NEW EDGE-GUIDED MODE ISOLATOR USING
FERROMAGNETIC RESONANCE ABSORPTION

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Abstract

A new edge-guided (E.G.) mode isolator has been proposed, in which nonreciprocal attenuation is obtained with the ferromagnetic resonance absorption caused by a strong d.c. magnetic field applied locally at one side edge of the ferrite microstrip line. Dominant forward and backward E.G. modes, which show nonreciprocal resonance attenuation, have been proved theoretically. Besides, a practical E.G. mode resonance isolator, which has an octave bandwidth, has been successfully developed.

Introduction

Since Hines' first investigation [1], the edge-guided (E.G.) mode isolator has been constructed by loading a resistive element on one side edge of the microstrip line on a ferrite slab. However, lately, K. Araki, T. Koyama and Y. Naito [2] presented an E.G. mode isolator in which an edge of the ferrite microstrip is short-circuited to the ground. It has a simple structure without lossy materials, but the bandwidth is not so large.

This paper proposes a new type wideband E.G. mode isolator, in which nonreciprocal attenuation is obtained with ferromagnetic resonance absorption. Instead of a resistive element, a local d.c. magnetic field, that is enough to cause ferromagnetic resonance, is applied along one edge of the line conductor.

Experimental result on new E.G. mode isolator

Experimental construction of the isolator reported here is shown in Fig. 1(A). A d.c. field is applied almost uniformly on the ferrite substrate by an electromagnet and is strengthened and distributed locally by a fringing field around a thin iron plate placed along one edge of the line conductor. A forward wave travels without attenuation along the edge where the field is weak. However, a backward wave travels along another edge, where the field is strong, and suffers attenuation due to the ferromagnetic resonance absorption.

In general, the bandwidth of a resonance isolator is narrow. In the present case, disadvantage is improved by distributing the local d.c. field. The frequency where the resoance absorption occurs is distributed, therefore, the bandwidth is widened. An experimental isolator performance is shown with solid lines A in Fig. 2. A fairly wideband characteristic over 4~7 GHz is obtained. Polycrystalline pure YIG substrate, whose saturation magnetization is 1800 Gauss, is used. An almost uniform d.c. field of 1800 Oe is applied.

In further experiments, one side edge of the center conductor, where a strong local field is applied, is short-circuited as shown in Fig. 1(B). In this case, the center conductor is a short-open boundary stripline, while a conventional center conductor is an open-open type stripline. Even in the short-open type stripline case, similar E.G. mode resonance isolator performance is obtained, as shown with solid lines B in Fig. 2. The fact that isolation level is raised higher may originate from concentration of r.f. magnetic field along the shoted edge. Dotted line B' indicates performance without an iron plate for focusing d.c. magnetic field. This is the isolator proposed by K. Araki et al.. The bandwidth is expanded remarkably by strengthening the local d.c. field with iron plate.

Model analysis in resonance isolator

In order to prove theoretically the nonreciprocal E.G. mode propagation along ferrite striplines, including those shortcircuited at one side edge, locally strong transversal variation of internal d.c. magnetic field and magnetic loss of ferrite substrate have been taken into consideration.

Figure 3 shows the internal field assumed here. The area under the line conductor is divided transversely into two regions, where internal fields are individually uniform. In each region, TE modes, with field components Ez, Hx and Hy, propagate. Short or open boundary condition is applied at each side of the line. Then, the tangential component would be equalized on the boundary plane between regions I and II. As a result, secular equations are obtained as follows;

Short-open case:

$$\left\{\frac{C}{B}P_1\frac{\cos P_1}{\sin P_1}+\frac{K_1}{\mu_1}K\right\}\cdot\left\{\frac{C}{A}P_2\frac{\cos P_2}{\sin P_2}+\frac{K_2}{\mu_2}K\right\}-\mu_{e2}\left(W^2-\frac{1}{\mu_1}K^2\right)=0 \qquad (1)$$

Open-open case:

$$\left\{\frac{C}{B}\cdot P_1\frac{\cos P_1}{\sin P_1}+\frac{K_1}{\mu_1}K\right\}\cdot\left\{W^2-\frac{1}{\mu_2}K^2\right\}+\left\{\frac{C}{A}\cdot P_2\frac{\cos P_2}{\sin P_2}-\frac{K_2}{\mu_2}K\right\}\cdot\left\{W^2-\frac{1}{\mu_1}K^2\right\}=0 \qquad (2)$$

where, $$\omega^2\varepsilon_0\varepsilon\mu_{e1}\equiv(\omega/V)^2\mu_{e1}=K_y^2+K_{x1}^2 \qquad (3)$$

$$(\omega/V)^2\mu_{e2}=K_y^2+K_{x2}^2 \qquad (4)$$

Suffixes 1 and 2 indicate regions I and II, respectively and μ, K= tensor permeability elements

$\mu_e=(\mu^2-K^2)/\mu$, $B=C-A$, $W=\omega C/V$, $K=K_yC$, $P_1=K_{x1}B$ and $P_2=K_{x2}A$

Propagation constants of any mode are obtained numerically on the complex plane with frequency as a parameter. Attenuation induced by magnetic loss can be determined from the imaginary part. Assuming a C-band isolator, typical values of the parameters are taken up for the computation: Saturation magnetization is 1800 Gauss, relative permittiveity is 14, and internal field in regions I and II are zero and 1.44 KOe, respectively.

Figures 4 and 5 show the dispersion relations of E.G. modes along the shot-open type stripline and their transversal variation of amplitude of the r.f. electric field, respectively. Similar figures have been obtained for the open-open type as well. Figure 6 shows the dispersion relations for the open-open type. From these results, it has been found that the mode 1 electric field concentrates at the interface between regions I and II. This mode propagates in the +y direction with large attenuation at 6 GHz frequency. On the other hand, the mode 2 r.f. field concentrates at the edge of region I. This mode propagates with small attenuation over almost all of the frequency range. This property corresonds clealy to the E.G. mode reported by Hines. Thus, dominant modes which consitute the E.G. mode resonance isolator, are recognized as modes 1 and 2.

The asymptotic frequency, where mode 1 suffers large absorptive loss, has been derived to coincide approximately with the resonance frequency of effective permeability of region II, for both short-open and open-open stripline. From the practical point of view cut-off frequencies of the first higher order mode have also been computed as a function of several design parameters.

E.G. mode resonance isolator characteristics

A practical E.G. mode resonance isolator has been successfully developed. The short-open type stripline, which is 10mm in length and width, has been used in the center portion between input and output tapered lines. The isolator case size (exclusive of connectors) is 60 × 38 × 19 in mm. Performances of the isolator are shown in Fig. 7. Isolation loss greater than 25 dB and insertion loss less than 1.0 dB are obtained over the 4 to 8 GHz frequency band in the -10°C +60°C temperature range. Input and output return loss is greater than 18 dB within the band.

Conclusion

A new type of edge-guided mode isolator, which makes use of ferromagnetic resonance absorption in the ferrite substrate, has been investigated theoretically and experimentally. The isolator will be useful in microwave circuits for its simple construction and wideband characteristics.

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References

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2 K. Araki, T. Koyama and Y. Naito, "New edge guided mode devices", Dig. of Tech. Paper, 1975 IEEE MTT-S Int. Microwave Symp. Polo Alto, pp. 250-253, May 1975.

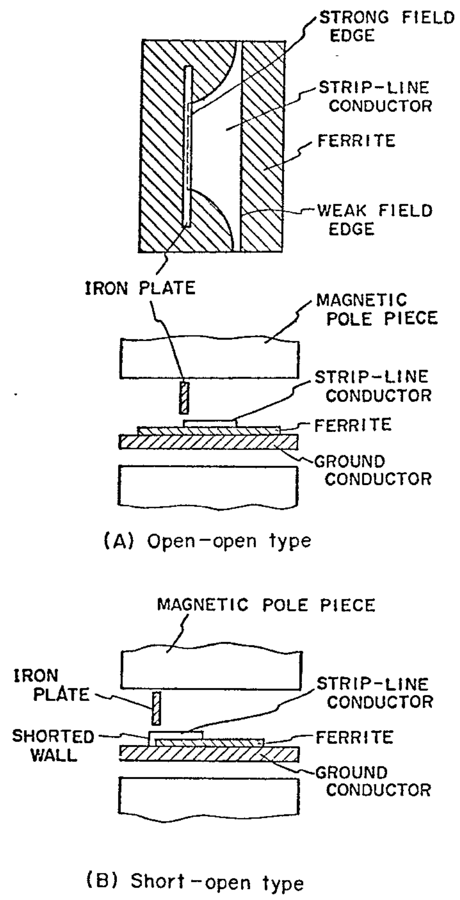

Fig. 1 Experimental ferromagnetic resonance E.G. mode isolator setup.

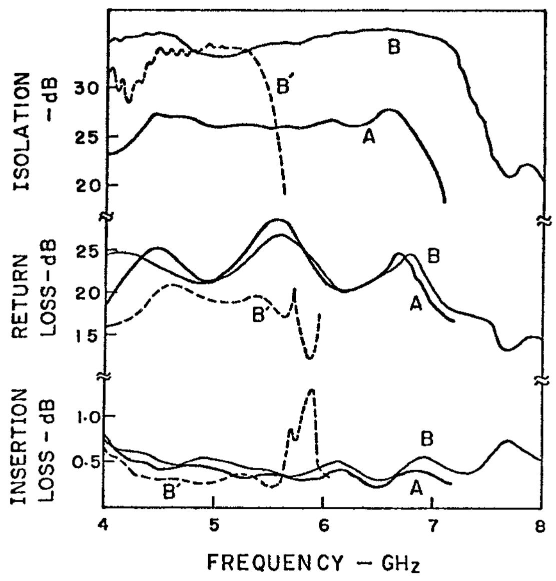

Fig. 2 E.G. mode isolator performances
A: Open-open type , B: Short-open type ,
B: Short-open type without the iron plate .

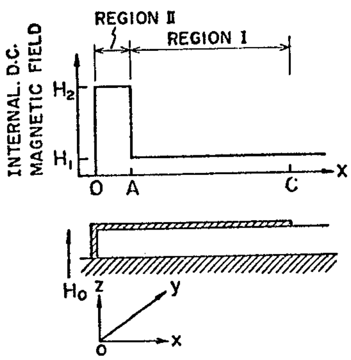

Fig.3 Internal field model and coordinates system for analysis.

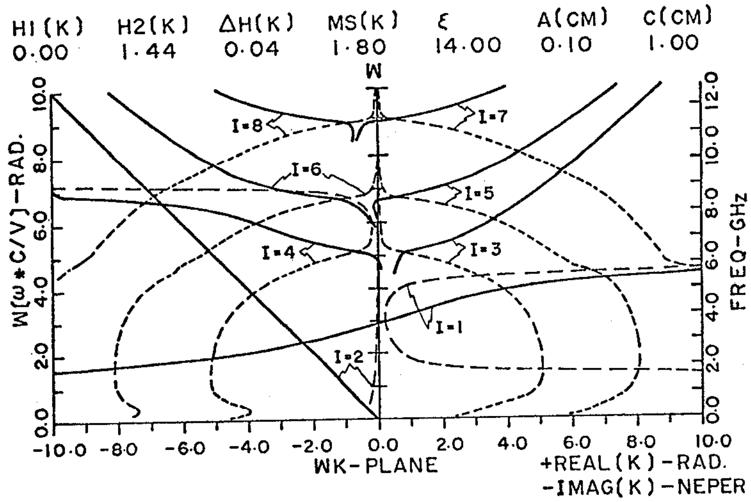

Fig. 4 Dispersion relations of several lower order modes along the short-open type stripline.

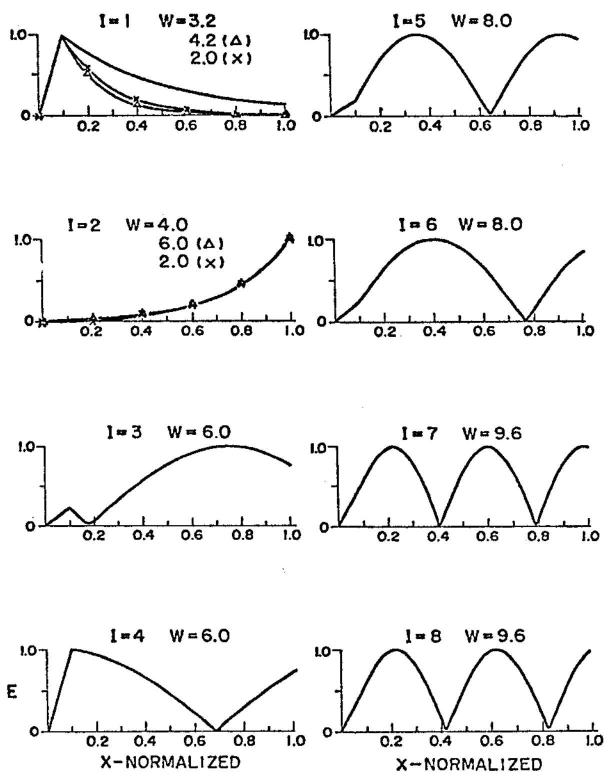

Fig. 5 Transversal r.f. field variation of each mode along the short-open type stripline.

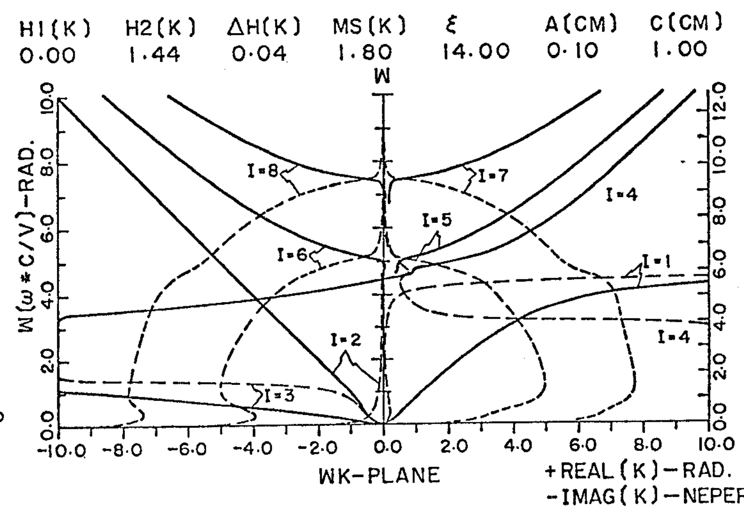

Fig.6 Dispersion relations of several lower order modes along the open-open type stripline

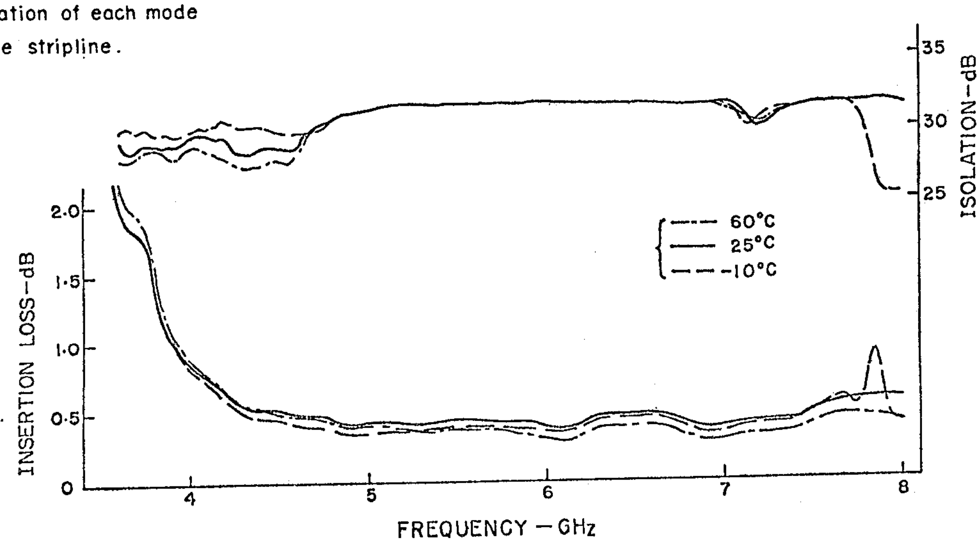

Fig.7 4~8GHz frequency band E.G. mode resonance isolator performance thoughout a -10°C~60°C temperature range.