

[54] **ENCAPSULATED MICROSTRIP CIRCULATOR WITH MODE ELIMINATION MEANS**

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[58] Field of Search **333/1.1, 82 B, 83 A, 98 M**

[56] **References Cited**

UNITED STATES PATENTS

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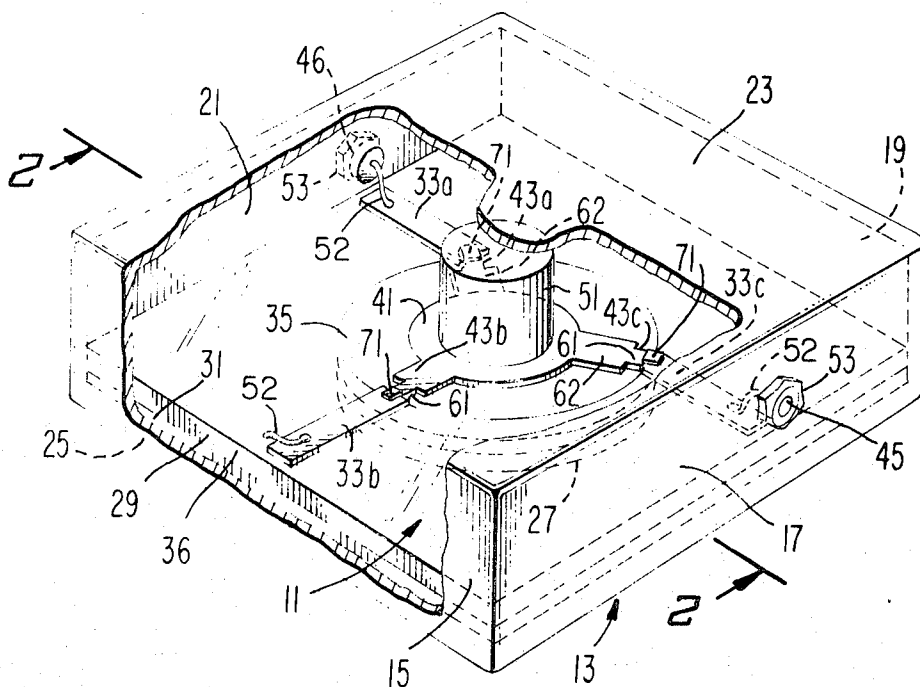
Primary Examiner—Paul L. Gensler

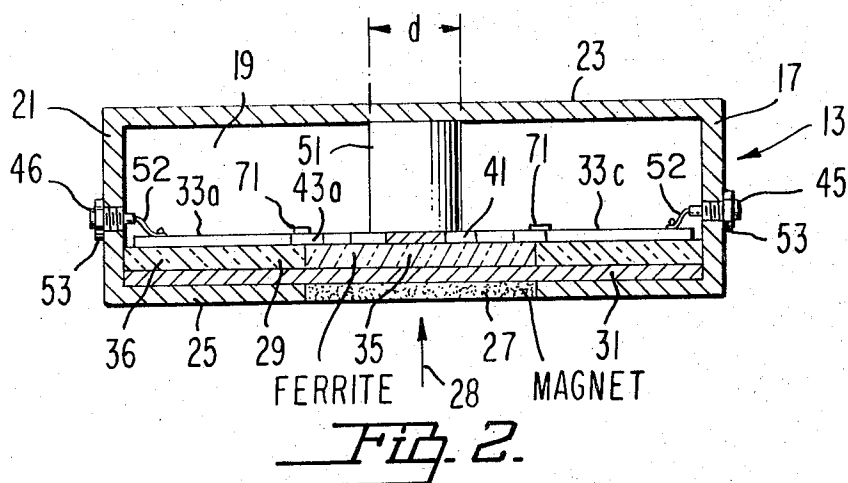
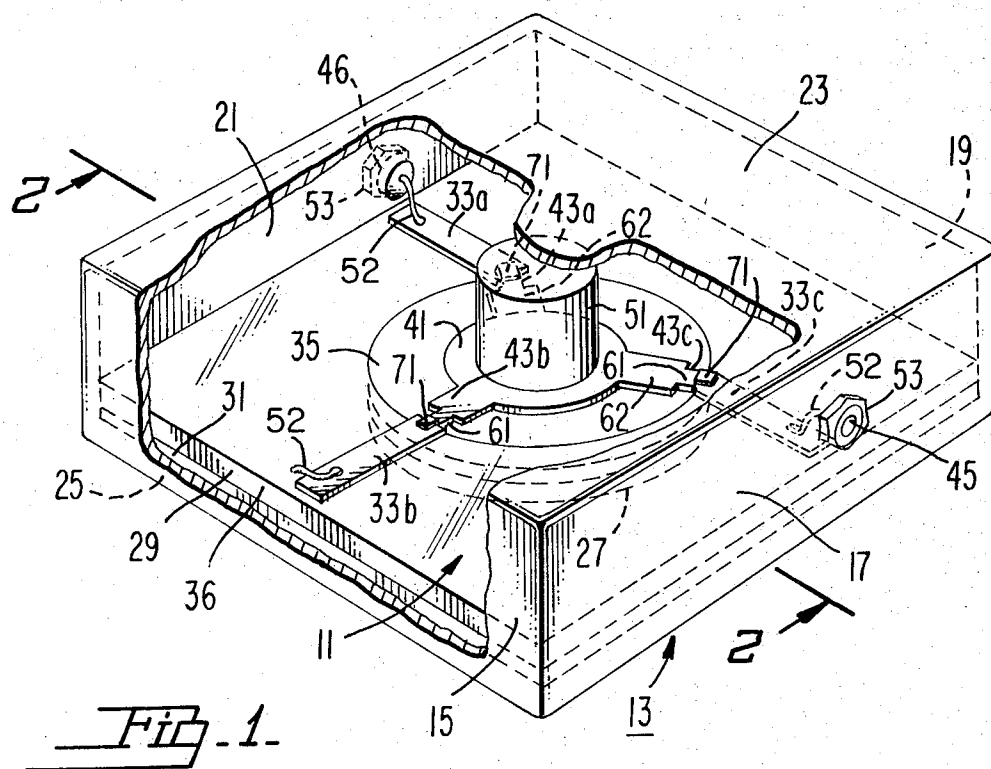
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[57] **ABSTRACT**

A microstrip circulator mounted within a metallic enclosure includes a dielectric substrate, a single ground planar conductor on one surface of the substrate and a plurality of narrow strip-like conductors extending from a common junction region on the opposite surface of the substrate. The substrate at the junction region includes gyromagnetic material so that when a D.C. magnetic field is applied in the direction perpendicular to the substrate, circulator action is provided. A metallic post positioned between the junction region of the narrow conductors and a wall of the metallic enclosure eliminates unwanted radiation modes.

3 Claims, 2 Drawing Figures





ENCAPSULATED MICROSTRIP CIRCULATOR WITH MODE ELIMINATION MEANS

The invention herein described was made in the course of or under a contract or subcontract thereunder with the Department of the Army.

BACKGROUND OF THE INVENTION

This invention relates to microstrip circulators and more particularly to microstrip circulators mounted within a metallic housing.

The term "circulator" as used in this application refers to high frequency devices of the type which direct electromagnetic input power therethrough in a non-reciprocal manner and which operate in the manner of a turnstile having ports distributed about their circumference. For example, in the case of a three-port circulator, power entering at one port exits at a second port and is isolated from the third port. Power entering at the second port exits at the third port and is isolated from the first port, whereby the circulation of power through the circulator is at all times in the same given direction for a given magnetic bias. Circulators are used extensively to provide radio duplexers, isolators, switching devices and other non-reciprocal transmission line junction devices. The non-reciprocal property of a circulator is determined by a non-reciprocal element disposed at the junction of the plurality of transmission lines which form the ports of the circulators. Generally, the non-reciprocal element comprises a material such as ferrite or garnet located at the junction of the transmission lines and biased by a magnetic field perpendicular to the plane of circulation.

The basic operational principles of a circulator using non-reciprocal elements may be found in various texts on the subject such as "Microwave Ferrites and Ferromagnetics" by B. Lax and K. J. Button, McGraw-Hill, 1962, pages 517-539, and 609-630.

The term "microstrip" as used in this application refers to a form of transmission line made of a dielectric substrate, a single ground planar conductor on one surface of that substrate and a narrow strip-like conductor on the opposite surface of the substrate. A junction circulator using this form of transmission line is described in U.S. Pat. No. 3,456,213.

It may be desirable both from a packaging point of view or for purposes of isolation to encapsulate the microstrip circulator in a metallic enclosure. This encapsulation physically protects the microstrip circulator, prevents electromagnetic radiation therefrom and the reception of extraneous electromagnetic fields. It has been found, however, that when this circulator is magnetized and placed within a metallic enclosure and electromagnetic fields are applied to the ports, unwanted box resonances occur. The cavity formed by the encapsulated structure will support an infinite number of transverse electric (TE) and transverse magnetic (TM) modes, the lowest of these being constrained by the box dimensions. These unwanted box resonances cause sharp increases in insertion loss, sharp decreases in isolation and some resonance loops in the phase of the reflection coefficient at discrete frequency points.

BRIEF DESCRIPTION OF INVENTION

In accordance with the present invention, a microstrip circulator is mounted within a metallic enclosure.

The circulator includes a dielectric substrate, a broad planar conductor on one surface of the substrate, and a plurality of narrow strip-like conductors extending from a common conductive region on the surface of the substrate opposite the one surface. The substrate includes gyromagnetic material adjacent the common conductive region. Means are provided for biasing the body of gyromagnetic material. A metallic conductor is coupled between the common conductive region and the enclosure to eliminate unwanted modes within the enclosure.

DETAILED DESCRIPTION

A more detailed description follows in conjunction with the drawings wherein:

FIG. 1 is a perspective view of an encapsulated microstrip circulator with a portion broken away for illustration; and

FIG. 2 is a cross-sectional view of the encapsulated microstrip circulator of FIG. 1 as taken along line 2-2.

Referring to FIGS. 1 and 2, a microstrip circulator circuit 11 is encapsulated within a rectangular metallic housing 13. The housing 13 includes side walls 15, 17, 19 and 21, top wall 23 and bottom wall 25. The bottom wall 25 has an aperture therein at about the center thereof with a magnet 27 fitted and fixed tightly within the aperture so as to form a continuous bottom surface below ground conductor 31.

The microstrip circulator 11 includes a dielectric substrate 29, a ground planar conductor 31 on one surface of the substrate 29 and narrow strip-like conductors 33a, 33b, 33c, 43a, 43b and 43c and common conductive resonator disk 41 on the opposite surface of the substrate 29. The substrate 29 comprises a ceramic substrate 36 having an aperture therein near the center and a disk 35 of gyromagnetic material bonded in the aperture of ceramic substrate 36. The term "gyromagnetic material" refers to a non-reciprocal material such as ferrite or garnet which when biased by a magnetic field produces the non-reciprocal operation of a junction circulator. For a more detailed description of these materials see text by Lax and Button cited previously. This material in the example of FIG. 1 is ferrite. The dielectric substrate 29 including the ferrite disk 35 with the ground conductor on the total one surface thereof is placed in the housing 13 such that the ground conductor 31 under the substrate 29 is adjacent to and in contact with the bottom wall 25 with the gyromagnetic disk 35 centered over the magnet 27. The stepped narrow strip-like conductors 43a, 43b and 43c extend over the ferrite disk 35 and meet at the common conductive resonator disk 41 centered above the ferrite disk 35. The narrow strip-like conductors 33a, 33b and 33c extend over ceramic substrate 36 and extend respectively from stepped conductors 43a, 43b and 43c toward the walls of housing 13. Good electrical contact between conductors 33a and 43a conductors, 33b and 43b, and conductors 33c and 43c is assured by soldered electrical bridging conductors 71. The stepped conductors 43a, 43b and 43c aid in matching the circulator junction or the portion adjacent to and including disk 41 to the microstrip transmission lines including narrow conductors 33a, 33b and 33c. The narrow strip-like conductors 33a, 33b and 33c are terminated short of the wall of the housing 13. Coaxial connectors such as connectors 45 and 46 in FIGS. 1 and 2 provide input and

output coupling to the circulator. The outer conductors 53 of the coaxial connectors such as connectors 45 and 46, for example, are coupled to the housing 13 and the inner conductors 52 are passed in insulative manner through small apertures in the walls of the housing 13 and individually contact the narrow conductors 33a, 33b and 33c. The circulator described above may be like that shown in FIGS. 2 through 4 of U.S. Pat. No. 3,456,213. The widths of these narrow strip-like conductors 33a, 33b, 33c, 43a, 43b and 43c are made sufficiently narrow relative to the ground conductor 31 to form microstrip transmission lines.

In the operation of the circulator shown in FIGS. 1 and 2 and with proper biasing provided by the magnet 27, indicated by arrow 28, electromagnetic signal waves coupled to coaxial connector 46 and coupled along narrow strip-like conductor 33a to the common conductive resonator disk 41 are coupled out along narrow strip-like conductor 33b with little or no significant coupling to narrow strip-like conductor 33c. Similarly, electromagnetic signal waves coupled along narrow strip-like conductor 33b toward common conductive resonator disk 41 are coupled along narrow conductor 33c and out of the circulator via connector 45 with little or no coupling of these signal waves along narrow conductor 33a. Electromagnetic signal waves coupled to connector 45 and propagated toward common disk 41 along narrow conductor 33c are coupled nonreciprocally along narrow conductor 33a and out of connector 46 with little or no appreciable coupling along narrow strip-like conductor 33b.

Whenever a microstrip circulator is magnetized and placed in a metallic enclosure there is always the possibility of getting unwanted box resonances in the device performance. These resonances show up as sharp increases in insertion loss, sharp decreases in isolation, and small loops in the phase of the reflection coefficient at discrete frequency points. These resonances occur due to the inherent *rf* radiation associated with microstrip circuits. A microwave cavity is set up when the circulator is enclosed in a metallic housing. This cavity will support an infinite number of transverse electric (TE) and transverse magnetic (TM) modes, the lowest of these being constrained by the box dimensions. If, however, a symmetric metallic element is inserted between and makes electrical contact with the resonator of the circulator and the inside of the lid of the box, then the cavity becomes coaxial and will only support the transverse electric and magnetic (TEM) mode. The only constraint placed on this element is that it must be equal or smaller in diameter than the resonator so as not to affect the circulator action itself. The resonance of this TEM mode is so much higher in frequency than the higher order TE and TM modes that any unwanted resonances in as much as an octave bandwidth are effectively eliminated.

Elimination of unwanted transverse electric (TE) and transverse magnetic (TM) modes is provided by post 51 coupled between the common conductive resonator disk 41 and the top conductive wall 23 of the housing 13. The post 51 is a circular symmetric column structure with a diameter, *d*, which is equal to or less than the diameter of the common conductive resonator disk 41. It is imperative in the operation of the circulator action itself that this diameter, *d*, of the post 51 be equal to or less than the diameter of this resonator disk 41.

A circulator, for example, designed for operation over the 10–14 GHz (gigahertz) frequency range had the following dimensions: Substrate 36 was of high purity alumina with dielectric constant of 9.6 and was purchased from Trans-Tech Inc., 12 Meem Ave., Gaithersburg, Md. The substrate thickness was 0.030 inch, and was about 0.500 inch square with 0.400 inch aperture to fit portion 35. Portion 35 was ferrite identified as TT1–3000 material purchased from Trans-Tech at address above. The diameter was 0.400 inch and of a thickness equal to 0.030 inch. The conductive disk 41 had a diameter of 0.155 inch. The enclosure 13 was 0.600 inch square and 0.500 inch high. The material of the enclosure 13 was brass, although any non-magnetic microwave conductor such as brass or aluminum could be used. The side wall thickness was 0.050 inch. The top wall 23 and bottom wall 25 was about 0.220 inch. The ground conductor 31 was a gold-plated, chrome-copper evaporation of a thickness 0.0001 inch. The post 51 had a diameter < 0.155 inch and a length of 0.030 inch. Magnet 27 of samarium cobalt was five-sixteenths of an inch in diameter by one-eighth of an inch and was fitted within bottom wall 25 and adjacent the ground conductor 31. The narrow conductors 33a, 33b and 33c form microstrip lines of 50 ohms and were 0.030 inch wide. The stepped sections 61, 62 of conductors 43a, 43b and 43c on the ferrite disk 35 match to the 50 ohms. The characteristic impedance of the stepped line sections 61 and 62 formed by stepped conductors 43a, 43b and 43c on the ferrite disk 35 were 48 ohms and 32 ohms respectively. Section 61 was 0.025 inch wide and section 62 was 0.050 inch wide.

The above described circulator when operated with a swept frequency signal over the 10 to 14 GHz frequency range exhibited an insertion loss of 2 to 6 db without the post 51. With the post 51, the insertion loss over the 10 to 14 GHz band was about 1 db and the isolation was improved 1 to 5 db. The same low insertion loss and isolation were provided when the circulator described in the example above with the post 51 was operated with swept frequency signals over the 8 to 16 GHz frequency range with a second magnet, not shown, like magnet 27 placed in the top wall 23 of housing 13. This second magnet was placed within the housing 13 in the same manner as magnet 27.

What is claimed is:

1. In a microstrip circulator mounted within a metallic enclosure wherein said microstrip circulator includes a dielectric substrate, a single ground planar conductor on one surface of said substrate in contact with one wall of said enclosure and a plurality of narrow strip-like conductors extending from a common conductive region on the opposite surface of said substrate, said substrate adjacent the common conductive region including gyromagnetic material, said circulator including means for biasing said body of gyromagnetic material, the improvement therewith for elimination of unwanted TE and TM modes associated with box resonances within said enclosure comprising:

a metallic conductor having a diameter no greater than that of the common region coupled between said common region and a second wall of said metallic enclosure extending above the common region.

2. The combination as claimed in claim 1 wherein said metallic conductor is a symmetrical post connected directly between said second wall of said metallic enclosure and said common region.

3. The combination as claimed in claim 1 wherein said second wall is directly opposite said one wall.

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