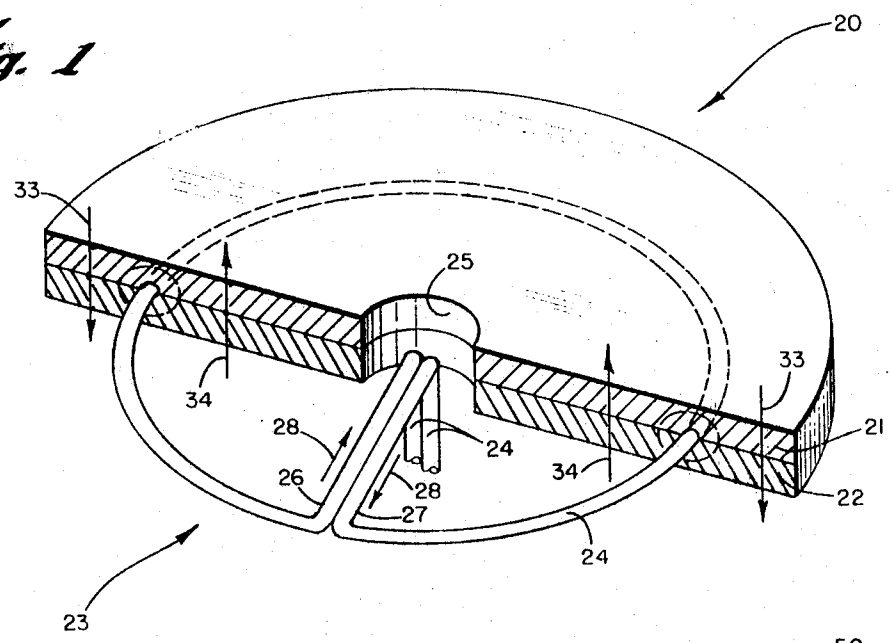
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FERRITE JUNCTION CIRCULATORS HAVING BIASING CONNECTOR WIRE AT FERRITE CENTER

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Fig. 1



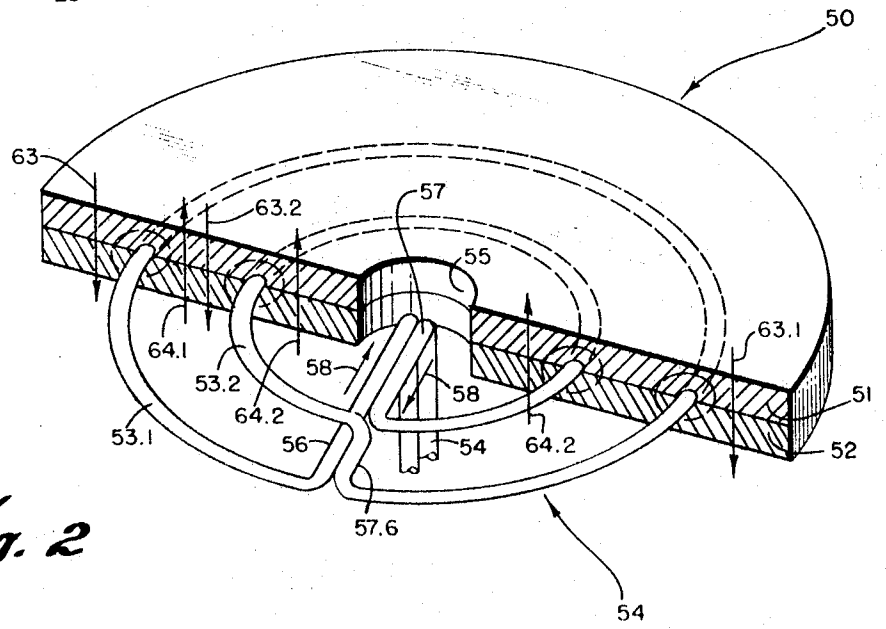
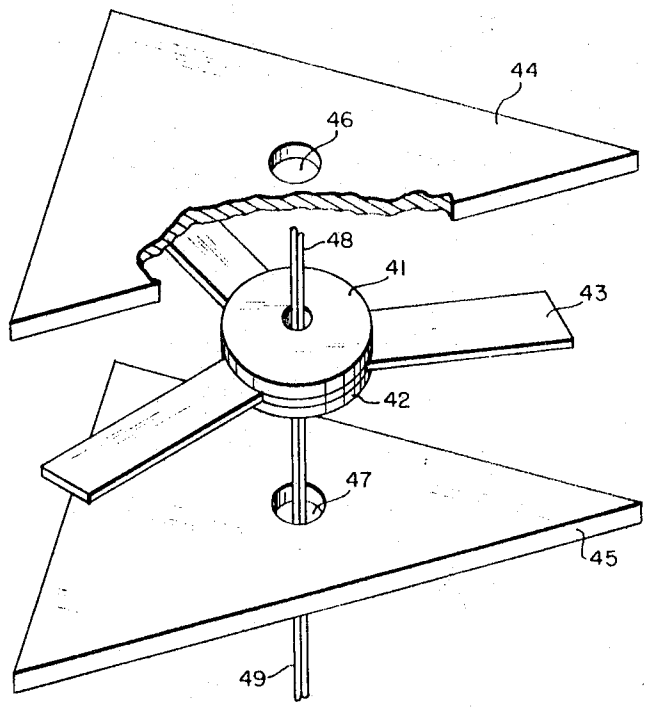


Fig. 2

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Fig. 3



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United States Patent Office 3,457,525 Patented July 22, 1969

3,457,525

FERRITE JUNCTION CIRCULATORS HAVING BIASING CONNECTOR WIRE AT FERRITE CENTER

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Filed May 16, 1967, Ser. No. 638,893
Int. Cl. H01p 1/32, 5/12
U.S. Cl. 333—1.1 12 Claims

ABSTRACT OF THE DISCLOSURE

A TEM junction circulator is made into a modulator or a microwave switch by reversing the direction of the magnetic field applied to the ferrite member(s), by applying current through a wire traversing the ferrite member(s) in a direction perpendicular to the direction of the magnetic field, so that the biasing magnetic field around the wire due to the current has two components parallel to the magnetic field direction but respectively in opposite senses. In a ferrite disc the wire is a loop (or a plurality of loops) located around the axis, preferably between the two flat surfaces, and the biasing magnetic field links in one axial direction with that part of the ferrite member which is outside the loop, and in the opposite axial direction with that part of ferrite member which is inside the loop.

Background of the invention

The difficulty in achieving fast switching speeds with junction circulators is caused by demagnetizing fields and eddy currents. The strong demagnetizing fields are due to the disk shaped ferrite geometries used. These fields oppose the applied magnetic field and more switching power is therefore needed. An existing technique for latching junction circulators in waveguide or strip transmission line uses a switchable magnetic material external to the microwave circuit. A disadvantage of this technique is that eddy currents are induced in the transmission line housing resulting in a certain degree of shielding of the modulating or switching pulse. These eddy currents increase the switching energy required by the driver and limit the switching speed. Generally, whether the junction is in waveguide or strip transmission line, this approach is compatible for switching speeds up to about 10 microseconds provided thin waveguide or transmission line walls are used; usually the switching times are in the 10 to 50 microseconds range.

Description of the invention

It is the object of this invention to provide high speed TEM junction ferrite modulators and switches. A further object is to provide improved TEM junction circulators which can be used as modulators or switches for continuous wave applications at elevated power levels. Still further objects of the invention are to provide latching ferrite TEM junction circulators for which switching energy is small, the shielding effects of the transmission line housing due to eddy currents is substantially eliminated, and there is no requirement for a holding current. Another object is to provide a magnet-less TEM junction circulator.

A specific object of the invention is to provide a latching ferrite TEM junction circulator in which switching is achieved by applying current through a wire loop inserted in the ferrite disc or discs of the junction.

Another specific object is to provide such a latching ferrite TEM junction circulator which employs a ferrite geometry that can be placed in contact over a wide area with the transmission line walls.

These and other objects and features of the invention will be apparent from the following description of exemplary embodiments of it. This description refers to the accompanying drawings, in which:

FIG. 1 shows a ferrite disc with a single loop of wire inserted in it;

FIG. 2 shows a ferrite disc with a double loop of wire inserted in it; and

FIG. 3 is an exploded schematic of a strip transmission line 3-port TEM junction circulator employing latching ferrite members according to the invention.

FIG. 1 shows the invention as applied to a disc-shaped ferrite member **20**. This member is made in two pieces **21** and **22**, each grooved to receive a loop **23** of wire **24**, and clamped together with the loop between them. A central aperture **25** is provided in the discs, which will be on the axis of a circulator incorporating the member **20** (see e.g. FIG. 3), and the wire **24** enters and leaves through this aperture, being brought to the loop via radially-disposed segments **26, 27**.

Current passing through the wire **24** in the direction of the arrows **28** will establish a magnetic field around the wire in the loop **23** which will have components perpendicular to the plane of the disc **20** but in opposite directions as shown by arrows **33** and **34**, respectively. If the current direction is reversed, the direction of this magnetic field will be reversed. In either case, the center of the ferrite disc **20**, within the loop **23** is biased in one direction, while the part outside the loop **23** is biased in the opposite direction. The ferrite disc can be latched in either of these two states by passing a pulse of current of appropriate amplitude through the wire loop **23**. No external magnet or holding current is needed.

The latching ferrite member **20** of FIG. 2 will be better understood from a consideration of FIG. 3. Two ferrite discs **41** and **42**, each similar to FIG. 1 are disposed one on each side of the center conductor **43** of a three-port strip transmission line circulator, at the junction of the three lines. This form of circulator is well-known (see, for example, H. Bosma, "On Stripline Y-Circulation at UHF," IEEE Transactions on Microwave Theory and Techniques, vol. MTT–12, January 1964, pages 61–72) and will therefore be described here only schematically. The ground plane members **44** and **45** have holes **46** and **47**, respectively, through which are passed the lead wires **48** and **49**, respectively, for the biasing loop conductors (not shown) of the respective ferrite discs. As is apparent, the holes in the discs and ground planes, and the lead wires, are all on the axis of the circulator, where the electric field of a wave propagating in circulator is relatively small and essentially independent of field orientation in the disc. Hence location of the lead wires on the axis avoids perturbing the wave. The wire loop of each disc is parallel to the ground planes and is therefore non-radiating. Since, as is noted above, the magnetic path for the biasing field in each ferrite disc is a closed magnetic circuit, there are no eddy currents induced in the ground planes due to the changing magnetic field when the direction of the magnetic field is reversed, and the shielding effect of the ground planes is eliminated. Since the ferrite disc remains latched in a given state once a current pulse has passed through its biasing loop, the current can be terminated until it is desired to reverse the magnetic field, and neither holding current nor external magnet is required to hold the ferrite in a given magnetic state. A magnet-less latchable ferrite circulator is thus provided.

It is noted that if the R.F. energy of a wave propagating in the circulator were uniformly distributed over the ferrite discs **41** and **42**, no circulation would result. However, the R.F. energy is not uniformly so distributed. The magnetic field is circularly polarized at the center of the discs, and becomes more elliptically polarized as the radius

of the disc increases. At the edge of the discs, it is linearly polarized. (Skomal "Theory of Operation of a 3-Port Y-Junction Ferrite Circulator," IEEE Trans. on Microwave Theory and Techniques, vol. 11, pp. 117–123, March 1963; Fay and Comstock "Operation of the Ferrite Junction Circulator," IEEE Trans. on Microwave Theory and Techniques, vol. MTT–13, pp. 15–27, January 1965). An essential feature of circulator theory is that circulation occurs for small splitting of the degenerate modes. Hence, a preferred direction of propagation results from the latching property of the ferrite discs **41** and **42**.

A more effective way to bias the ferrite discs is to use two concentric wire loops, as shown in FIG. 2. Here a disc-shaped ferrite member **50** is made of two confronting pieces **51** and **52**, each grooved to receive two concentric loops **53.1** and **53.2** of wire **54**. The wire **54** enters and leaves through a central aperture **55**, being brought to the loops via radially-disposed segments **56**, **57**. The loops **53.1** and **53.2** are connected in series between these segments through a sub-segment **57.6**. Current passing through the wire **54** in the direction of the arrows **58** will establish a magnetic field around each loop which will have components perpendicular to the plane of the disc **50** but in opposite directions as shown by arrows **63.1** and **64.1**; **63.2** and **64.2**; respectively, for the two loops **53.1** and **53.2**. The confronting components **64.1** and **63.2** due to the two loops essentially cancel each other, and the net magnetic components normal to the plane of the disc **50** are those **63.1** in one direction in the part of the disc outside the two loops and those **64.2** in the opposite direction in the part of the disc inside the two loops.

The invention is not limited to the 3-port example shown and described, but is applicable to other configurations, of four or more ports, for example. While no particular thickness of the disc shapes has been found critical to the operation of the invention, the current in the loop or loops required for circulation (i.e. biasing to a given state of remanence) may be reduced in a given case by making the discs thicker. No attempt has been made to illustrate all possible embodiments of the invention, but rather only to illustrate its principles and the best manner presently known to practice it. Therefore, such other forms of the invention as may occur to one skilled in this art on a reading of the foregoing specification are also within the spirit and scope of the invention.

We claim:

1. In a transmission line circulator comprising a TEM junction in a multi-port configuration of transmission lines for the propagation of electric wave energy and ferrite means located in said junction for circulating such energy when suitably magnetized, the improvement in which said ferrite means comprises at least one disc-shaped member disposed with its axis perpendicular to the plane of the disc substantially coincident with the axis of said junction, electric conductor means passing through said member in a path curved about the axis of said junction, and connector wires for said conductor means disposed substantially coincident with said axis of said junction for passing electric current through said conductor means to establish a biasing magnetic field closed within said disc-shaped member and having components oriented to provide electric wave circulation among the ports of said configuration.

2. A circulator according to claim **1** in which said path is in a plane between the flat surfaces of said disc-shaped member.

3. A circulator according to claim **1** in which said disc-shaped member has a hole centered about its axis and said wires enter said disc-shaped member at said hole and pass radially within said disc-shaped member to said conductor means.

4. A circulator according to claim **1** in which said transmission lines have first and second electrically conductive spaced apart walls lying in parallel planes and said disc-shaped member is located between and parallel to them.

5. A circulator according to claim **4** made of strip transmission lines having an inner conductor between said walls and at least two of said disc-shaped members in said junction located one on each side of said inner conductor.

6. A circulator according to claim **5** having an axially-located hole in each of said walls and an axially-located hole in each of said disc-shaped members, and connector wires for the conductor means of each of said disc-shaped members extending in one direction through one of said wall holes from one of said disc-shaped members and in the opposite direction through the other of said wall holes from the other of said disc-shaped members.

7. A circulator according to claim **1** in which said path makes a plurality of serially-connected loops about said axis.

8. A ferrite member for a junction circulator comprising a disc of ferrite material and electrical conductor means passing through said member in a path curved about the axis in the center of and perpendicular to the plane of said disc, and having connector wires passing radially from said conductor means to said axis.

9. A ferrite member according to claim **8** in which said path is a circular loop.

10. A ferrite member according to claim **8** in which said path is two circular loops connected together in series.

11. A ferrite member according to claim **10** in which said loops have different diameters and lie substantially in the same plane.

12. A ferrite member according to claim **8** having an axial bore through which said connector wires pass in a radial direction to said path.

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U.S. Cl. X.R.

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