Oct. 13, 1970 K. L. CARR 3,534,296

TANDEM CONNECTED CIRCULATORS

Filed Nov. 6, 1967 3 Sheets-Sheet 1

PRIOR ART

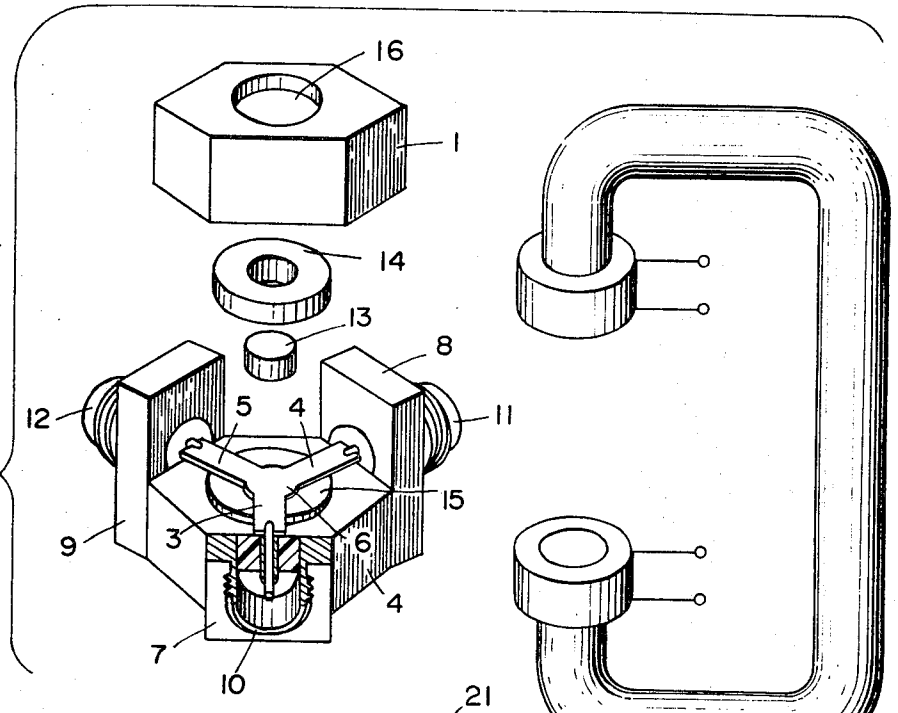


FIG. 1

PRIOR ART

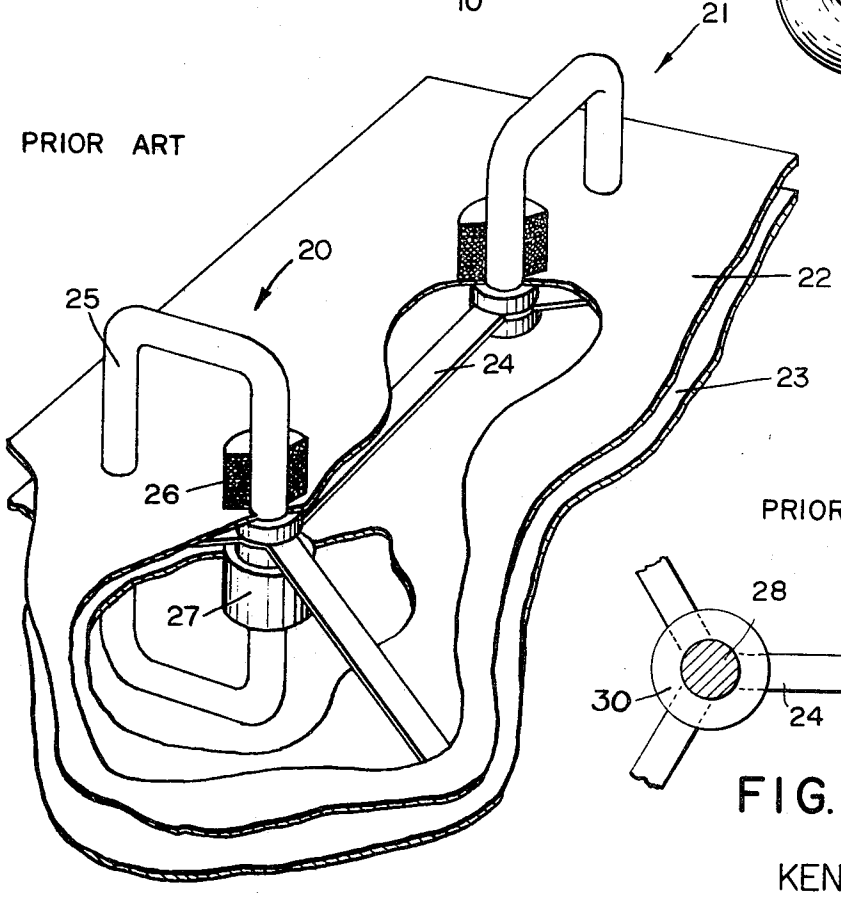


FIG. 2

PRIOR ART

FIG. 3

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TANDEM CONNECTED CIRCULATORS

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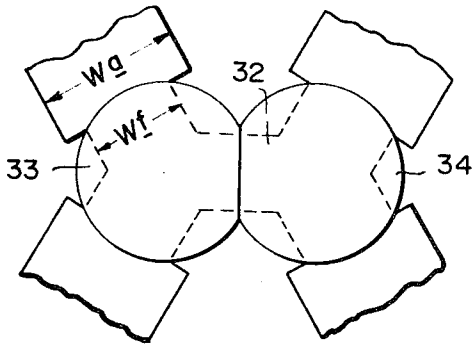


FIG. 4

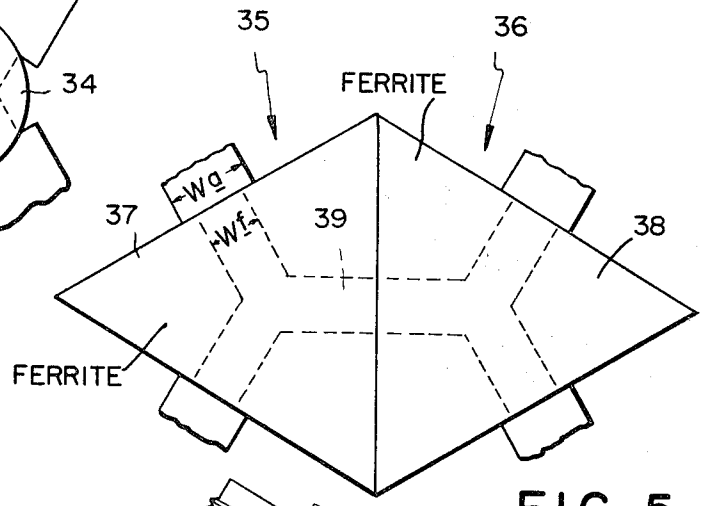


FIG. 5

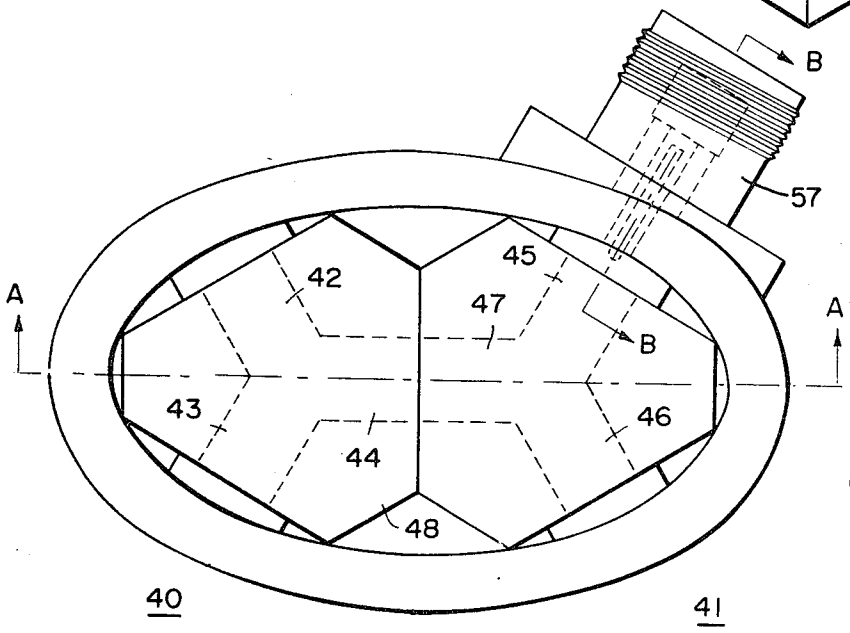


FIG. 6

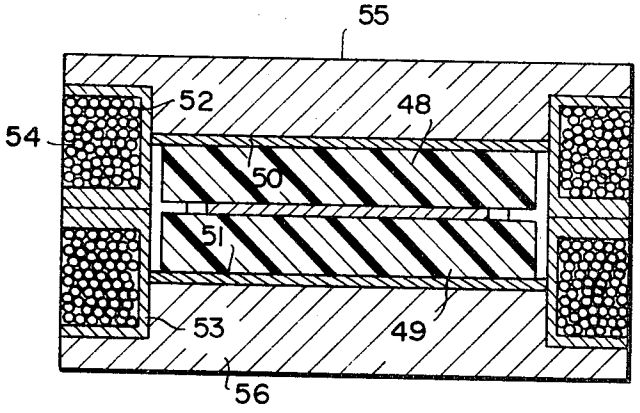


FIG. 7

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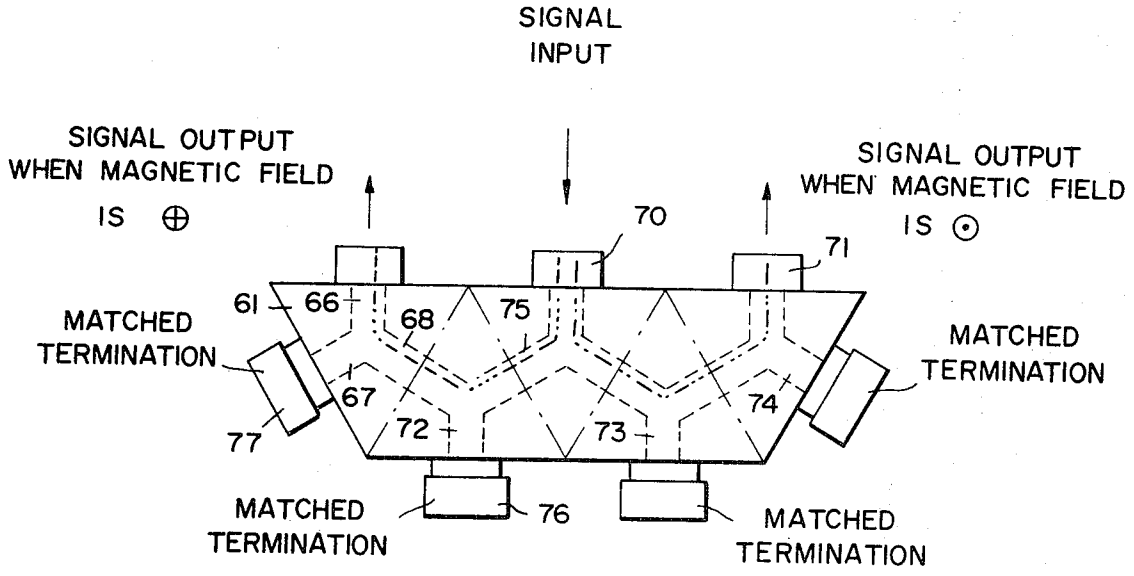


FIG. 9

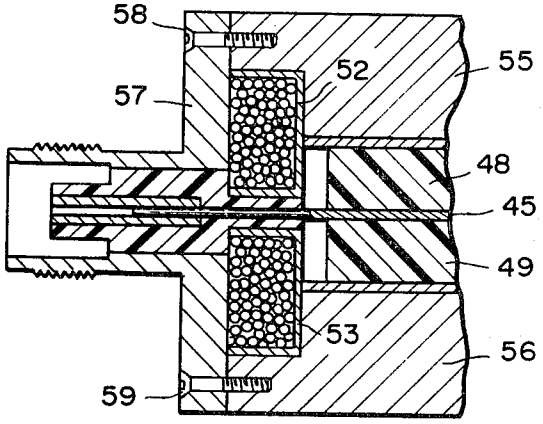


FIG. 8

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United States Patent Office 3,534,296 Patented Oct. 13, 1970

3,534,296

TANDEM CONNECTED CIRCULATORS

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Int. Cl. H01p 1/32, 5/12
U.S. Cl. 333—1.1 4 Claims

ABSTRACT OF THE DISCLOSURE

Ferrite circulators of the strip transmission line type are connected in tandem. The circulators are brought close together by eliminating the conventional dielectric matching rings that encircle the junctions. The ferrite members at the junctions of adjacent circulators are caused to abut so that the arms which connect the circulators are disposed entirely between ferrite members. The compact arrangement permits a common magnetic field to extend over adjacent circulators.

SUMMARY OF THE INVENTION

This invention relates to the non-reciprocal transmission of electromagnetic wave energy and pertains to devices employing ferrites to control the transfer of microwave energy. The invention concerns ferrite circulators of the type in which the center conductor of a strip transmission line has a plurality of arms connected to a common junction situated between a pair of ferrite members. More particularly, the invention pertains to compact and efficient arrangements of two or more circulators.

DISCUSSION OF THE PRIOR ART

The conventional manner of connecting strip line ferrite circulators in tandem is to bridge the intervening space with a length of strip line to permit wave energy from the output arm of one circulator to be transmitted to the input arm of another circulator. In the conventional arrangement, each circulator is provided with its own electromagnet to produce the magnetic field for that circulator only. The coil of the electromagnet is bulky and prevents the separate circulators from being brought closely together. Further, the conventional strip line circulator employs a dielectric ring which surrounds the ferrite members at the junction. The dielectric ring is, in essence, a form of quarter wave impedance transformer. If the coils of the electromagnets did not prevent two circulators from being brought closely together, the dielectric rings would do so. Conventional arrangements of tandem circulators are relatively bulky and because of the impedance transformations in the transmission path and the line lengths between circulators, significant losses can be incurred in transmitting signals, especially where more than two circulators are in the tandem arrangement. Where the tandem arrangements are employed as switches, the relatively long line lengths between circulators (i.e., relative to the wave length of the signals transmitted over the line), causes a deterioration in bandwidth and the impedance transformations in the transmission path prevent the attainment of high isolation.

THE INVENTION

The objective of the invention is to permit strip line circulators to be arranged in tandem in a manner which avoids long intervening line lengths and eliminates impedance transformations in the transmission path between circulators. By bringing the circulators close together, the use of a common magnetic field may be realized. The invention resides in an arrangement of strip line circulators in which the circulators are abutted

so that the connecting line length between circulators is eliminated. In the invention, the ferrite members at the junctions of abutting circulators may have a common border or the ferrite members may be united so that no distinct border exists. In the invention, dielectric rings are not employed at the junctions of the circulators so that impedance transformations in the path between abutting circulators do not occur. The center conductor connecting the junction of one circulator to the junction of the adjacent circulator is entirely a ferrite filled line and the signal is thus transmitted between circulators over an electrically smooth path. Surrounding the abutting circulators with an electromagnetic coil permits the coil to establish a magnetic field that is common to the abutting circulators.

THE DRAWINGS

The invention, both as to its construction and its manner of operation, can be better apprehended from the exposition which follows when it is considered in conjunction with the accompanying drawings in which:

FIG. 1 depicts a "prior art" strip line circulator;

FIG. 2 shows a "prior art" arrangement of two strip line circulators connected in tandem;

FIG. 3 is a top plan view of the arrangement shown in FIG. 2 with the ground plane plates and electromagnets removed;

FIG. 4 shows the invention applied to two circulators of the type employing ferrite discs at their junction;

FIG. 5 illustrates the invention applied to circulators of the type using triangular ferrites at their junctions;

FIG. 6 shows an embodiment of the invention having an electromagnetic coil arranged to supply a common magnetic field for two abutting circulators which are connected in tandem;

FIG. 7 is a sectional view taken along the parting plane A—A in FIG. 6;

FIG. 8 is a sectional view taken along the parting plane B—B in FIG. 6 and shows the transition from strip transmission line to a coaxial connector, and

FIG. 9 is a schematic showing of the invention embodied in an arrangement of five tandem connected circulators.

DESCRIPTION

A strip line Y-junction circulator of conventional construction is shown in the partially exploded view of FIG. 1. The ground planes of the strip line are constituted by plates **1** and **2** and between those plates is disposed a center conductor having three arms **3**, **4**, **5** meeting at a central junction **6**. To fix the ground plane plates so that they are parallel and separated, the plates are secured to three spacers **7**, **8**, and **9**. The spacers are electrically conductive and act as short circuits which manitain the ground planes at the same electrical potential. Each spacer is, in addition, electrically connected to the outer conductor of a coaxial connector which has its center conductor insulated from and extending through the spacer into electrical connection with one of the arms of the strip line's center conductor. The arm **3**, for example, is joined to the center conductor of the coaxial connector **10** whose outer conductor is joined to spacer **7**. Similarly, arm **4** is connected to the center conductor of coaxial connector **11** and arm **5** is joined to the center conductor of coaxial connector **12**.

The central junction **6**, at which the three arms meet, is disposed between a pair of ferrite disks, only one of which, the disk **13**, is in view in FIG. 1. Each disk is fitted within a dielectric ring, **14** or **15**, and the dielectric and ferrite assemblages fill the spaces between the central conductor and the ground plane plates above and below the assemblages.

In the operation of the circulator, the ferrite disks are

situated in a magnetic field established by a magnet having its pole pieces accommodated within depressions, such as the depression **16**, in the ground plane plates. The bandwidth over which the circulator operates satisfactorily is, as is known, dependent upon the degree of matching that is achieved, the size of the ferrite disk, and the intensity of the magnetic field. In order to alleviate the impedance mismatch caused by the ferrite at the junction, dielectric loading of the strip line is employed to obtain an electrically smoother path. The conventional manner of dielectric loading is the placement of a dielectric ring around the ferrite disk, as illustrated in FIG. 1. The dielectric ring preserves the symmetry of the junction and extends somewhat the bandwidth over which satisfactory operation of the circulator is obtained.

The wave energy proceeding through the conventional circulator propagates through three dielectric media, viz, air, the material constituting the dielectric rings, and ferrite; that is wave energy proceeding from an input arm to an output arm sees, in consecutive order, an air filled strip transmission line, a dielectrically loaded strip transmission line, a ferrite filled line, a dielectrically loaded line and an air filled line. Because the dielectric constants of the media are different each from the other, impedance discontinuities are present at each transition from one medium to another. The reflections from those impedance discontinuities interfer with the operation of the device as a circulator and prevent high isolation from being obtained at the arm that is not in the intended signal transmission path.

In FIG. 2, two circulators **20** and **21** are shown connected in tandem in the conventional manner. Each of circulators, **20** and **21**, is essentially the same as the circulator of FIG. 1. In the tandem arrangement, however, the ground plane plates **22** and **23** are common to both circulators and the gap between the two circulators is bridged by a length of line **24** situated between the ground plates to act as an air filled strip transmission line. That bridging arrangement essentially avoids the use of coaxial line as the connection between the two circulators and eliminates the need for two coaxial connectors. The conventional tandem arrangement of FIG. 2 is an improvement over connecting two circulator units by a length of coaxial line because it avoids a transition from strip transmission line to coaxial line at the output arm of the first circulator in the tandem arrangement and a transition from coaxial line to strip transmission line at the input arm of the second circulator. By eliminating those transitions, a smoother electrical path between the circulators is obtained because there are less impedance changes in that path.

Each circulator in the conventional tandem arrangement of FIG. 2 is provided with its own electromagnet to establish the magnetic field necessary to the circulator's operation. The electromagnet of circulator **20**, for example, employs a C-shaped core **25** and coils **26** and **27** which surround the poles of the core. The coils are bulky and prevent the circulators from being brought close together. To reduce transmission losses, it is desirable to make line **24** as short as possible but the electromagnets limit the extent to which the circulators can be brought together. The arrangement of FIG. 2 is not compact and where the line **24** is long compared to the signal's wavelength, a significant loss in transmission of the signal can occur.

FIG. 3 is a top plan view of the tandem circulators illustrated in FIG. 2, with the ground plane plates and the electromagnets absent from the FIG. 3 view. Ferrite disks **28** and **29** are within the dielectric rings **30** and **31** and the two circulators are connected by the center conductor **24** of the strip transmission line. Even if the bulky coils of the electromagnets were eliminated so that the circulators could be brought close together, the dielectric rings would limit the extent to which the circulators could be brought together.

The invention, as shown in FIG. 4, resides in eliminating the dielectric rings and bringing the ferrite disks together so that the junctions of the circulators are in essence abutting and the common arm **32** is completely between the upper and lower ferrite members. In FIG. 4, the ferrite disks **33** and **34** are shown as separate units but a single ferrite member can be used in their place, if desired.

FIG. 5 shows the invention applied to Y-junction circulators of the type using triangular ferrites at their junctions. The circulators **35** and **36** have their triangular ferrites **37** and **38** abutting along the entire length of a common side. By employing triangular ferrites in the arrangement of FIG. 5, the symmetry at the junction of each circulator is retained.

It can be observed in FIGS. 4 and 5 that the width W_f of the center conductor arms under the ferrite is less than the width W_a of the center conductor arms outside the ferrite. Because the dielectric ring that normally surrounds the ferrite is not used in the invention, the impedance mismatch occurring at the transition from air filled strip transmission line to ferrite filled strip transmission line is compensated by reducing the width of the center conductor under the ferrite in accordance with the teaching of my U.S. Pat. 3,355,679. As an alternative to reducing the width of the center conductor under the ferrite, the ground plane spacing can be increased as taught in the aforesaid copending application.

In the embodiments of FIGS. 4 and 5, the connecting arms **32** and **39** are disposed entirely between the ferrite and therefore constitute ferrite filled strip transmission lines. Those embodiments avoid the transitions from ferrite filled line to air filled line to ferrite filled line that occur in the connecting line **24** of the conventional arrangement shown in FIGS. 2 and 3.

FIGS. 6 and 7 illustrate an embodiment of the invention having an electromagnetic coil arranged to supply a common magnetic field for two abutting circulators **40** and **41** that are connected in tandem. In FIG. 6, the upper ground plane plate and the pole piece has been removed to provide a top plan view of the junctions of the two circulators. The center conductor arms **42**, **43**, and **44** of circulator **40** and the center conductor arms **45**, **46**, and **47** of the circulator **41** are situated between an upper ferrite member **48** and a lower ferrite member **49** which, in turn, are disposed between oval ground plane plates **50** and **51**. The ferrite members are identical and each ferrite member is a plate with the shape of two equilateral triangles having a common side and having the apices of the triangles truncated. The triangular ferrite within each circulator is symmetric with respect to the junction of the arms and, because the triangles abut, the structure can be viewed as having a connecting line of zero length between circulators.

The two circulators are disposed within a hollow oval tube formed by two bobbins **52** and **53** upon which the coil **54** of the electromagnet is wound. In order to have the electromagnetic coil closely encircle the ferrite members, the wall of the tube formed by the bobbins preferably is thin. The top and bottom of the tube are capped by pole pieces **55** and **56** which have portions that extend into the tube and rest against the ground plane plates **50** and **51**. The tube, formed by the bobbins, is constructed from a material exhibiting low magnetic permeability so as not to provide an easy path for the magnetic flux of the field established by the current flow in the electromagnet. Aside from the oval shape of the electromagnet and the enclosure by the electromagnetic coil of two tandem connected circulators, the construction of the embodiment shown in FIGS. 6 and 7 is quite similar to the device described in my U.S. Pat. No. 3,295,074. Because the electromagnet provides the magnetic field for both circulators in the FIGS. 6 and 7 embodiment, reversing the direction of current flow in the electromagnet causes both circulators to switch simultaneously. That is, reversal of current flow in the electromagnet, in turn, reverses the direction of the magnetic field applied to the

circulators and causes both circulators to simultaneously switch their directions of circulation of wave energy.

To provide an exterior electrical connection to the arms of the circulators protruding from the junctions, coaxial connectors can be employed. By way of example, a coaxial connector **57** is shown in FIG. 6 which provides an electrical connection to the arm **45** of circulator **41**. As depicted in FIG. 8, the connector **57** is secured to the ground plane plates **55, 56** by screws **58, 59**. The body of the connector is electrically conductive and acts to maintain both ground plane plates at the same electrical potential. The center conductor **60** of the coaxial connector protrudes through the oval tube formed by bobbins **52, 53** and is secured to the arm **45**. Essentially, the coaxial connection is the same as the connection described in my U.S. Pat. No. 3,295,074.

The protruding arms of the circulators need not terminate in coaxial connectors. Instead, those arms can be connected to components such as semiconductor diodes which are located within the ferrite region so that arms of the circulator need not protrude beyond the ferrite.

FIG. 9 is a schematic representation of five circulators, **61, 62, 63, 64,** and **65,** connected in tandem. Such an arrangement is usually employed as a high isolation switch and the operation of the array will be described on the assumption that that arrangement is so employed. Circulator **61** has three strip line center conductor arms **66, 67, 68** forming a symmetrical Y-junction, and each of the other circulators has three corresponding arms. The center conductor arms are disposed between a pair of ferrite members, only one of which, the member **69,** is visible in FIG. 9. The shape of the ferrite member can be considered to be composed of five equilateral triangles as indicated by the phantom lines in FIG. 9 although the member is a unitary slab of ferrite.

Assuming that a common magnetic field is employed for all five circulators and that the input signal is impressed at arm **70** of circulator **63,** the input signal emerges at either arm **71** or arm **66,** depending upon the direction of the common magnetic field and high isolation from the signal is obtained at the other output arm. If the magnetic field is considered to be coming out of the plane of the paper, as indicated by the symbol ⊙ in FIG. 9, the signal emerges at arm **71** whereas if the magnetic field is into the plane of the paper, as indicated by the symbol ⊕, the signal emerges at arm **66.** The arms **67, 72, 73,** and **74** are terminated in matched loads which absorb substantially all the wave energy that enters those arms.

If it is desired to switch the input signal to output arm **71,** for example, a magnetic field is established whose direction is out of the plane of the paper as viewed in FIG. 9. The signal impressed on arm **70** is then transmitted along the path indicated in FIG. 9 to the arm **71.** Energy which enters arm **75** is diverted into arm **72** and is absorbed by the matched termination **76.** If any energy manages to get into arm **68,** it is diverted into arm **67** and is absorbed by matched termination **77.** Thus, arm **66** has very high isolation when the magnetic field is in the direction to transmit energy to arm **71.** The input signal can be switched to arm **66** simply by reversing the direction of the common magnetic field and high isolation is then obtained at arm **71.**

The switching arrangement of FIG. 9 permits isolation of greater than 100 db to be obtained. Further, by using a common magnetic field, all the circulators in the arrangement are switched simultaneously. The arrangement is compact and permits a single electromagnetic coil to be used to establish the magnetic field for all the circulators.

On the basis of data collected from an embodiment of the invention, it has been concluded that the tandem arrangement is comprised of a plurality of 3 port circulators rather than being a pure N port junction.

Although several embodiments of the invention have been here illustrated and described, it is apparent that the

invention can take other forms. For example, while the ferrite at the junction has been described as being either a disk or a triangle, it is apparent that the ferrite may take other configurations. Because the invention may be embodied in varied structures, it is not intended that the invention be limited to the forms here illustrated or described. Rather, it is intended that the invention be construed to embrace those structures which, in essence, utilize two or more circulators in the manner here disclosed.

I claim:

1. In an arrangement of tandem connected strip transmission line circulators wherein each circulator is of the type having

a plurality of symmetrically disposed center conductor arms extending from a junction,

a pair of ferrite members between which the junction and a portion of each arm are situated,

and a pair of ground plane plates between which the ferrite members are situated,

the ferrite members having gyromagnetic properties which cause those members to produce circulator action at the junction when the ferrite members are situated in a magnetic field of appropriate strength,

the improvement wherein

adjacent circulators having their ferrite members abutting to provide a continuous wave transmission medium extending between the junctions of the adjacent circulators, and

the center conductor arm which connects the junctions of the adjacent circulators is situated for its entire length between the ferrite members.

2. The invention according to claim **1,** further including means for establishing a magnetic field that is common to all the circulators in the tandem arrangement and which is of sufficient strength to produce circulator action at each circulator in the arrangement.

3. In an arrangement of tandem connected strip transmission line circulators wherein each circulator is of the type having

a plurality of symmetrically disposed center conductor arms extending from a junction,

a pair of ferrite members between which the junction and a portion of each arm are situated,

and a pair of ground plane plates between which the ferrite members are situated,

the ferrite members having gyromagnetic properties which cause those members to produce circulator action at the junction when the ferrite members are situated in a magnetic field of appropriate strength,

the improvement wherein

adjacent circulators have their ferrite members meeting to provide a continuous wave transmission medium extending between the junctions of the adjacent circulators, and

the center conductor arm which connects the junctions of the adjacent circulators is situated for its entire length between the ferrite members.

4. The improvement according to claim **3,** wherein the ground plane plates of adjacent circulators meet to provide a pair of ground planes having uniform separation therebetween and having the entire length of the connecting arm situated therebetween.

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PAUL L. GENSLER, Primary Examiner

U.S. Cl. X.R.

333—84