

Oct. 13, 1970

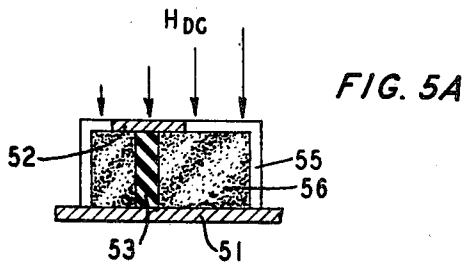
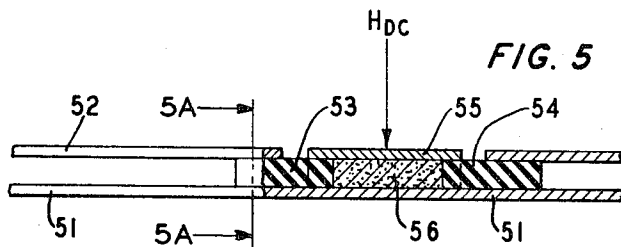
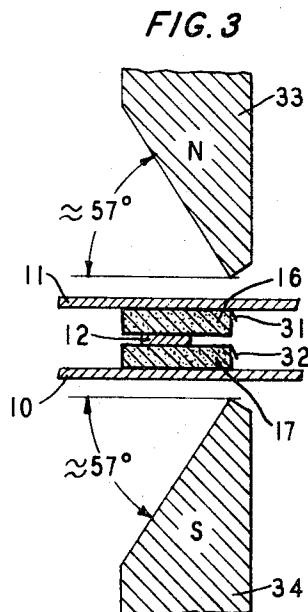
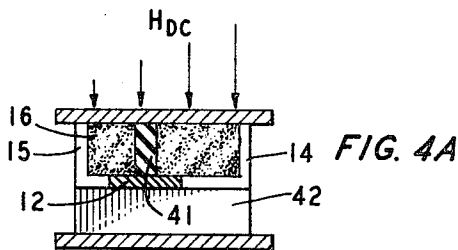
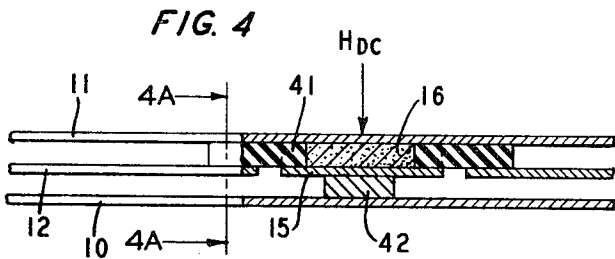
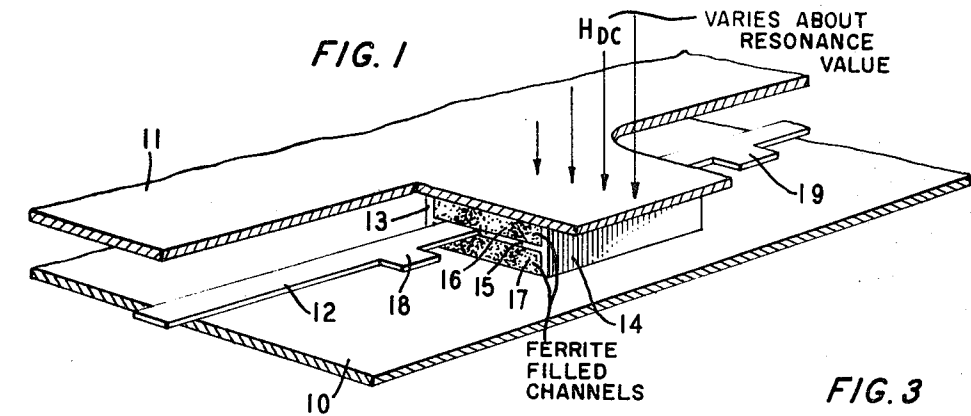
N. EBERHARDT

3,534,299

MINIATURE MICROWAVE ISOLATOR FOR STRIP LINES

Filed Nov. 22, 1968

2 Sheets-Sheet 1



INVENTOR
N. EBERHARDT
BY
Roy M. Porter
ATTORNEY

Oct. 13, 1970

N. EBERHARDT

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MINIATURE MICROWAVE ISOLATOR FOR STRIP LINES

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2 Sheets-Sheet 2

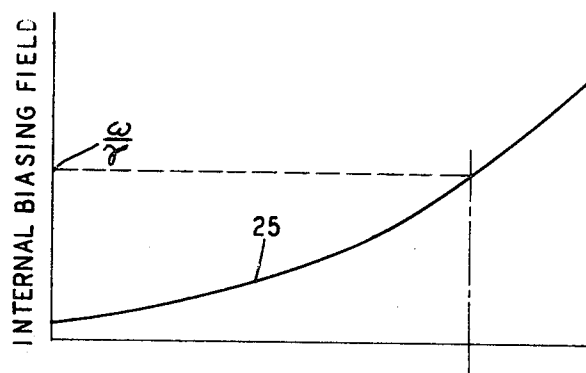


FIG. 2A

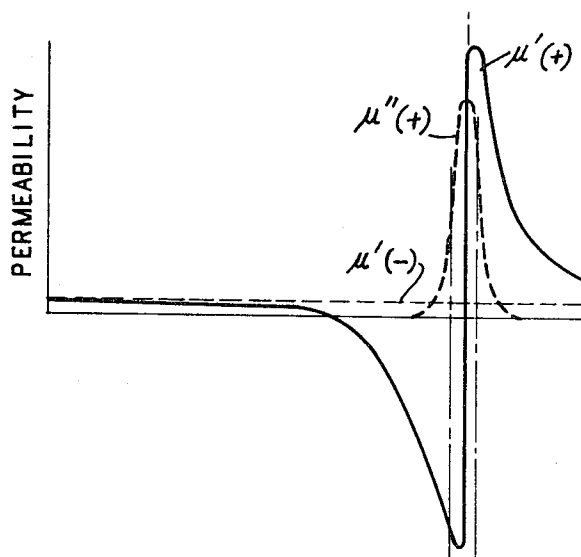


FIG. 2B

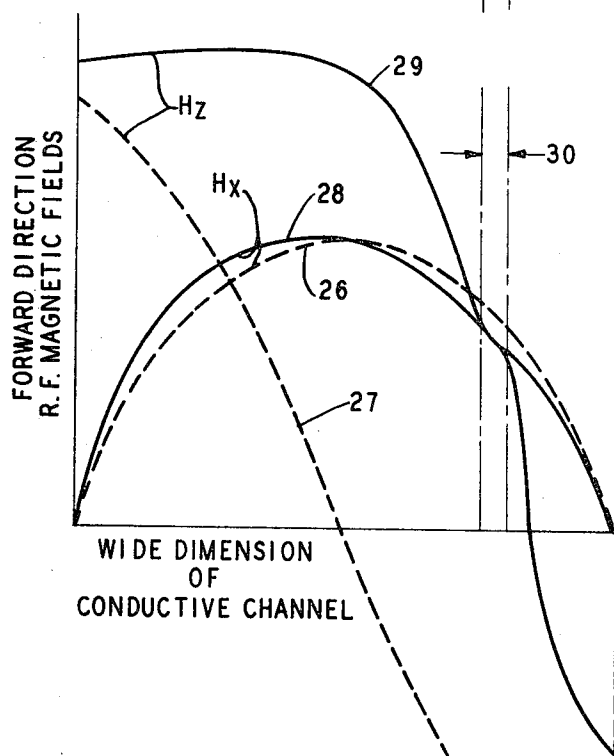


FIG. 2C

1

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MINIATURE MICROWAVE ISOLATOR FOR STRIP LINES

Nikolai Eberhardt, Bethlehem, Pa., assignor to Bell Telephone Laboratories, Incorporated, Murray Hill, N.J., a corporation of New York

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6 Claims

ABSTRACT OF THE DISCLOSURE

A microwave resonance isolator of such small physical dimensions that it can be integrated with a microwave strip line assembly. The isolator comprises a conductively bounded channel completely filled with gyromagnetic material that is biased by a magnetic field varying across the channel cross section and passing through the value producing gyromagnetic resonance at a point near one of the side walls of the channel.

BACKGROUND OF THE INVENTION

This invention relates to microwave strip line devices and more particularly to nonreciprocal gyromagnetic attenuating devices of the general class known as resonance isolators.

The operating principles of resonance isolators in conductively bounded waveguides of the usual dimension are well known and many versions have been described for which different advantages have been asserted. In general all of these devices involve an element of gyromagnetic material, such as ferrite, located in the field pattern of electromagnetic wave energy and magnetically biased to the point at which the material becomes resonant in a gyromagnetic sense at the frequency of the energy. In a certain plane parallel to one of the narrow walls, the wave energy has a transverse magnetic field component and a longitudinal magnetic field component that are equal in amplitude and 90° out of phase so that the magnetic field is circularly polarized and appears to rotate in one direction for propagation along the guide and in the opposite sense for propagation in the opposite direction. When this rotation is in the sense defined as positive with respect to the direction of the biasing field, there is strong coupling to the material and high dissipation of energy. When negative, there is little coupling and little dissipation. However, the region of pure circularization is usually narrow in width so that within the resonant material there are minor field components that rotate in a sense opposite to the desired sense and dilute the nonreciprocal effect, usually by increasing the forward loss.

Several proposals have been made for inhomogeneously loading the guide cross section and/or inhomogeneously biasing the material according to particular profiles to reduce the forward loss. These proposals generally attempt to increase the ratio of forward propagating purely circularly polarized components rotating in the noncoupling sense to that of the components rotating in the opposite and coupling sense. The structures resulting from these proposals have been in general too complicated, large and bulky to be integrated directly with strip transmission lines. Typical of this prior art are the disclosures of W. W. Anderson et al. in Pat. 3,051,908 granted Aug. 28, 1962 or F. S. Chen in Pat. 3,142,026, granted July 21, 1964. Isolators in reduced size wave-guides using heavy gyromagnetic loading have also been proposed, but these structures have had high forward losses. Typical of the latter prior art is the disclosure of H. Seidel et al. in 38 BSTJ 1427, November 1959.

2

SUMMARY OF THE INVENTION

In accordance with the present invention it has been recognized that if a short section of very small cross-sectioned conductively bounded rectangular waveguide channel is completely filled with ferrite and biased by a magnetic field that increases across the wide dimension from a strength near one narrow wall that is substantially below that for resonance at the frequency of interest, through the strength for resonance at a particular intermediate point, and to a value above that for resonance near the other narrow wall, an isolator is produced which simultaneously has an unusually low forward loss, and a field distribution and size which are compatible with strip lines. In a particular embodiment the isolator comprises simply a small block of ferrite, no more than a fraction of the corresponding air filled waveguide dimension for the same frequency, plated with conductive material or wrapped in conductive foil that covers four of its sides to form a miniature heavily loaded waveguide. This guide or conductive channel is disposed between the strip line center conductor and one or the other, or both, of the strip line ground planes. Pole pieces of simple design provide a biasing field of the profile desired. It has been found that this biasing field so distorts the magnetic field pattern of the high frequency wave within the ferrite loaded foil boundary that the longitudinal and transverse components are equal in amplitude in a relatively broad region that substantially coincides with the region of resonance. The biasing field is directed in the noncoupling sense for forward transmission through this region to obtain low forward loss. For the reverse direction, high reverse loss is obtained since the gyromagnetic filling factor is high. It has been further found that this distorted field is one to which strip lines can be well matched.

BRIEF DESCRIPTION OF DRAWING

FIG. 1 is a cutaway perspective view of a strip line embodiment in accordance with the invention;

FIGS. 2A, 2B, and 2C, given for the purpose of explanation, show significant parameter variations across a cross section of FIG. 1;

FIG. 3 illustrates by means of a cross-sectional view one means of applying the required biasing field to and certain other modifications of the embodiment of FIG. 1;

FIG. 4 is a longitudinal cross section and FIG. 4A a transverse cross section of a further embodiment of the invention; and

FIG. 5 is a longitudinal cross section and FIG. 5A a transverse cross section of an unbalanced version of the invention.

Referring more particularly to FIG. 1 an isolator in accordance with the invention is shown in combination with a section of microwave strip line of the type which supports a wave usually designated as a TEM mode. The strip line itself is conventional and comprises a pair of flat, spaced, conductive ground planes 10 and 11 together with an interposed center conductor 12. While these elements are shown in a self-supporting form it is understood that they may be fabricated in the familiar sandwich fashion in which a dielectric substrate is included between one or both of the ground plates and the center conductor, and in which the center conductor itself may be formed by printing, plating or etching a thin narrow conductive layer on one or the other of the substrates. Since the transverse extent of ground planes 10 and 11 are immaterial, they are truncated to illustrate that the elements shown may comprise a small part of a larger integrated strip line package.

The isolator comprises a pair of conductively bounded channels 16 and 17 located respectively above and below center conductor 12 each completely filled with gyromag-

netic material. In the form illustrated the outside wide conductive boundaries of each channel comprise the ground planes 10 and 11 and the side or narrow boundaries comprise conductive partitions 13 and 14 extending between and fastened to the ground planes. A conductive center divider 15 lies in the plane of and is connected to center conductor 12 and separates the two channels.

The material within each channel thus formed is of the type having electrical and magnetic properties of the type described by the mathematical analysis of D. Polder in Philosophical Magazine, January 1949, volume 40, pages 99 through 115. More specifically, it may be made of any nonconducting ferromagnetic material. For example, it may comprise iron oxide with some of the oxides of one or more bivalent metals such as nickel, magnesium, zinc, manganese, or aluminum, combined in a spinel crystal structure. This material is known as ferromagnetic spinel or as ferrite. Since a narrow resonance line width is preferred for the invention as will be discussed hereinafter, it may comprise one of the ferromagnetic garnet materials. Any of these materials are sometimes first powdered and then molded with a small percentage of a plastic binder. Hereinafter the term "ferrite" will be used exclusively as descriptive of the material, but it will be understood that equivalent materials having similar gyromagnetic properties may be used to practice the invention. It will also be convenient to refer to the ferrite filling as well as to the conductively bounded channels merely by the reference numerals 16 and 17.

The relative sizes of channels 16 and 17 may be given in terms of the free space wavelength of the frequency of interest. Since the channel is so heavily loaded by the ferrite, the wide dimension of each channel may be only in the order of .15 to .2 free space wavelengths (as compared to 0.5 to 0.75 wavelengths for a standard waveguide) and a narrow dimension in the order of .02 to .05 free space wavelengths (as compared to 0.25 wavelengths in the standard waveguide). Thus at a frequency of 6 GHz, the ground planes are typically spaced 0.122 inch, each channel has a narrow dimension of 0.0625 inch and a wide dimension of 0.38 inch. The length of each channel is a few tenths of an inch depending upon the isolation to be introduced.

The material within each channel 16 and 17 is biased by a steady magnetic field schematically represented by the vectors H_{DC} directed normal to ground planes 10 and 11 and having a strength which increases across the channels as will be shown in connection with FIG. 2A. Thus FIG. 2A illustrates by means of the characteristic 25 the variation of internal biasing magnetic field across the wide dimension of either channel 16 or 17. Near one narrow wall the field has a very small value. At a point displaced from the center line of the channel and near the other narrow wall the field increases through the value ω/γ , the well-known strength producing gyromagnetic resonance at the operating frequency ω where γ is the gyromagnetic ratio. Beyond this point the field continues to increase. Good performance has been obtained when the location of the resonance region falls between 15 and 25 percent of the channel width away from the nearer narrow wall. The curvature of characteristic 25 is the result of demagnetizing factors inherent with the simple pole pieces to be described and does not appear to be significant. FIG. 2B illustrates the significant permeability components of the ferrite produced by the magnetization of FIG. 2A. These components are well known and a full definition and description of them may be found in a text book such as Microwave Ferrites and Ferrimagnetics by Lax and Button (1962) or in articles such as "Behavior and Application of Ferrites in the Microwave Region" by A. G. Fox et al., 34 BSTJ 5, January 1955. Thus the value $\mu'(-)$, the real portion of the permeability for negatively circularly polarized components, remains slightly greater than unity regardless of

the field strength. The value $\mu'(+)$, the real part of the permeability for positively circularly polarized components, is approximately unity over most of the cross section, sharply becomes negative as resonance is approached, passes through zero at resonance to positive values above resonance, and decreases for higher field values. The imaginary or loss component of the permeability for positively circularly polarized components is shown by the curve $\mu''(+)$ which is zero over most of the cross section but rises sharply to a maximum at resonance. The width of the loss characteristic is known as the resonance line width and is a property of the particular material. FIG. 2C illustrates the relative values of transverse and longitudinally radio frequency magnetic field components H_x and H_z respectively. For comparison the broken line curves 26 and 27 illustrate the usual transverse and longitudinal components in a waveguide of symmetrical cross section and are also typical of the distribution in either channel in the absence of the biasing field H_{DC} . The solid curves 28 and 29 represent the respective distribution of the transverse and longitudinal components as determined experimentally by field probing techniques when the biasing field according to FIG. 2A is applied. A mathematical analysis of the boundary conditions responsible for this distribution would add little to an understanding of the invention and is not offered. What is significant, however, is that the biasing field profile of FIG. 2A produces in the region where the field strength passes through the resonance value, the loss characteristic $\mu''(+)$ of FIG. 2B as well as a region in which H_z and H_x are substantially equal as illustrated by the region 30 on FIG. 2C. Thus a region of circular polarization exists which appears to have a width very nearly equal to and coinciding with the resonance line-width for positive circular polarization. When the sense of the biasing field H_{DC} is negative with respect to this circular polarization produced by one direction of propagation, there is for this direction little absorption. In a typical embodiment the loss thus introduced has been no greater than 0.7 db. Reversing the direction of propagation reverses the sense of circular polarization. It cannot be determined by field probing techniques exactly what is the reverse field distribution since the components are absorbed and dissipated in such a short length of material, but the distribution is clearly one in which substantial positively circularly polarized components exist in region 30. In a typical embodiment it has been found that this loss is in the order of 10 db for each 0.1 inch of channel length, the large magnitude being due to the high filling factor of the ferrite. Thus a channel length of only a few tenths of an inch produces a dissipation equivalent to that of much longer prior art isolators.

FIG. 3 illustrates by means of a cross-sectional drawing a preferred modification of the structure of FIG. 1 and corresponding reference numerals have been used to designate corresponding components. Modification will be seen to reside in the simplified form of the conductive boundary for ferrite elements 16 and 17 obtained by way of the expedient of wrapping layers of conductive foil 31 and 32 about each of ferrite blocks 16 and 17, respectively. The wide dimension of each foil contacts a ground plane 10 or 11 on one side and the center conductor 12 on the other. Thus the foil wrapped blocks of ferrite can be directly introduced into the existing space between the center conductor and the ground planes to form an isolator in an integrated strip line assembly.

FIG. 3 also illustrates the simple cross section of pole pieces 33 and 34 to produce the field distribution of FIG. 2A. The angle of approximately 57 degrees incline of the pole piece face has been determined experimentally to give good results for the particular ferrite and geometry used and will in general be dependent upon the material properties and geometry of the ferrite.

Obviously the match between the strip line and the conductively bounded channel must be good to eliminate

a loss introducing impedance discontinuity at this point. In general the transition may be the same as any other strip line to waveguide transition and the numerous transducers already known to the art may be used in miniature form to make the junction.

For the particular transition illustrated in FIG. 1 it is preferred that each channel be located on center conductor 12 so that the strip line couples with each channel in a region displaced from the channel center line on the low biasing field side thereof. This location tends to couple maximum transverse fields on the strip to maximum transverse fields in the channel and to match the respective electric fields. The precise point of match depends upon the contour of the biasing field and is best determined experimentally. The match is further improved by capacitive stubs 18 and 19 on center conductor 12. Other impedance matching aids such as capacitive posts, screws or tapers may be used to improve the match as required.

A further transition is shown in FIG. 4 and the transverse cross section thereof in FIG. 4A in the form of a dielectric waveguide 41 comprising a narrow strip of material having a high dielectric constant that overlaps center conductor 12 at one end and extends into the channel region at the other. The end of dielectric waveguide 41 that overlaps center conductor 12 can be tapered in accordance with known practice if desired. A pair of dielectric strips can obviously be used on either side of a center conductor to feed a pair of conductively bounded channels.

In FIG. 4 however a further modification of the invention is shown in which a single ferrite channel 16 is employed between ground plane 11 and center divider 15. The space between divider 15 and the other ground plane 10 is preferably filled with a block of conductive material 42, appropriately set back from the end of channel 16 to allow the wave fields to reform.

The principles of the invention are by no means limited to symmetrical strip lines. As illustrated in FIG. 5 and the transverse cross section thereof in FIG. 5A these principles are applicable to the unsymmetrical form, sometimes referred to as Microstrip, in which a single ground plane 51 is related to a spaced conductive strip 52. As in FIG. 4, dielectric transition members 53 and 54 are employed to couple the strip to and from the conductively bounded channel 55. It should be apparent that the performance of ferrite member 56 is essentially the same as either one of the elements 16 or 17 of FIG. 1.

In all cases it is to be understood that the above described arrangements are merely illustrative of a small number of the many possible applications of the princi-

ples of the invention. Numerous and varied other arrangements in accordance with these principles may readily be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A nonreciprocal device for electromagnetic wave energy of given frequency comprising a channel of rectangular transverse cross section having a conductive boundary defining pairs of wide and narrow walls, said channel being substantially completely filled with gyromagnetic material, means for applying a steady magnetic field to said material that increases transversely across the extent of said wide walls of said channel from a first strength substantially below to one substantially above that producing resonance in said material at said frequency, and means for applying said wave energy to said channel with the electric field thereof polarized normal to said wide walls to propagate in a direction normal to said transverse cross section.
2. The device according to claim 1 wherein the point at which said biasing field has the value producing gyromagnetic resonance at said frequency falls on said wide walls between the center line thereof and one of the narrow walls thereof.
3. The device according to claim 2 wherein said means for applying said wave energy is located on the same side of said center line thereof as said first field strength.
4. The device according to claim 2 wherein said channel has cross sectional dimensions which are very small fractions of the free space wavelength of said energy.
5. The device according to claim 2 wherein said means for applying said wave energy comprises a thin strip of conductive material and a spaced conductive ground plane each substantially lying respectively in the plane of the wide walls of said channel.
6. The device according to claim 5 including a transition member of high dielectric constant material interposed between said strip and said channel.

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PAUL L. GENSLER, Primary Examiner

U.S. Cl. X.R.

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