

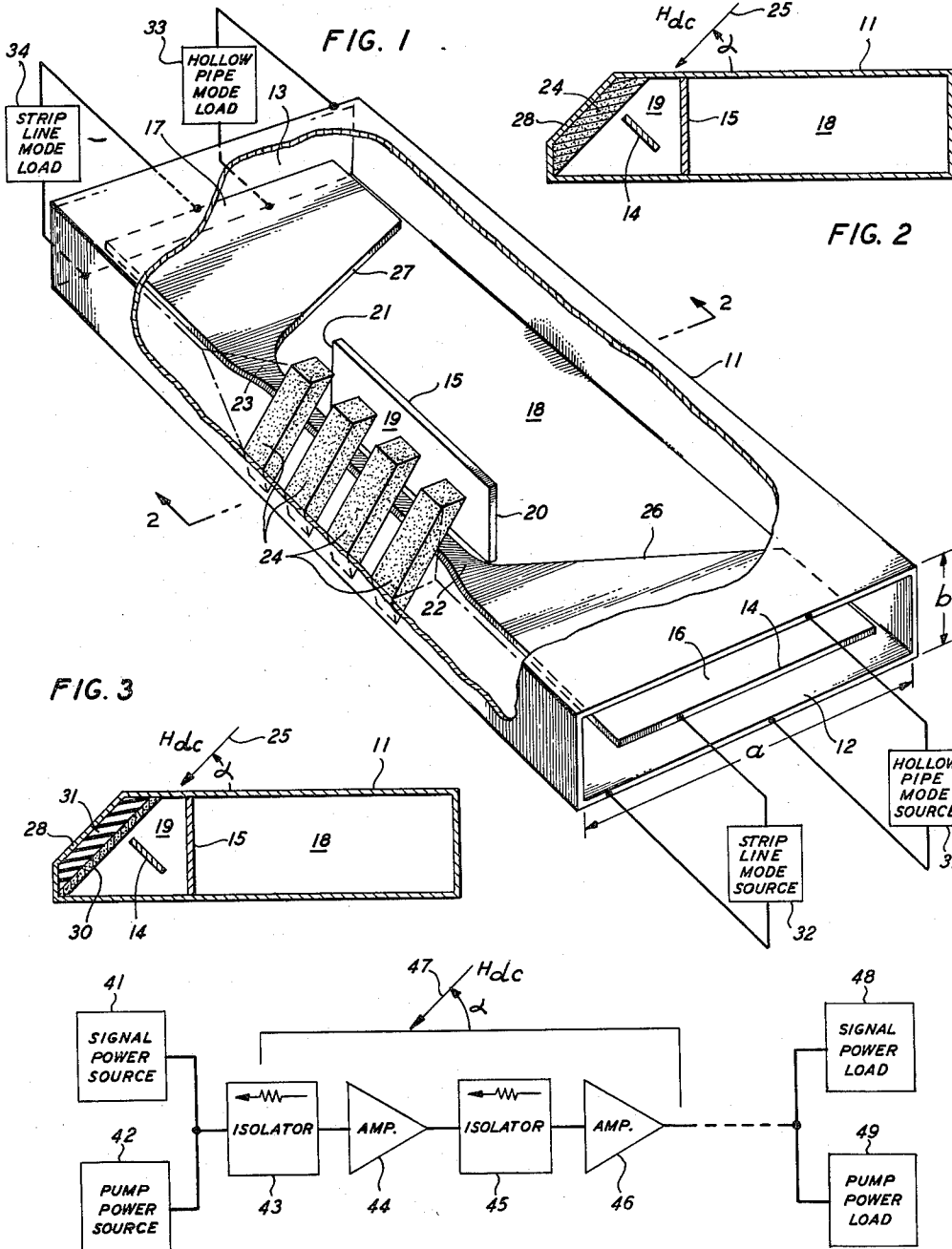
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MICROWAVE SELECTIVE MODE ISOLATOR

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MICROWAVE SELECTIVE MODE ISOLATOR

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This invention relates to electromagnetic wave transmission systems and more particularly to devices having nonreciprocal transmission loss properties for use in such systems.

The use of materials having gyromagnetic properties to obtain both reciprocal and nonreciprocal effects in microwave transmission circuits is widely known and has found numerous and varied applications in transmission systems of both the wave guide and the transmission line types. A comprehensive survey of the uses and characteristics of gyromagnetically active devices appears in the "Proceedings of the IRE," vol. 44, No. 10, October 1956. More recent developments are reported in the quarterly publication entitled "IRE Transactions on Microwave Theory and Techniques."

Included among the new transmission devices which have found widespread use in the microwave art is the so-called "isolator." An isolator may be described as a circuit element in which electromagnetic wave energy propagating in one direction, designated the forward direction, experiences but slight transmission loss while wave energy propagating in the opposite direction, designated the reverse direction, experiences transmission loss to the extent required by the system.

At least four distinct classes of isolators are presently known. These include the Faraday rotation types, the gyromagnetic resonance types, the field displacement types, and, more recently, the mode turbulence types. The latter is described in detail in the copending applications of H. Seidel, Serial No. 774,547, filed November 17, 1958, now U.S. Patent No. 3,010,086, and Serial No. 60,439, filed October 4, 1960, now U.S. Patent No. 3,010,084, the latter being a continuation-in-part of applications bearing Serial Nos. 774,496, and 774,548, both filed November 17, 1958, and since abandoned.

During the period of the development of gyromagnetic devices, both hollow pipe type wave guide embodiments and multiple conductor or strip line guide embodiments have emerged in each one of the four classes of isolator. In general the structures within each isolator class for hollow pipe systems differ from those for strip line or coaxial systems. In some applications different isolator types are required at different locations within the system. Recently system applications have arisen in which a plurality of noncoupled wave modes of differing types are propagated within a common volume. It is desirable in these applications that isolation be selectively introduced into one mode or channel without affecting the other modes. Prior art isolator structures in general affect all mode channels present.

Accordingly, it is an object of the present invention to introduce nonreciprocal transmission loss selectively to one channel of a multiple channel wave guide system without at the same time affecting transmission in either direction in the other channel or channels.

One specific field in which the principles of the present invention have potential application is that of solid state microwave amplification in which the amplification occurs as the result of the simultaneous presence of a plurality of transmission modes within a region comprising magnetically polarized paramagnetic material. In such devices at least two noncoupled wave modes or channels are simultaneously present, one of which is often a hollow

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pipe mode and represents pump power, the other or others of which is often a strip line mode and represents the signal to be amplified. As is the case of the majority of microwave devices, provision is made for preventing reflected signal power from returning toward the generator. At the same time there are other considerations which allow relaxation of system specifications with respect to reflected pump power and eliminate any need for pump power isolation. By placing isolator means heretofore known within the dual channel portions of the amplifiers, both signal and pump power were affected.

Accordingly, it is a further object of the invention to isolate signal power in a solid state amplifier without at the same time affecting pump power.

Furthermore, in some dual channel devices including gyromagnetic material for some purpose other than isolation, an external magnetic biasing field is applied at an acute angle to the plane of the radio frequency magnetic field loops of the propagating energy. When isolation by means of gyromagnetic action is introduced into such a device it is advantageous to utilize the angularly related field for dual purposes.

Thus a further object of the invention is to utilize, for the purpose of introducing isolation, a magnetic biasing field whose spatial relationship to a multiple channel guide is determined by considerations other than those pertaining to isolation.

It is a more specific object of the invention to orient the field pattern of the channel to be isolated with respect to the external field to produce maximum nonreciprocal effect.

A feature in the utilization of the invention in a systems application is its compactness, which results in part from the use of a single magnetic bias producing means for a plurality of different gyromagnetic operations.

In accordance with the present invention a first energy source applying electromagnetic waves in a hollow pipe wave mode and a second energy source supplying electromagnetic waves in a strip line wave mode simultaneously excite a dual channel structure adapted to support both modes. Within the structure the strip line wave mode is diverted into a guiding section incapable of supporting the hollow pipe mode in which section isolation means are provided. The hollow pipe mode passes through a guiding section incapable of supporting the strip line mode and, beyond the section containing the isolator these modes again enter a common propagation path and proceed to their respective loads.

According to one embodiment of the invention, the hollow pipe wave mode is supported in a conductively bounded guide section within which is disposed a flat center conductor supportive of the strip line wave mode. Along a central longitudinal portion of the dual channel section a conductive septum extends longitudinally to divide the hollow guide into two electrically isolated guide portions, one of which is supportive of the hollow pipe mode at its assigned frequency, the other of which is nonsupportive of the hollow pipe mode. The flat center conductor is narrowed and diverted into the latter guide portion. Within the guide portion containing the strip, gyromagnetic material is appropriately disposed to produce directional transmission loss as disclosed for example in the above-mentioned Seidel application Serial No. 774,547, now U.S. Patent No. 3,010,086. Within the gyromagnetically loaded region the strip may be physically reoriented by physical twists in the vicinity of the septum ends to effect maximum coupling between the strip line wave mode power and the gyromagnetic material, as dictated by the particular spatial orientation of an external magnetic bias. At the end of the conductive septum the narrowed conductive strip widens to its original

width in the enclosing hollow guide and both wave mode channels again propagate within a common volume.

The above and other objects and features of the present invention, its nature and its various advantages will appear more fully upon consideration of the specific illustrative embodiments shown in the accompanying drawing and described in the following detailed description thereof:

In the drawing:

FIG. 1 is a partially broken away perspective view of an isolator in accordance with the invention;

FIG. 2 is a transverse cross sectional view of the isolator of FIG. 1;

FIG. 3 is a cross sectional view of an alternate isolator embodiment; and

FIG. 4 is a block diagram representation of a solid state amplifier system incorporating the invention.

Referring more particularly to FIG. 1, there is illustrated a conductively bounded wave energy transmission path 11 into which various conductive and dielectric media are disposed. Wave guide 11 is of rectangular transverse cross section in the region of its terminal end portions 12, 13 and is proportioned such that unequal transverse dimensions a , b are sufficiently large to enable guide 11 to support electromagnetic wave energy in the dominant TE_{10} mode within the operating range of frequencies. Extending longitudinally within guide 11, and spaced away from the conductive walls thereof, is conductive strip 14, which is proportioned to support a strip line type wave mode confined in transverse extent by the walls of guide 11. Portions 16, 17 of strip 14 which extend through terminal end portions 12, 13 of guide 11 have their wider transverse dimension parallel to the broad walls of the external guide. Extending longitudinally within a central portion of guide 11 is conductive septum 15 which extends in a plane perpendicular both to the broad walls of guide 14 and to the end portions 16, 17 of strip 14. Septum 15 divides guide 11 into two conductively separate guide portions or channels 18, 19. The ends 20, 21 of septum 15 would be provided with means for matching the impedance of the dual channel portion of guide 11 with that of the single channel portion. These matching means may take the form of a quarter-wave transformer, a long physical taper, or any other appropriate matching device. For the sake of clarity, the impedance matching means have been omitted from FIG. 1. The transverse placement of septum 15 across the wider dimension of guide 11 is selected such that the dimensions of each of the channels 18, 19 in a direction parallel to dimension a of guide 11 differ. As is well known, this particular transverse dimension of a rectangular wave guide determines the largest wavelength wave energy which will be supported by the guide. Wave energy of larger wavelength or lower frequency will not be propagated in the guide; i.e., the guide will be "cut-off." Septum 15 divides guide 11 such that the cut-off determining dimension of channel 18 is large enough for channel 18 to support wave energy in the dominant TE_{10} mode at the frequency introduced into guide 11 while the cut-off determining dimension of channel 19 is small enough that channel 19 will not support, or is cut-off for, the TE_{10} mode wave energy supported by guide 11 and channel 18.

Conductive strip 14 is shaped to extend only through channel 19. For reasons which will become more apparent hereinafter, the plane of the widest face of strip 14 in channel 19 is generally different from the corresponding plane of end portions 16, 17. That is, strip 14 undergoes a twist 22 of one rotational sense in the vicinity of the end 20 of septum 15 and a twist 23 of the opposite rotational sense but equal magnitude in the vicinity of the end 21 of the septum.

Distributed along one sidewall of channel 19 are segments of elements 24 of material which is capable of introducing nonreciprocal transmission loss to energy

propagating therealong. These elements are spaced apart sufficiently to allow the surrounding material, which in the illustrated embodiment comprises air, to fill the regions between the segments. The number of segments is dependent upon the elected spacing and the total length of channel 19. In any event one surface of each of the elements is preferably in close proximity to strip 14 in accordance with the isolation principles set out in the copending Seidel applications. As a specific embodiment, elements 24 may comprise material which exhibits gyromagnetic properties over a range of operating frequencies of interest, commonly designated gyromagnetic material. The term gyromagnetic material is employed in this specification in its accepted sense as designating the class of magnetically polarizable materials having portions of the atoms thereof that are capable of exhibiting a significant precessional motion at frequencies within the frequency range of interest under the combined influence of an external magnetic polarizing field and an orthogonally directed varying magnetic field component. This precessional motion is characterized as having an angular momentum, a gyroscopic moment, and a magnetic moment. Included in this class of materials are ionized gaseous media, paramagnetic materials, and ferromagnetic materials including the spinel ferrites and the garnet-like yttrium iron compounds. One particular class of gyromagnetic materials suitable for use as nonreciprocal elements 24 in the present invention comprises an iron oxide combined with a quantity of bivalent metal such as nickel, magnesium, zinc, manganese or other similar material. As a specific example elements 24 may comprise magnesium aluminum ferrite prepared in the manner described in United States Patent 2,748,353 which issued to C. L. Hogan on May 29, 1956. As disclosed in the above-mentioned copending applications of H. Seidel, this material has been found to operate successfully as a non-reciprocal mode turbulence attenuator structure in the presence of a magnetic biasing field applied externally and directed orthogonally to the high frequency magnetic field components of a strip line type wave mode. The relative orientations among the various elements and channels already described may be more readily appreciated by reference to FIG. 2 of the drawing.

FIG. 2 is a transverse cross sectional view of the isolator of FIG. 1 taken at line 2—2. Thus channel 18 is seen to be of greater horizontal transverse dimension than channel 19, while both strip 14 and elements 24 appear in channel 19. Magnetic polarizing field H_{dc} , illustrated by arrow 25, is applied to elements 24 from a source, not shown, external to guide 11. As shown in FIG. 2, H_{dc} is applied at an angle α to the top and bottom walls of guide 11. Such an orientation is often encountered for example in multiple energy channel systems in which solid state amplification is produced. Strip 14, in the vicinity of its entry into channel 19 is given a physical twist of magnitude sufficient to orient the plane of the strip normal to the direction of arrow 25. When the elements and field are so oriented, elements 24 produce most efficient isolation. The wall 28 itself of guide 11 in the vicinity of channel 19 may extend in part perpendicular to the plane of rotated strip 14 as shown, or a conductive plate so oriented may merely be inserted within a rectangular guide. In either case the loading material should be contiguous to the slanted conductive boundary to insure efficient mode turbulence isolator performance.

In the operation of the microwave isolator of FIGS. 1 and 2, guide 11 is excited in a hollow pipe wave mode, the dominant TE_{10} wave mode for example, at terminal end 12 by source 31. Strip 14 is excited by source 32 in a strip line wave mode at the same terminal end. Both mode channels enter guide 11 and are propagated normally as uncoupled wave modes for several wavelengths until the vicinity of septum 15 is approached. Power on strip line 14 is then, by virtue of the taper 26, di-

verted to one side of guide 11. Passing matched end portion 20 of septum 15, power in the hollow pipe mode passes into and through channel 18 while power in the strip line mode passes into and through channel 19. No power in the hollow pipe mode propagates in channel 19 due to its restricted dimensions. Likewise no power in the strip mode propagates in channel 18 due to the lack of proper mode supporting means. Within channel 19 the strip mode is spatially reoriented at twist 22 and passes through the gyromagnetic region with little or, preferably, no attenuation. Any reflected energy, propagating within channel 19 in a direction opposite to that of the primary signal is significantly attenuated by elements 24. Thus little or no unwanted reflected strip mode power will reach the components preceding the isolator. Upon reorientation at twist 23 and emergence from channel 19, the strip line mode power expands spatially along taper 27 until it is again supported by original width strip 14. Hollow pipe mode power expands beyond septum 15 to fill guide 11 once more. No mixing of the power in the two modes has occurred, and only power in the strip line wave mode has been affected by the isolator means. Subsequent operations upon the strip mode may occur or, as illustrated in FIG. 1, connection to respective loads 33, 34 may be made.

FIG. 3 is a transverse cross sectional view of an alternate isolator embodiment of the invention. In general, reference numerals from FIG. 2 have been carried over to corresponding parts of FIG. 3 where appropriate. In FIG. 3, the gyromagnetic element takes the form of a single thin element 30 of gyromagnetic material. Filling the region between the gyromagnetic element 30 and the boundary wall 28 is dielectric slab 31. In general, the dielectric element 31 should have a thickness measured parallel to the plane of strip 14 of the order of three times that of the gyromagnetic element, and should have a dielectric constant of the order of 10. The composite structure of FIG. 3 serves to attenuate power in the strip line wave mode propagating in a direction opposite to the desired direction by virtue of the magnetic field differential across element 30 produced by the presence of dielectric slab 31.

Practical applications of an isolator in accordance with the invention may involve the isolation of a signal source from a load, which may comprise an amplifier section, or the isolation of successive amplifier sections from each other. Thus, in FIG. 4, a typical solid state amplifier application of the invention is illustrated in block form. In FIG. 4, signal power from source 41 and pump power from source 42 pass through isolator 43 which precedes amplifier 44. In this manner reflected signal power from the amplifier is prevented from reaching the source. A second isolator section 45 is interposed between amplifiers 44 and 46 to prevent reflections from amplifier 46 from reaching amplifier 44. The signal power and pump power from amplifier 46, which may then pass through successive amplifiers and isolators, eventually arrives at respective loads 48, 49. The entire system of isolator and amplifier sections shown in FIG. 4 need have only a single applied external polarizing field H_{dc} indicated as arrow 47. As set out above, due to amplifier considerations this polarizing field may be angularly related to the broad faces of both the signal supporting strip line and the pump power supporting hollow pipe guide. Within the isolator sections 43, 45, however, the twisted strip enables maximum isolator performance.

In all cases it is understood that the above-described arrangements are merely illustrative of the many specific embodiments which can represent applications of the principles of the invention. Thus, while a specific illustrative embodiment of the novel isolator has been disclosed with reference to a solid state amplifier system, the device is not limited to such an application. Additionally, applications of the invention are possible in which the external biasing magnetic field, rather than being related by an

acute angle to the broad walls of the hollow pipe guide, is applied in a direction normal to these walls. It is evident therefore that numerous and varied arrangements other than those illustrated can readily be devised in accordance with the principles of this invention by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. In combination, a transmission path for electromagnetic wave energy adapted to support first and second independent wave modes simultaneously, means within said path for segregating said first wave mode into a first channel and said second wave mode into a second channel which is physically separate from said first channel, one of said channels including means for attenuating wave energy propagating in one direction therethrough while freely transmitting wave energy propagating in the opposite direction therethrough, and means for recombining said modes in said path.

2. In a solid state amplifier system, microwave signal power in a first wave mode, microwave pump power in a second wave mode different from said first wave mode, means for propagating said first and said second wave modes simultaneously in a region loaded with paramagnetic material, means for subjecting said region to a magnetic polarizing field which is applied at an acute angle to the predominant electronic field lines of said first mode in said region, and means for attenuating signal power in one direction of propagation to the exclusion of pump power, comprising a bounded guiding section having first and second transverse portions, said signal power wave mode being coupled in said first portion and said pump power wave mode being coupled into said second portion, gyromagnetic material disposed within said first portion along one boundary thereof in the presence of said magnetic polarizing field, and means for reorienting the field pattern of said signal wave mode in the vicinity of said gyromagnetic material.

3. Apparatus according to claim 2 in which said first wave mode is a strip line wave mode, said second wave mode is a hollow pipe guide wave mode, and said reorienting means comprises a strip line section having a twisted center conductor.

4. In an electromagnetic wave system, a transmission path comprising a conductively bounded enclosure having a rectangular transverse cross section and having a conductive member extending within and spaced away from the boundary walls of said enclosure, means for exciting said conductive member in a strip line wave mode and said conductively bounded enclosure in a hollow pipe wave mode of a given frequency, a conductive septum extending longitudinally within said enclosure over a portion of its length and dividing said enclosure transversely into a first channel the transverse dimensions of which are less than those necessary to support said hollow pipe wave mode at said given frequency, and into a second channel the transverse dimensions of which are sufficient to support said hollow pipe wave mode, said conductive member extending solely through said first channel, means for directionally attenuating the energy propagated along said member disposed within said first channel adjacent said member, said means comprising a material exhibiting gyromagnetic properties, and means for impressing a magnetic biasing field upon said gyromagnetic material.

5. Apparatus according to claim 4 in which said biasing field is applied at an acute angle to the walls of said enclosure and said conductive member is reoriented within said first channel to align the plane defined by its broader transverse dimension normal to the magnetic flux lines of said biasing field.

6. A microwave isolator comprising a conductively bounded wave guiding structure adapted to propagate energy of a given frequency, a flat conductive strip within and longitudinally coextensive with said structure having

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first, second, and third longitudinally successive portions, a conductive septum normal to the plane of said strip in said first and third portions extending within said structure coextensively with said second portion and positioned to divide said structure into a first channel which is below cut-off for energy of said given frequency and a second channel which is above cut-off for said energy, said strip extending only into said first channel, means for impressing an external magnetic field on said structure, said strip being oriented such that the plane defined by its broader transverse dimension in said second portion is normal to the direction of said field, and nonreciprocal means for attenuating energy supported by said strip disposed adjacent said strip in said second portion.

7. The combination according to claim 6 in which said external magnetic field is applied at an acute angle to the

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plane defined by the broadest dimension of said strip in said first and third portions.

8. The combination according to claim 6 in which said nonreciprocal means comprise elements of gyromagnetic material disposed adjacent said strip.

9. The combination according to claim 6 in which said nonreciprocal means comprise an element of gyromagnetic material and a slab of dielectric material of moderate dielectric constant different from said element with said gyromagnetic element positioned between said strip and said slab.

References Cited in the file of this patent

UNITED STATES PATENTS

2,907,959 Robertson ----- Oct. 6, 1959