

Dec. 25, 1962

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3,070,760

BROADBAND COMPACT JUNCTION CIRCULATOR

Filed Sept. 30, 1960

2 Sheets-Sheet 1

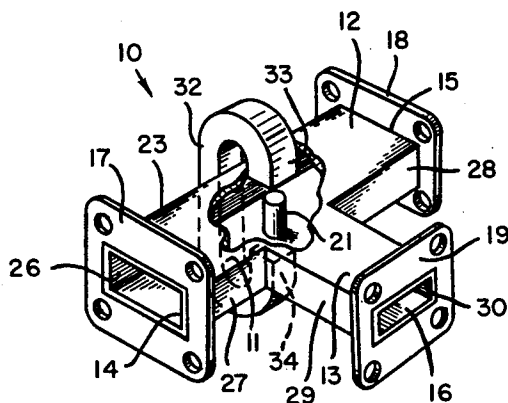


FIG-1

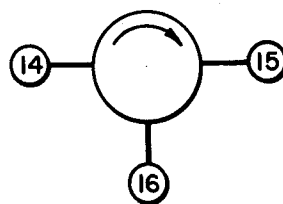


FIG-2

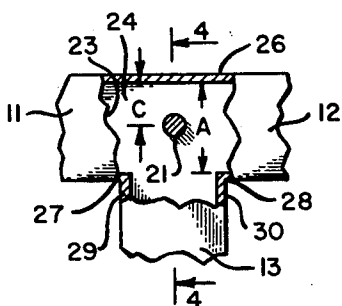


FIG-3

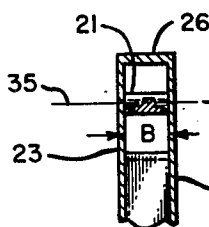


FIG-4

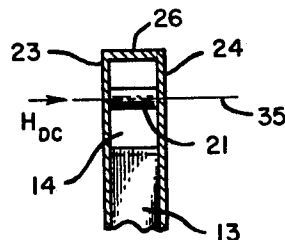


FIG-5

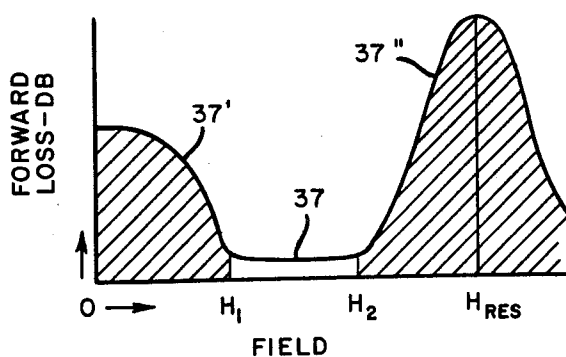


FIG-6

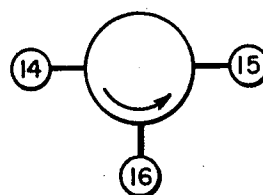


FIG-7

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2 Sheets-Sheet 2

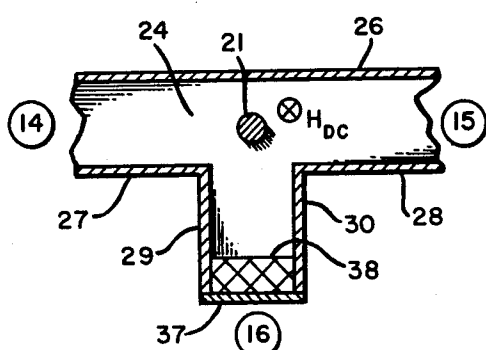


FIG-8

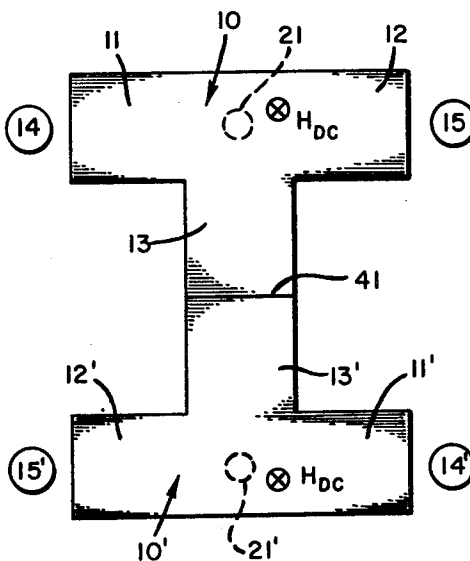


FIG-9

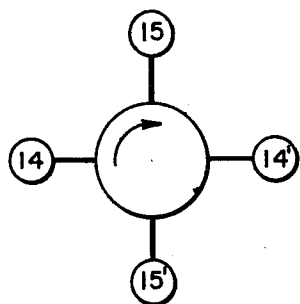


FIG-10

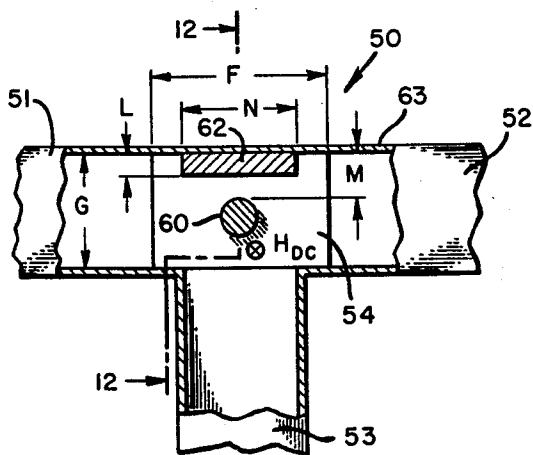


FIG-11

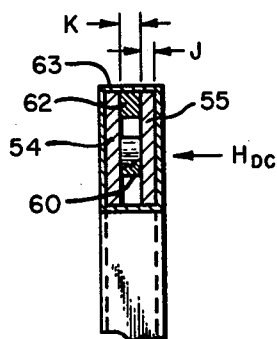


FIG-12

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BROADBAND COMPACT JUNCTION CIRCULATOR
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Electric Products Inc., a corporation of Delaware
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7 Claims. (Cl. 333-1.1)

This application is a continuation-in-part of S.N. 759,544, filed September 8, 1958, entitled "Nonreciprocal Microwave Transmission Device."

This invention relates to microwave transmission devices and more particularly to a multiple port device designed to transmit a signal from one of its ports to an adjacent port while isolating the signal from all other ports. Devices of this type are known as microwave circulators.

The nonreciprocal properties of magnetically biased ferromagnetic materials, such as ferrites, have been utilized in the past to construct microwave circulators of the general type described, for example, in Miller Patent No. 2,748,352 and Mumford Patent No. 2,769,960. A circulator of this type is characterized by generally satisfactory coupling ratios and isolation characteristics, but the unit itself has been constructed with a number of special parts including high power magnets, hybrid couplers, phase shifters and twisted waveguide or rectangular-to-round guide transitions. These components are costly and difficult to assemble. Moreover, the necessity of using several individual components including the transition members has resulted in a bulky unit which has been difficult to adapt to applications in which minimum space and weight requirements are specified.

In accordance with the present invention, a nonreciprocal three-branch microwave network comprising a circulator is made from a single standard H-plane rectangular T-section. A rod or post of gyromagnetic material, such as ferrite, is mounted at the junction of the three arms of the T parallel to the plane of the E-vector of the dominant microwave mode transmitted in the section and is biased by a unidirectional magnetic field oriented substantially parallel to the axis of the rod. The intensity of the magnetic field is not critical but has a magnitude greater than saturation magnetization and less than that which produces ferromagnetic resonance in the ferrite. Accordingly, low strength inexpensive magnets having fields as low as 100 gauss may be used. This device effects nonreciprocal coupling of two of the three ports in the manner of a three-port circulator and has excellent isolation characteristics over a useful but limited frequency range. By novel tuning means within the junction of the three arms, this operating bandwidth is extended considerably. A four-port circulator readily may be constructed by joining together one port each of two such three-port circulators, the remaining four ports being coupled together for nonreciprocal transmission of microwave energy in the manner described above.

An object of this invention is the provision of a circulator constructed with a standard waveguide component and a ferrite element having simple geometric configuration.

A more specific object is the provision of an H-plane, T-junction circulator having high coupling efficiency and isolation characteristics and low insertion loss and a minimum voltage standing-wave ratio (VSWR).

A more specific object is the provision of a compact broadband circulator in which tuning is accomplished within the junction itself, thereby eliminating the need for tuned lengths of transmission line.

Other objects and purposes of the invention will become apparent from the following description of preferred embodiments thereof, reference being had to the accompanying drawings in which:

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FIGURE 1 is a perspective view, partially cut away, of a three-port microwave junction member embodying my invention;

FIGURE 2 is a diagrammatic representation of the coupling characteristics of the device of FIGURE 1;

FIGURE 3 is a fragmentary plan view, partially cut away, of the junction member of FIGURE 1 with the magnet omitted;

FIGURE 4 is a section taken on line 4-4 of FIGURE 3;

FIGURE 5 is a graphical representation of a typical plot of energy loss in decibels against magnetic field in the ferrite and showing the limits of field strength for proper operation of the circulator;

FIGURE 6 is a section of the member similar to FIGURE 4 with the direction of the magnetic field reversed for changing direction of flow of microwave energy in the circuit;

FIGURE 7 is diagrammatic representation of the coupling characteristics of the reversely magnetized member of FIGURE 5;

FIGURE 8 is a central section of a modified form of the three-port junction member wherein one arm is terminated in a matched load and shorting plate to provide nonreciprocal transmission between the other two ports in the manner of an isolator;

FIGURE 9 is a plan view of a pair of three-port junctions connected together to provide a four-port circulator;

FIGURE 10 is a diagrammatic sketch showing the coupling characteristics of the circulator of FIGURE 9;

FIGURE 11 is an enlarged plan view, partially broken away and in section, of T member which includes tuning elements located at and within the junction of the three arms; and

FIGURE 12 is a section taken on line 12-12 of FIGURE 11.

Referring now to the drawings, a preferred embodiment of my invention is illustrated in FIGURE 1 as an open-type T-junction member 10 comprising three rectangular waveguide arms 11, 12 and 13 having end openings or ports 14, 15 and 16, respectively, facing outwardly from the junction. The ported ends of the three arms may have mounting flanges 17, 18 and 19, respectively, for mechanically connecting the member 10 to associated microwave circuits. In the preferred form of the invention, member 10 is an H-plane T-junction unit which is defined as one in which the magnetic field vector of the dominant electromagnetic wave in each arm is parallel to the plane of the longitudinal axes of the guides comprising the arms.

In accordance with my invention, an element 21 of gyromagnetic material such as ferrite in the form of a cylindrical post or rod is mounted at the junction of the three arms 11, 12 and 13 between the top wall 23 and bottom wall 24 thereof and generally parallel to the arm side walls 26, 27, 28, 29 and 30. The rod is located preferably mid-way between the side walls 29 and 30 of the right angle arm 13 at the distance C (see FIGURE 3) from the side wall 26. The dimension C varies between 1/4 to 1/2 of the long cross-sectional dimension A of the member in accordance with variation of the operating frequency of the device. The height of the rod preferably is equal to the height B of the waveguide as shown in FIGURE 4.

A magnet 32, which may be a permanent magnet or an electromagnet, is mounted exteriorly of the junction member with its poles 33 and 34 aligned with opposite ends of the ferrite rod 21 so as to produce a unidirectional magnetic field in the rod parallel to its axis 35. Magnet 32 is designed to produce a magnetic field having an intensity greater than that for saturation magnetization and less than that for the resonance field. This operating range of magnet field values is indicated on the loss-field

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curve 37 in FIGURE 5, the lower limit H_1 being the saturation value located at the upper end of the well-known "near zero" loss region indicated in shaded line under portion 37', and the upper limit H_2 being situated at the lower end of the resonance loss region represented by the shaded portion under curve 37". H_1 may have a value of 100 to 200 gauss, and H_2 in the order of 500 gauss, and so it is readily apparent that the magnetic field required is neither critical nor high in magnitude. Small, inexpensive magnets may be used effectively in this device.

When junction member 10 is connected to a microwave transmission circuit through which electromagnetic waves are propagated, the unit functions in the manner of a circulator to couple, for example, port 14 to port 15 (see FIGURE 2), while isolating port 16 from the other two. In other words, substantially all of the microwave power that is introduced into member 10 through port 14 passes out port 15 while substantially none is transmitted through arm 13. Power which is fed into the device through port 15 is directed by the magnetized ferrite rod into arm 13 and passes out port 16 with substantially no power reaching port 14. Similarly ports 16 and 14 are coupled together when the former is the input port.

If the direction of the field through the ferrite rod 21 is reversed, as shown in FIGURE 6, the direction of coupling of the three ports is reversed, see FIGURE 7. An electromagnet is used as a magnetic field source, and reversal of its field is achieved by reversing the flow of direct current through the magnet coils. Other means may be employed to effectively bias the ferrite in opposite directions although the electromagnet and the control therefor appear to be the simplest and most convenient.

FIGURE 8 illustrates a modification of the three-port member of FIGURE 1 wherein a shorting plate 37 has been placed across the port end 16 of arm 13. The shorted end of arm 13 is provided with a matched load 38, such as Aquadag or similar material, which absorbs microwave power passing through arm 13. With this arrangement, microwave energy entering port 14 flows out port 15 without loss, but energy entering port 15 is directed by the ferrite rod 21 into arm 13 where it is totally absorbed by the matched load 38. This device, then, is essentially a nonreciprocal attenuator, known in the art as an isolator. By the simple expedient of adding a matched load and a shorting plate to one arm, a three-port circulator may be transformed into an isolator.

Certain microwave transmission networks require the use of four-port circulators to control transmission of energy from four branches of a circuit. A four-port circulator may be constructed readily in accordance with my invention by combining two substantially identical T-junction members 10 and 10' as shown in FIGURE 9. Each of the members 10 and 10' is substantially the same as that shown in FIGURE 1, and their respective arms 13 and 13' are joined together at 41 to permit the flow of microwave power from one member to the other. The ferrite rods 21 and 21' are suitably biased by a magnetic field as indicated by the symbols marked H_{DC} . The coupling between ports 14, 15, 14' and 15' is illustrated diagrammatically in FIGURE 10.

The circulators described above are believed to operate on the field displacement principle wherein the biased ferrite rod reacts with the microwave fields in such a manner as to prevent magnetic coupling of arm 11 with arm 13 for a given direction of microwave propagation, namely, in a direction from port 14 to port 15. For the reverse direction of propagation, that is, when port 15 is the power inlet port, the displacement of the microwave fields by ferrite rod is such that transmission of the energy in a straight line is essentially blocked and substantially all of it enters arm 13 for transmission to port 16. Since this is a field displacement application, substantially no microwave power is absorbed by the ferrite element which therefore has high power handling capabilities without incidental temperature rise.

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A three-port H-plane T-junction circulator with a matching element in the shunt arm and having the following dimensions and characteristics has been constructed and has been operated successfully in practice:

5	Waveguide:	
	Dimension A.....	0.900 inch.
	Dimension B.....	0.400 inch.
	Dimension C.....	0.221 inch.
10	Rod 21:	
	Material.....	Magnesium-Manganese Ferrite.
	Diameter.....	0.254 inch.
	Length.....	0.400 inch.
15	Frequency range.....	9.3 to 9.5 kmc.
	Isolation:	
	Minimum.....	20 db.
	Maximum.....	>35 db.
	Insertion loss.....	0.2 db.
20	VSWR.....	Less than 1.3.
	Magnetic field intensity:	
	H_1 (minimum).....	200 gauss.
	H_2 (maximum).....	1000 gauss.

25 The circulators described above are particularly well adapted to narrow band applications wherein the range of operating frequencies, is limited to 3% to 5%. Over wider frequency ranges, performance deteriorates and hence the inherent narrow band characteristic of this type of circulator has limited its utility. A modified form of the invention shown in FIGURES 11 and 12 substantially improves performance by more than doubling the operating bandwidth of the device and comprises an H-plane T-junction unit 50 having rectangular waveguide arms 51, 52 and 53. Mounted at the junction of the three arms are flat plates 54 and 55 of electrically conductive material secured as by cement or solder to the inner surfaces of broad walls 57 and 58 of colinear arms 51 and 52. These plates are positioned in alignment with each other in the direction normal to the broad walls 57 and 58 and are substantially identical in size. Each of the plates has a length F slightly greater than the wider inner dimension of each waveguide arm, a width G equal to that wider dimension of the arm, and a thickness J (see FIGURE 12) substantially less than one-half the narrower inside dimension of the waveguide arm. The ferrite post 60 extends the distance K between plates 54 and 55 at a point substantially along an extension of the central longitudinal axis of arm 53, and is biased by a unidirectional magnetic field H_{DC} as described previously. In addition to plates 54 and 55, an electrically conductive pad 62 is mounted on the inside of narrow common wall 63 of colinear arms 51 and 52. Pad 62 projects inwardly from wall 63 a distance L which is in the order of slightly more than one-half the spacing M of post 60 from wall 63. The length N of the pad preferably is about the same as the wide inside dimension of arm 53.

It will be noted that these matching elements are located at and almost entirely within the junction, and are fixed. This is conducive to a simpler matching of the nonsymmetrical T configuration by avoiding tuned lengths of line and discontinuities in them.

By way of example, a modified circulator shown in FIGURES 11 and 12 and having the following dimensions and characteristics has been built and successfully tested and operated:

70	Waveguide:	
	Dimension A.....	0.900 inch.
	Dimension B.....	0.400 inch.
	Rod 60:	
	Diameter.....	0.282 inch.
	Length K.....	0.152 inch.
	Spacing M.....	0.350 inch.
75	Frequency range.....	8.5 to 9.6 kmc.

Isolation:

Minimum.....	18.0 db.
Maximum.....	19.5 db.
Insertion loss.....	0.4 db.
VSWR.....	Less than 1.3.

Magnetic field intensity:

H ₁ (minimum).....	200 gauss.
H ₂ (maximum).....	1000 gauss.

Matching elements:

Plates 54 and 55—

Length F.....	1.375 inches.
Thickness J.....	0.124 inch.

Pad 62—

Length N.....	0.900 inch.
Width L.....	0.200 inch.
Thickness K.....	0.152 inch.

Plates 54 and 55 may be formed integrally with the broad walls 57 and 58, respectively, and essentially function to symmetrically step down and reduce the narrow transverse internal dimension of the junction. Pad 62, on the other hand, serves to unsymmetrically reduce the wide transverse dimension of the junction.

Modifications and changes may be made to the above-described embodiments of my invention without departing from the precepts thereof, and accordingly, the appended claims define whatever features of patentable novelty reside in the invention.

I claim:

1. In combination, a three-terminal circulator consisting of first, second and third rectangular waveguides directly joined together with the planes of the magnetic field vectors of microwaves in said guides parallel, each of said guides having a terminal port, and means located within the junction of said guides for coupling to the second guide substantially all of the microwave energy applied to the port of the first guide and simultaneously blocking from said third guide substantially all of the applied microwave energy, said means also coupling to said third guide substantially all of the microwave energy applied to the port of the second guide and simultaneously blocking from the first guide substantially all of the energy applied to the port of the second guide, said means also coupling to said first guide substantially all of the microwave energy applied to the port of the third guide and simultaneously blocking from the second guide substantially all of the energy applied to the port of the third guide.

2. The combination according to claim 1 in which said means comprises a magnetized ferrite element.

3. The combination according to claim 2 in which the strength of the magnetic field in said element is greater than that which produces saturation magnetization and less than that which produces ferromagnetic resonance at the oscillation frequency of said microwaves.

4. The combination according to claim 1 in which said wave guides are joined together in a T configuration.

5. The combination according to claim 2 in which said ferrite element is a post transverse to the wider dimension of the wave guide.

6. In combination, a circulator comprising first, second and third rectangular waveguides directly joined together with the planes of the magnetic field vectors of microwaves in said guides parallel, each of said guides having a terminal port, and means located within the

junction of said guides for coupling to the second guide substantially all of the microwave energy applied to the port of the first guide and simultaneously blocking from said third guide substantially all of the applied microwave energy, said means also coupling to said third guide substantially all of the microwave energy applied to the port of the second guide and simultaneously blocking from the first guide substantially all of the energy applied to the port of the second guide, said means also coupling to said first guide substantially all of the microwave energy applied to the port of the third guide and simultaneously blocking from the second guide substantially all of the energy applied to the port of the third guide all of the wave guides of the circulator lying in one plane.

7. In combination, a three-terminal circulator consisting of first, second and third rectangular waveguides directly joined together in a T configuration with the planes of the magnetic field vectors of microwaves in said guides parallel, each of said guides having a terminal port, and means located within the junction of said guides for coupling to the second guide substantially all of the microwave energy applied to the port of the first guide and simultaneously blocking from said third guide substantially all of the applied microwave energy, said means also coupling to said third guide substantially all of the microwave energy applied to the port of the second guide and simultaneously blocking from the first guide substantially all of the energy applied to the port of the second guide, said means also coupling to said first guide substantially all of the microwave energy applied to the port of the third guide and simultaneously blocking from the second guide substantially all of the energy applied to the port of the third guide, said means comprising a ferrite post transverse to the wider dimension of the waveguide, a spaced aligned pair of conducting plates mounted on the interior broad walls, respectively, of said waveguides at said juncture and engaging the opposite ends of said post, and a pad of conducting material projecting from the narrow wall opposite one of the waveguides to a point spaced from said post, said pad extending between said plates whereby the internal cross-sectional open area of the junction is reduced.

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