 inch in length, .125 inch in thickness, and extending from wall to wall (broad wall).

FIG. 5 shows a four port circulator constructed by placing two three port circulators **30** and **31** of FIG. 2 together with an interconnection by means of a common waveguide from each circulator. Such a circulator may typically have a junction separation **31** as small as ½ guide wavelength. Losses of the order of ¾ db with reflection and isolation greater than 18 db from 9200 to 9400 megacycles are readily obtainable.

FIG. 6 shows an additional circulator configuration where the principles of the present invention are applied to a four port circulator, the various arms of the ports being separated by 360/4 or 90 degrees. Waveguide dimensions are substantially the same as those conventionally employed for frequencies typically as outlined for X band in the preceding illustrations, thus the apparatus of FIG. 6 employs four waveguides **35**, **36**, **37** and **38** intersecting at 90 degrees, FIG. 6 showing a view taken in the broad dimension of the waveguides. Four cylindrical sections of ferrite are employed. For X-band with a waveguide inner width of 0.9 inch, the cylinders are centrally disposed relative to the longitudinal axes of the waveguide, are 0.3 inch in diameter and are spaced 0.876 inch as measured along the longitudinal axis extending through opposite waveguides. The result is an arrangement wherein the ferrite material is partly within the region common to all four waveguides and partly in the waveguides in the region near such common region. Such a device as FIG. 6 provides low losses with isolation and reflection of the same order as that typified in connection with the previously described figures.

Although the apparatus of the present invention is more likely to be used with a relatively small number of ports, typically the three or four shown in the various figures thus far described, it is to be understood that the basic principles of the invention may be applied to devices employing a greater number of ports for which appropriate intersection angles and configurations of the ferrite post would be employed. For example, it would be a logical extension of the principles of the invention to provide for five port intersection or greater numbers should the need arise. In any event, each waveguide leading to or from the junction is counted so that the arrangement of FIG. 6 is considered a four port circulator even if it is constructed from two crossing waveguides which are cut and then attached together in the common region.

Obviously many modifications and variations of the present invention are possible in the light of the above teachings. It is therefore to be understood that within the scope of the appended claims the invention may be practiced otherwise than as specifically described.

What is claimed is:

1. A circulator comprising, three waveguides having their longitudinal axes in the same plane intersecting at equal angles enclosing a common region shared by the waveguides, ferrite material disposed in the circulator in at least a part of a region consisting of the common region and portions of the waveguides contiguous thereto, and means for magnetizing the ferrite material to such degree that energy incident at a first waveguide leaves at a second waveguide, energy incident at the second waveguide leaves at the third waveguide, energy incident at the third waveguide leaves at the first waveguide.

2. A circulator comprising, three waveguides having their longitudinal axes in the same plane intersecting at equal angles enclosing a common region shared by the waveguides, ferrite material disposed in the circulator in at least a part of a region consisting of the common region and portions of the waveguides contiguous thereto, said ferrite possessing symmetry for all waveguides, and means for magnetizing the ferrite material to such degree that energy incident at a first waveguide leaves at a second waveguide, energy incident at the second waveguide leaves at the third waveguide, energy incident at the third waveguide leaves at the first waveguide.

3. A circulator comprising, three waveguides intersecting at equal angles in the same plane enclosing a common region shared by the waveguides, ferrite material disposed in the circulator in the common region, and means for magnetizing the ferrite material to such degree that energy incident at a first waveguide leaves at a second waveguide, energy incident at the second waveguide leaves at the third waveguide, energy incident at the third waveguide leaves at the first waveguide.

4. A circulator comprising, three rectangular waveguides intersecting at equal angles to enclose a common region shared by all waveguides, the H plane of said waveguides and said common region being coincident, ferrite material disposed in the circulator in at least a part of a region consisting of the common region and contiguous portions of the waveguides, said ferrite possessing symmetry for all waveguides, and means for

magnetizing the ferrite material to such a degree that energy incident at a first waveguide leaves at a second waveguide, energy incident at the second waveguide leaves at the third waveguide, energy incident at the third waveguide leaves at the first waveguide.

5. A circulator comprising, three rectangular waveguides intersecting at equal angles to enclose a common region shared by all waveguides, the H plane of said waveguides and said common region being coincident, ferrite material disposed in the circulator in the common region, said ferrite material having a circular cross-section in said H plane of the waveguides, and means for magnetizing the ferrite material to such degree that energy incident at a first waveguide leaves at a second waveguide, energy incident at the second waveguide leaves at the third waveguide, energy incident at the third waveguide leaves at the first waveguide.

6. A circulator comprising, three rectangular waveguides intersecting at equal angles to enclose a common region shared by all waveguides, the H plane of said waveguides and said common region being coincident, ferrite material in slab form disposed adjacent to the walls of said waveguides perpendicular to the H plane in the common region, and means for magnetizing the ferrite material to such degree that energy incident at a first waveguide leaves at a second waveguide, energy incident at the second waveguide leaves at the third waveguide, energy incident at the third waveguide leaves at the first waveguide.

7. A circulator comprising, three rectangular waveguides intersecting at equal angles to enclose a common region shared by all waveguides, the H plane of said waveguides and said common region being coincident, ferrite material disposed in the circulator in the common region, said ferrite material possessing symmetry for all waveguides, and magnetic field producing means external to the waveguides for magnetizing the ferrite material to such degree that energy incident at a first waveguide leaves at a second waveguide, energy incident at the second waveguide leaves at the third waveguide, energy incident at the third waveguide leaves at the first waveguide.

8. A circulator comprising, three rectangular waveguides intersecting at equal angles to enclose a common region shared by all waveguides, the H plane of said waveguides and said common region being coincident, ferrite material disposed in the circulator in the common region, said ferrite material possessing symmetry for all waveguides and magnetic field producing means disposed within the waveguide for magnetizing the ferrite material to such degree that energy incident at a first waveguide leaves at a second waveguide, energy incident at the second waveguide leaves at the third waveguide, energy incident at the third waveguide leaves at the first waveguide.

References Cited in the file of this patent

UNITED STATES PATENTS

2,794,172	Kock	May 28, 1957
2,848,688	Fraser	Aug. 19, 1958
2,849,687	Miller	Aug. 26, 1958
2,867,772	Allen	Jan. 6, 1959
2,870,418	Hewitt	Jan. 20, 1959
2,978,649	Weiss	Apr. 4, 1961
3,015,787	Allin et al.	Jan. 2, 1962
3,018,443	Bloom et al.	Jan. 23, 1962

OTHER REFERENCES

Chang et al.: "Proceedings of the IRE," July 1958, pages 1383–1386.

Swanson et al.: "1958 IRE Wescon Convention Record," Part 1, pages 151–156.

Weiss: "Physical Review," July 1, 1957, page 317.

"Electrical Manufacturing," February 1959, pages 61–63.

Auld: "IRE Transactions on Microwave Theory and Techniques," April 1959, pages 238–246.