Sept. 17, 1963 J. G. LEETMAA ETAL 3,104,361

FERRITE CIRCULATOR WITH CONDUCTIVE PLATE OF UNIFORM THICKNESS HAVING TAPERED ANGULAR APEXES FOR BROAD BANDING

Filed Feb. 26, 1960 2 Sheets-Sheet 1

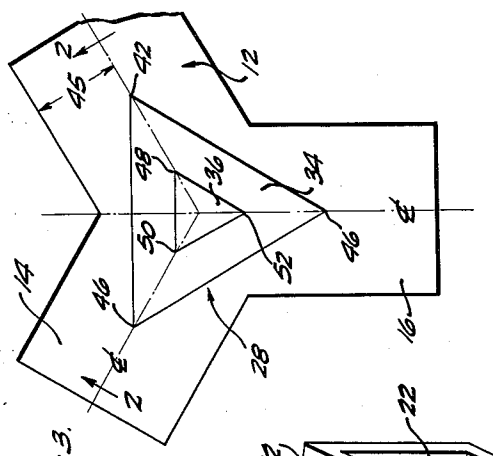


FIG. 3.

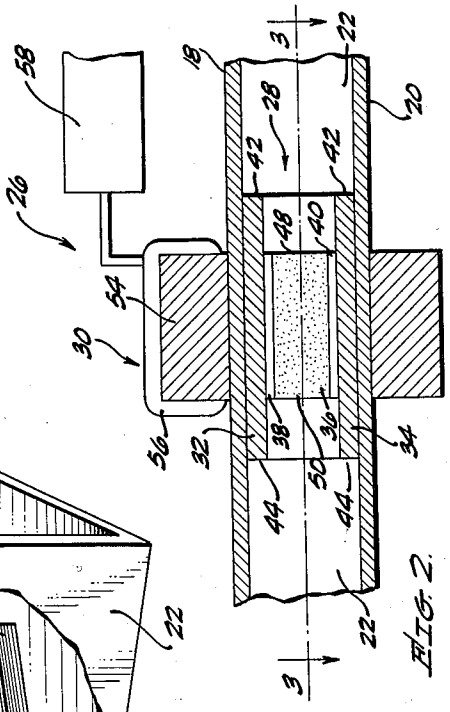


FIG. 2.

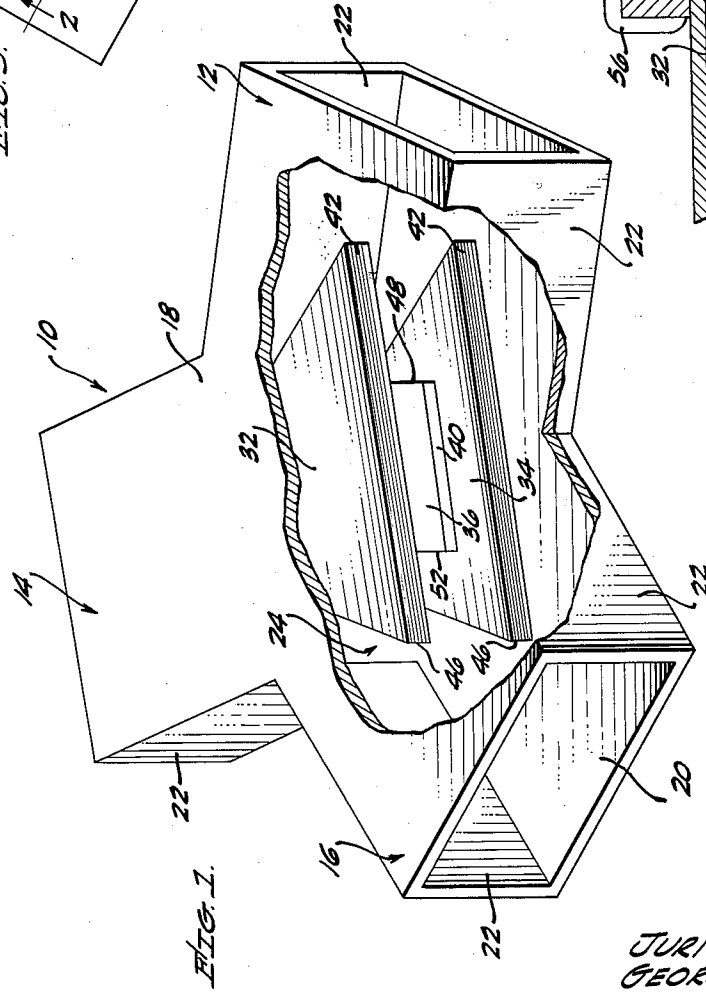


FIG. 1.

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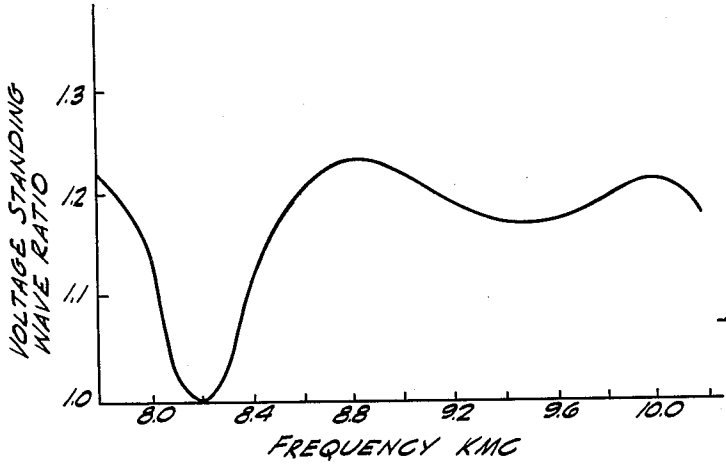


FIG. 4.

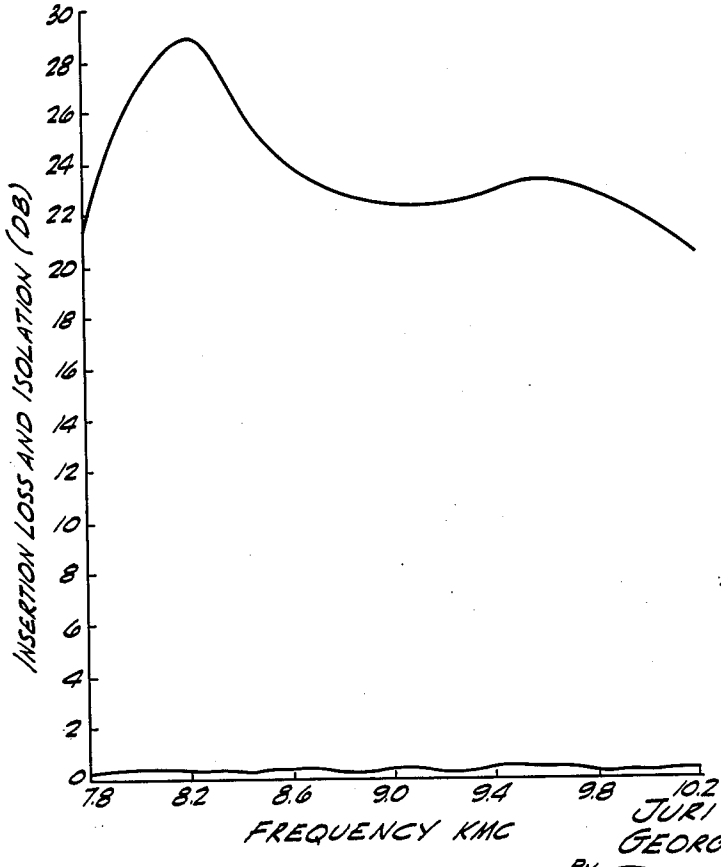


FIG. 5.

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FERRITE CIRCULATOR WITH CONDUCTIVE PLATE OF UNIFORM THICKNESS HAVING TAPERED ANGULAR APEXES FOR BROAD BANDING

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The present invention relates to means for transmitting electromagnetic energy from one point to another and more particularly to means for controlling the transmission of such energy.

In the operation of so-called microwave equipment, it is frequently desirable to transfer electromagnetic energy between various portions of the equipment and to control the path of such transfer by circulating or switching means. In the past, a large number of such means have been proposed, some of which have been acceptable for some applications. Probably the most successful circulators and switches for use in the microwave spectrum employ an element of nonreciprocal material such as a ferrite. This material is disposed in one or more sections of wave guides so that the microwave energy will be propagated therethrough. By creating a magnetic flux field through this element there will be a gyromagnetic effect which may be effectively utilized to control the microwave energy in the desired manner.

Unfortunately, the presence of such a ferrite element in the waveguide may cause a change in the impedance through which the electromagnetic energy is propagated. The resultant mismatching of impedances will in turn cause standing waves and other losses to occur in the waveguides. In an effort to overcome this effect, it has been proposed to match the impedance of the section of waveguide containing the ferrite with the surrounding portions of the waveguides. Although such prior attempts have been somewhat successful in improving the operation of the devices, the frequency band over which the desired characteristics can be maintained is relatively narrow. For example, in electromagnetic energy transmission means employing circulators and/or switches of the foregoing variety designed to operate in the portion of the spectrum around 10 kilomegacycles, the bandwidth over which the desired operating characteristics can be maintained is normally in the range of 3% to 5%.

It is therefore proposed, in accordance with the present invention, to provide electromagnetic energy transmission means in which the energy may be controlled in the required manner more uniformly over a considerably greater bandwidth. More particularly, this is to be accomplished by providing in the energy transmission means a device such as a circulator embodying the present invention. In the present instance, this circulator has one or more waveguides that intersect each other at a substantially common junction and a member of a nonreciprocal material such as a ferrite that is disposed at the junction. The ferrite member is mounted on one or more impedance matching members so as to be disposed in the electromagnetic energy being propagated through the energy transmission means. The ferrite and/or impedance matching members include separate portions for each of the sections of waveguides that intersect at the common junction. Each of these portions extends toward and/or at least partially into the associated section of waveguide. Each portion possesses a cross-sectional shape that tapers in an axial direction of the waveguide section. In addition, the cross section of the portion is substantially centered on the centerline of the waveguide. Thus, a substantially symmetrical configuration will be presented

to the energy being propagated through the waveguide section. The combination of the symmetrically disposed and axially tapering cross sections of the ferrite and/or impedance matching members will provide a less frequency sensitive matching of the impedance. Thus, by creating a magnetic flux field through the ferrite member the desired control over the electromagnetic energy may be obtained over a broad frequency range. It will therefore be seen that a microwave device which may be used as a circulator, switch, etc., has been provided which will provide a greater degree of control over the energy over a much broader frequency range.

In the drawings:

FIGURE 1 is a perspective view, with portions thereof broken away, of a microwave device embodying the present invention;

FIG. 2 is a cross-sectional view of the device of FIG. 1 taken substantially along the plane of line 2—2 in FIG. 3; and

FIGS. 4 and 5 are graphs illustrating the characteristics of a device embodying the present invention.

Referring to the drawings in more detail, the present invention may be embodied in any desired microwave device for use in an electromagnetic energy transmission means having waveguides for propagating electromagnetic energy from one location to another. In the present instance, the invention is embodied in a circulator **10** adapted to be interconnected with the waveguides of the transmission means.

The present circulator **10** includes a plurality of waveguide sections **12, 14, 16** that are adapted to be directly interconnected with the waveguides in the remaining portions of the electromagnetic energy transmission means. Each section **12, 14, 16** may have an interior cross-sectional shape that corresponds with the interiors of other waveguides. Although any desired number of sections may be employed, in the present instance for illustrative purposes, three sections are shown as being equally spaced so as to form a so-called Y circulator.

The broad walls of each section of waveguide are formed by portions of parallel spaced conductive members **18, 20**. The side walls of the waveguide sections are formed by a plurality of conductive members **22** that are normal to the broad walls **18, 20**. As a consequence, the waveguide sections **12, 14, 16** will have a rectangularly shaped interior through which the energy may be propagated and the outer ends thereof will be adapted to be connected to the cooperating waveguides in the transmission means.

All of the sections of waveguide sections **12, 14, 16** are preferably disposed in a common plane and are spaced approximately one hundred and twenty degrees apart. As a result, the waveguides **12, 14, 16** will intersect each other substantially symmetrically about an axis normal to the common plane.

It may thus be seen that the intersecting waveguides will form a junction **24** that comprises an enlarged space having a prismatic shape. The parallel sides of the prismatic shape are bounded by the parallel conductive members **18, 20** and the other three sides are formed by openings that communicate with the waveguide sections **12, 14, 16**.

In order to regulate the flow of energy through the circulator **10**, control means **26** may be provided at the junction **24** of the waveguides **12, 14, 16**. The present control means **26** includes an internal portion **28** that is disposed inside of the junction **24** and an external portion **30** that is disposed outside thereof. The internal portion **28** includes a pair of impedance matching members, **32, 34**, a member **36** consisting of a nonreciprocal material such as a ferrite, and a pair of dielectric supports **38, 40**.

In the present instance, the impedance matching members 32, 34 are substantially identical to each other. Each of these members 32, 34 is a flat plate of conductive material of substantially uniform thickness and is adapted to be disposed on the inside surface of one of the broad walls 18 or 20. As a result, the members 32, 34 will be disposed on the opposite sides of the junction 24 substantially parallel to each other. It will thus be seen that the transverse dimension of the junction 24 will be reduced by an amount equal to the thickness of the two plates 32, 34. As a consequence, the impedance to the flow of energy through the junction 24 may be varied by the thickness of the impedance matching members 32, 34.

The members 32, 34 may have a separate portion 42, 44, 46 for each of the waveguide sections 12, 14, 16 that communicates with the junction 24. The portions 42, 44, 46 are arranged to project axially toward and/or at least partially into the associated waveguide sections 12, 14, 16. The projecting portions 42, 44, 46 are preferably centered about the centerline of the waveguide sections 12, 14, 16 so as to be symmetrical to the energy being propagated through the sections. In addition, the cross sections of the portions 42, 44, 46 preferably vary gradually in an axial direction from some predetermined minimum to some predetermined maximum. More particularly, the members 32, 34 have a triangular shape with the apexes 42, 44, 46 disposed on the centerlines and the straight sides extending across the junction 24. It may thus be seen that the impedance to the flow of energy will vary gradually from that of the waveguide sections 12, 14, 16 to a different amount at the center of the junction 24.

The member 36 of nonreciprocal material is composed of a substance such as a ferrite which possesses a so-called gyromagnetic property. This member 36 may be mounted on a pair of spacers or supports 38, 40 consisting of a dielectric material such as Teflon. In the present instance, the spacers 38, 40 are substantially identical to each other and have the same shape as the ferrite member 36 so that the ferrite member 36 will be symmetrically disposed in the center of the junction 24.

The ferrite member 36 preferably has a separate portion 48, 50, 52 for each of the waveguide sections 12, 14, 16 that projects toward and/or into the associated section. Preferably the shape of the ferrite member 36 is similar to that of the impedance matching members 32, 34, i.e., a triangle. The apexes of the spacers 38, 40 and ferrite member 36 are disposed on the centerlines of the waveguide sections and thereby provide a symmetrical front to the energy being propagated through the sections 12, 14, 16.

The external portion 30 includes a magnetic core 54 that has the faces thereof aligned with the ferrite member 36 so as to form a magnetic circuit. A coil 56 may be wound around the core 54 and interconnected with a variable current source 58. It may thus be seen that a current through the coil 56 will create a magnetic flux field through the ferrite member 36 substantially transverse to the direction of propagation. The amount and direction of the flux field may be determined by the amount and direction of the current in the exciting coil 56 which in turn is determined by variable current source 58.

It may thus be seen that during operation of the circulator 10, each section 12, 14, 16 of the circular may be interconnected with a corresponding waveguide in an electromagnetic energy transmission means. Thus the energy in one of the waveguides will be propagated into one of the sections, for example section 12. This energy will then be propagated through the section 12 and continue on toward the junction 24. When it arrives at the apexes 42 of the matching members 32, 34 the energy will be at least partially propagated into the space between the two members 32, 34. As the energy continues

into the junction, increasing portions thereof will be propagated between the two members 32, 34. Since the widths of the plates change gradually as a function of the axial position in the section 12, the impedance against which the energy is being propagated will change gradually. It may thus be seen that there will be no abrupt changes in the impedance that will cause reflections or standing waves of the energy.

When the energy enters the junction 24 it will reach the apex 48 of the ferrite member 36 and be propagated therethrough. Since the width of the ferrite member 36 will progressively increase as the energy enters it, there will be a progressive increase in the amount of ferrite rather than an abrupt change. It should also be noted that since the apexes 42, 48 of the ferrite and matching members 32, 34 and 36 are on the centerline of the waveguide section 12 the energy will be symmetrically divided.

If the current source 58 supplies a current to the coil 56, a magnetic flux field will be created through the ferrite member 36. This field will be normal to the direction in which the electromagnetic energy is being propagated, and as a result of the so-called gyromagnetic effect the electromagnetic energy will be directed substantially entirely into one or the other of the waveguide sections, for example section 14. The particular waveguide section into which the energy will be directed will, of course, depend on the amount and direction of the current in the coil 56.

If the current remains the same in the coil 56 and electromagnetic energy enters section 14, it will be propagated into the junction 24 and through the ferrite member 36. Due to the nonreciprocal nature of the gyromagnetic effect substantially all of this energy will be directed into and through the section 16. Similarly, if the energy enters through section 16 and is propagated into and through the ferrite member 36, it will be directed substantially entirely into waveguide section 12 provided that the current in coil 56 remains the same.

In addition to operating as a circulator, the device may be used as a switch by causing the current control 58 to reverse the polarity of the current in the coil 56. More particularly, if the energy is traveling through the waveguide section 12 into the junction 24 when the current in the coil 56 has a polarity that is of the reverse of that in the foregoing description, substantially all of the energy will be directed into the waveguide section 16. As a consequence, the flow of energy entering the device through section 12 may be switched into either waveguide section 14 or waveguide section 16 by varying the current flowing in the coil 56.

It may thus be seen that a microwave device suitable for use in an energy transmission means has been provided which may act as a circulator, switch, etc. By providing the impedance matching members 32 and 34 and/or the ferrite element 36 with separate projecting portions for each of the waveguide sections 12, 14, 16 the insertion loss through the use of the device will be very small and the range of frequencies over which the device will operate may be increased by a substantial amount.

For example, the operating characteristics of a circulator designed for use in the X band of the microwave frequency spectrum are illustrated by the graphs in FIGS. 4 and 5. The voltage standing wave ratio was found to be less than 1.2 in a frequency range of 7.8 to 10.0 kilomegacycles. In the same frequency range the insertion loss remained below 0.5 decibel while the isolation was in excess of 20 decibels. This circulator thus has a frequency bandwidth of approximately 25% which is approximately five to ten times greater than has been obtainable heretofore.

What is claimed is:

1. A microwave circulator comprising:

(*a*) a plurality of rectangular waveguides joined at a common junction and having a pair of common opposite broad walls at said junction;

(*b*) a conductive plate of substantially uniform thick-

ness disposed within said junction and having a major surface adjacent the inside surface of one of said broad walls and having angular apexes protruding into said waveguides along longitudinal axes thereof,

(*c*) a plate of nonreciprocal microwave transmission material of substantially uniform thickness disposed within said junction and having major surfaces substantially parallel to said broad walls, said material being substantially centrally positioned between said broad walls and having angular apexes extending along said longitudinal axes of said waveguides;

(*d*) and a magnet adjacent said junction providing a magnetic field within said material.

2. A microwave circulator comprising:

(*a*) three rectangular waveguides joined at a common junction and having a pair of common opposite broad walls at said junction;

(*b*) a conductive plate of substantially uniform thickness disposed within said junction and having a major surface adjacent the inside surface of one of said broad walls and having angular apexes protruding into said waveguides along longitudinal axes thereof,

(*c*) a plate of nonreciprocal microwave transmission material of substantially uniform thickness disposed within said junction and having major surfaces substantially parallel to said broad walls, said material being substantially centrally positioned between said broad walls and having angular apexes extending along said longitudinal axes of said waveguides;

(*d*) and a magnet adjacent said junction providing a magnetic field within said material.

3. A microwave circulator comprising:

(*a*) a plurality of rectangular waveguides joined at a common junction and having a pair of common opposite broad walls at said junction;

(*b*) a conductive plate of substantially uniform thickness disposed within said junction and having a major surface adjacent the inside surface of one of said broad walls and having angular apexes protruding into said waveguides along longitudinal axes thereof,

(*c*) a plate of ferrite material of substantially uniform thickness disposed within said junction and having major surfaces substantially parallel to said broad walls, said ferrite material being substantially centrally positioned between said broad walls and having angular apexes extending along said longitudinal axes of said waveguides;

(*d*) and a magnet adjacent said junction providing a magnetic field within said ferrite material.

4. A microwave circulator comprising:

(*a*) a plurality of rectangular waveguides symmetrically joined at a common junction and having a pair of common opposite broad walls at said junction;

(*b*) a conductive plate of substantially uniform thickness disposed within said junction and having a major surface adjacent the inside surface of one of said broad walls and having angular apexes protruding into said waveguides along longitudinal axes thereof,

(*c*) a plate of nonreciprocal microwave transmission material of substantially uniform thickness disposed within said junction and having major surfaces substantially parallel to said broad walls, said material being substantially centrally positioned between said broad walls and having angular apexes extending along said longitudinal axes of said waveguides;

(*d*) and a magnet adjacent said junction providing a magnetic field within said material.

5. A microwave circulator comprising:

(*a*) three rectangular waveguides symmetrically joined at a common junction to form a Y configuration and having a pair of common opposite broad walls at said junction;

(*b*) a pair of triangular conductive plates of substantially uniform thickness disposed within said junction and each having a major surface in contact with the inside surface of a different one of said broad walls with apexes protruding into said waveguides along longitudinal axes thereof,

(*c*) a triangular ferrite plate of substantially uniform thickness disposed within said junction and having major surfaces substantially parallel to said broad walls, said ferrite plate being substantially centralley positioned between said broad walls and having apexes extending along said longitudinal axes of said waveguides;

(*d*) and a magnet adjacent said junction providing a magnetic field within said ferrite plate.

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