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SHORT ISOLATOR WITH RESONANT ELEMENTS

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FIG. 1

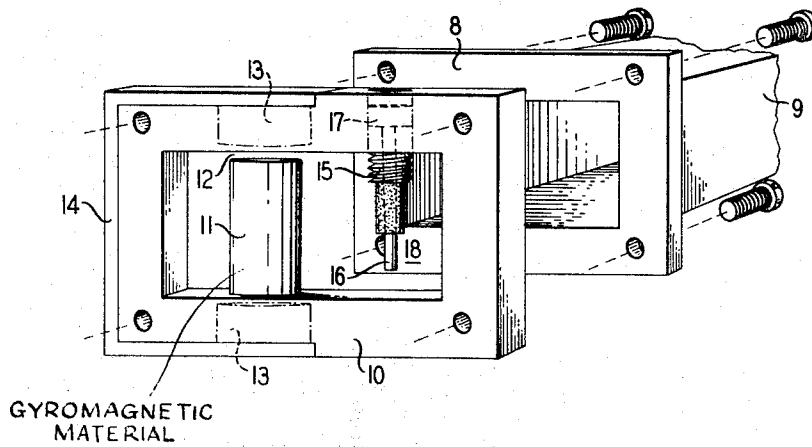


FIG. 3

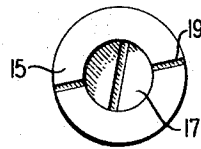
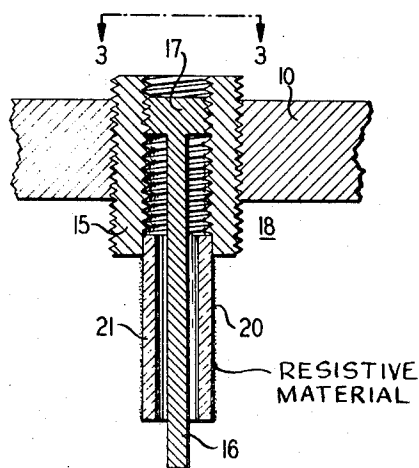


FIG. 2



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SHORT ISOLATOR WITH RESONANT ELEMENTS

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7 Claims

ABSTRACT OF THE DISCLOSURE

A miniature field displacement isolator in which the gyromagnetic displacing element is in the form of a resonant post and the loss element is in the form of a shorted, quarter wavelength long coaxial stub and inner conductor probe, loaded with lossy material. The slim profile of the probe makes it possible to decouple from the displaced electric fields for the forward direction while its resonance adds high loss to the reverse direction fields.

BACKGROUND OF THE INVENTION

This invention relates to electromagnetic wave transmission structures having nonreciprocal attenuating properties and more particularly to waveguide isolators of reduced size.

The use of materials having gyromagnetic properties to obtain nonreciprocal effects in microwave transmission circuits is widely known and has found numerous and varied applications. Early work is contained in an article entitled "The Behavior and Applications of Ferrites in the Microwave Region," by A. G. Fox, S. E. Miller, and M. T. Weiss, Bell System Technical Journal, January 1955, pp. 5-103. The Proceedings of the IRE, vol. 44, No. 10, October 1956, is devoted to a survey of the uses of gyromagnetic material.

Included among the new transmission components is the so-called isolator, defined as a circuit element in which wave energy propagating in one direction designated the forward direction, is but slightly attenuated while wave energy propagating in the other direction, designated the reverse direction, is attenuated to the extent required by the system.

Among the various types of isolators is the so-called "field displacement" isolator particularly disclosed and claimed in S. E. Miller Pat. 2,946,025, July 19, 1960. In accordance with one simple explanation of the theory of the prior art field displacement isolator, the wave field pattern is displaced in one sense relative to the gyromagnetic element for the forward direction and in an opposite sense relative to the element for the reverse direction. Thus a small electric field of the wave is caused to exist in one region for the forward direction while a preferably large electric field is caused to exist at that same region for a wave propagating in the reverse direction. Resistive material is disposed in the region with the result that very low attenuation is introduced in the forward direction while the large electric field in the region of the resistive material introduces significant attenuation for the reverse direction. This attenuation is referred to as the reverse loss of the isolator.

The design of all isolators is concerned with optimizing the reverse loss without undesirably increasing the forward loss. One form which has produced exceptionally good results employs the resistive material in the form of a long, very thin vane. This vane is carefully placed to minimize forward loss and can be made as long as desired, usually several wavelengths, to achieve the required reverse loss. Recently shorter isolators have appeared on the market which seem to achieve adequate reverse loss

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by a large bulk of resistive material, usually protruding into a rectangular waveguide section through an aperture in one narrow wall. These devices however achieve their short length at the expense of increased forward loss. No published description of this form of short isolator is known.

SUMMARY OF THE INVENTION

In accordance with the invention the length of an isolator is further shortened, and high isolation and low forward losses are obtained by imparting a resonant condition to both the gyromagnetic element and to the loss introducing element. In particular the gyromagnetic element takes the form of a post extending substantially between the wider walls of a short section of rectangular waveguide at a point on one side of the longitudinal center line of the wider walls. The size of the post and its location is such that the cross section of the guide at the location of the post is resonant at the frequency of interest. The loss element is in the form of a shorted, quarter wavelength long coaxial probe in the same transverse cross section of the guide as the post and extending through one wider wall at a point on the other side of the longitudinal center line from the post. The outer conductor of the coax is shorter than the inner conductor by an amount which matches the impedance of the coaxial stub to that of the guide. When such a stub is loaded with lossy material, the loss is tightly coupled to the resonant, reverse direction electric fields allowing the reverse loss to be optimized at the resonance frequency. The slim profile of the probe, however, makes it possible to substantially completely decouple it from the displaced electric fields for the forward direction. Thus high reverse losses and low forward losses are obtained with a structure which adds only a fraction of a wavelength to the waveguide system in which it is inserted.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1 is a perspective view of a microwave isolator in accordance with the present invention; and

FIG. 2 is a transverse cross sectional view of a portion of the isolator of FIG. 1, showing the relative orientation of its elements; and

FIG. 3 is a top view of the portion shown in FIG. 2.

DETAILED DESCRIPTION

Referring more particularly to FIGS. 1 and 2 a field displacement isolator in accordance with the present invention is shown to comprise a section of conductively bounded rectangular waveguide 10 having pairs of oppositely disposed parallel conductive walls, the wider transverse dimension of which is greater than one-half wavelength but less than one wavelength of the lowest frequency wave energy to be transmitted. Generally the narrow dimension is equal to one-half of the wide dimension. The longitudinal dimension (parallel to the direction of propagation) is about one-half of the narrow dimension. In the form illustrated the wall thickness is increased so that the outside cross section of the structure is more or less equivalent to that customarily employed for typical waveguide flanges allowing the isolator to be inserted directly between terminal flanges such as 8 at the ends of the connecting waveguide system 9.

Extending across the narrow dimension within guide 10, at a location between one narrow wall and the longitudinal center line of the guide section, is a post shaped element 11 of magnetically polarizable material of the type which exhibit gyromagnetic properties at microwave frequencies. Suitable materials will be referred to in this specification as gyromagnetic materials, the more completely descriptive phrase given above being implied

in all cases. Included in this class of materials are ferromagnetic materials including the spinel ferrites and the garnet-like yttrium-iron compounds. One particular gyromagnetic material suitable for use as element 11 in the present invention comprises aluminum substituted yttrium iron garnet having a saturation magnetization of 400 gauss, line width of 100 oersteds and a dielectric constant of 15.

Gyromagnetic element 11 is subjected to a polarizing magnetic biasing field directed along its axis and therefore transverse to the longitudinal axis of guide 10 and parallel to the narrow guide walls. Suitable means for producing the field may comprise permanent magnets 13 recessed in the thickened wall of guide 10 above and below element 11. Alternatively, element 11 may itself be permanently magnetized. The strength of the applied field is adjusted to a value which is approximately that necessary to saturate element 11 but less than that necessary to cause element 11 to become lossy from gyromagnetic resonance. In accordance with usual practice a small air gap 12 can be left at one end of post 11 and the magnetic field completed through a return path structure shown as 14.

It is well known that with this degree of bias and in the location described, element 11 is exposed to circularly polarized magnetic fields of the propagating wave and presents different effective permeability values to this wave energy propagating in opposite directions through guide 10. For one propagation direction, the effective permeability is less than unity and wave energy is repelled by the element so that the electric field intensity in the guide on the side opposite from element 11 is large. For the opposite direction of wave propagation, the effective permeability is greater than unity, and wave energy is attracted into the element and the electric field intensity in the guide on the side opposite from element 11 is small.

In accordance with one aspect of the invention, these effects are both enhanced by proper choice of the cross sectional dimension of ferrite post 11 and its spacing from the nearer narrow wall. In general it appears preferable that the diameter of a post of circular cross section should be in the order of one-half wavelength calculated within the gyromagnetic material and taking into account its dielectric constant. Post 11 need not be of circular cross section, but for other shapes, its dimensions must be empirically determined. Having selected the diameter and with a magnetic field sufficient to saturate it, post 11 is adjusted transversely across the guide until the position producing the lowest standing wave ratio for both directions of propagation is obtained. In general this location as measured from the nearer narrow wall is in the same order as the diameter of the post itself. While applicant does not intend to be bound by the following theory, field probing experiments tend to indicate that when the foregoing conditions are met, two distinct conditions of resonance exist. For the forward direction of propagation there is a resonance at the cross section of the post in which substantially all energy is within the material of the post itself. An electric field minimum exists on either side of the post in the same transverse cross section as the diameter of the post. For the reverse direction of propagation most of the field is outside of the post and a condition of resonance exists between the guide narrow walls, not unlike the phenomenon known as cutoff, in which the direction of wave propagation is more or less perpendicular to the guide walls. These two vastly different wave field patterns have not only different electric field intensities in a given region but also vastly different wave impedances in the same region for waves propagating in opposite directions through the region.

In accordance with a further aspect of the invention, a particular dissipative assembly 18 is disposed in the above-described region, matched and tuned so that it

couples strongly and repeatedly to the reciprocating fields for the backward direction until these fields are dissipated. Having been matched in its impedance to the backward wave, assembly 18 is thereby substantially uncoupled from the forward traveling wave of different wave impedance and small field strength as compared to the backward wave parameters.

To perform these particular functions dissipative assembly 18 comprises a shorted resonant and lossy coaxial stub, matched to the reverse propagating wave in the guide by extending the stub through one wide wall of guide 10 on the opposite side of the longitudinal center line of the guide from post 11 but on the same transverse cross section as post 11. While the less clearly defined field patterns on the same side of the longitudinal center line as the post can be used, this results in a more crowded structure. More particularly, assembly 18 includes outer conductor 15 and inner conductor 16 having one end of each extending into guide 10 and connected together by shorting member 17 at the other ends thereof. For reasons to be specified hereinafter, inner conductor 16 extends beyond the end of conductor 15 in guide 10.

Thus the structure includes three principal variables comprising the distance from short 17 to the conductive boundary of guide 10, the distance from the boundary to the end of outer conductor 15 and the distance from short 17 to the end of inner conductor 16. Together these parameters should be proportioned such that the resulting coaxial structure is resonant at the operating frequency and matched to the reverse wave impedance. Resonance theoretically requires an electrical one-quarter wavelength of the shorted stub. Matching on the other hand is determined by the ratio of the lengths of the outer conductor within the guide to the extending portion of the inner conductor within the guide similar to the principles described in Pat. No. 2,408,032 granted Sept. 24, 1946 to A. C. Beck. It has been found experimentally that the distance from short 17 to the end of inner conductor 16 is preferably made very nearly one-quarter wavelength. Vernier adjustments in tuning and matching are then easily made by adjusting the separate penetration of the inner and/or outer conductors into the guide. To facilitate this adjustment outer conductor 15 is provided with outside threads to be threaded into the thickened wall of guide 11 and with inside threads to receive the threaded member forming short 17 which in turn carries inner conductor 16. Members 15 and 17 are then provided with means for being twisted as shown by slots 19 in the view of FIG. 3.

The resulting resonant circuit is now suitably loaded to introduce loss. While numerous resistive structures could be introduced between outer conductor 15 and inner conductor 16 to attenuate resonant currents circulating in the coaxial cavity, the preferred structure comprises a thin cylindrical layer 20 of resistive material, such as nichrome, deposited on a hollow glass cylinder 21 which in turn surrounds inner conductor 16 and is supported from the end of outer conductor 15. Cylinders 20 and 21 therefore move together with outer conductor 15 during tuning. Alternatively, a hollow cylinder of granulated carbon or other loss material could be supported from the outer conductor 15 to surround, but not touch, inner conductor 16. The freedom of movement thus reserved for inner conductor 16 allows it to be adjusted to sharply peak the reverse direction loss.

The reduced forward losses attributed to the invention appear to stem from the limited extent of assembly 18 in the direction of wave propagation and its ability therefore to fit into the more or less restricted region of the minimum electric field of the forward direction. In this respect the invention bears sharp contrast to lossy vanes and bulk resistive material of the prior art. Further, the fact that assembly 18 is matched to the fields in the reverse propagating wave configuration results in its be-

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ing greatly unmatched to fields in the forward propagation configuration. This adds one further degree of decoupling in the forward direction. Finally, by comparison to the reciprocating fields of the reverse direction, the forward direction fields are exposed to the slim profile of assembly 18 during only a single pass through guide section 10.

An illustrative embodiment of the invention designed to operate in the 4 GHz. frequency range has the following significant dimensions. The section of rectangular waveguide has inside dimensions of 1.15 x 2.29 inches. A gyromagnetic post having the composition defined above has a diameter of 0.57 inch and is spaced from the nearer narrow wall by 0.57 inch to achieve a voltage standing wave ratio of 1.07. The outer coaxial conductor penetrates 0.15 inch into the guide as measured from the guide conducting boundary. The short is located 0.75 inch from the end of the inner conductor. When the short and inner conductor are tuned together for optimum reverse loss, a reverse loss substantially in excess of 30 db is obtained with a forward loss of only 0.15 db over a bandwidth of 25 MHz. The physical length of the isolator need be only long enough to contain the post of given diameter.

What is claimed is:

1. A nonreciprocal transmission structure for electromagnetic wave energy in a given frequency range comprising a section of conductively bounded rectangular waveguide having a pair of wide walls and a longitudinal dimension that is no greater than one-quarter wavelength of said wave energy, a member of magnetically polarized gyromagnetic material disposed within said section on one side of the longitudinal center line thereof, a coaxial structure having an outer conductor and inner conductor extending through one wide wall in said section, said

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coaxial structure being shorted to that length for which it is resonant in said given range, and lossy material surrounding at least a part of said inner conductor.

2. The structure of claim 1 wherein said member of gyromagnetic material forms a post extending substantially between said wide walls and wherein said coaxial structure is located on the other side of said center line from said member.

3. The structure of claim 2 wherein said coaxial structure and said member of gyromagnetic material are centered on the same transverse cross section of said guide.

4. The structure of claim 1 wherein said outer conductor is of length shorter than said inner conductor.

5. The structure of claim 4 wherein said lossy material comprises a cylindrical extension of said outer conductor.

6. The structure of claim 5 wherein said lossy material comprises a thin film of resistive metal deposited upon a cylinder of glass.

7. The structure of claim 4 wherein means are provided for separately adjusting the penetration of said inner and outer conductors into said guide.

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