NEW EDGE GUIDED MODE DEVICES

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Abstract

New type edge guided mode devices that are isolator and quasi-circulator, are proposed. The new type isolator has some desirable characteristics; (a) a large isolation and a small insertion loss, (b) simple structure without electric lossy materials, (c) considerable wide frequency band. On the other hand, the quasi-circulators have the following scattering matrix. These isolations are very large compared to the usual circulators.

$$\begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix}$$

1. Introduction

It has been initialy shown by M.E.Hines that an edge guided mode (E.G.MODE) of propagation occurs in a wide microstrip transmission line using a ferrite slab magnetized perpendicular to the ground plane. And he applied this principle of nonreciprocal wave propagation to isolators, multi-port circulators and nonreciprocal phase shifters.[1]

Since then, several authors have discussed the characteristics of this mode and improved the E.G.mode isolator. The conventional E.G.mode isolator has a very wide band about 2 octaves, but untill now a ratio of backward loss to forward loss is not so large as desired.

We have been also engaged to improve the E.G.mode devices. Here, we would like to propose a new type E.G.mode isolator and a version of the E.G.mode circulator which we will call as quasi-circulator.

2. New type E.G.mode isolator

The circuit structure of this isolator is shown in Fig.1. One edge of a wide strip is shorted to the ground plane, and there are no electric lossy materials in this circuit. Tapered line sections are inserted between the wide strip section in order to suppress the reflection due to the change in characteristic impedance of this trnsmission line.

In spite of using no lossy materials, our type isolators have a large isolation. Their available frequency range is considerably wide, and approximately equal to a range in which μeff<0. Substantially, ferrite losses are used also in this isolator, as ina gyromagnetic resonance type, but at the gyromagnetic resonance frequency, both forward loss and backward loss are very large and an available frequency range for this isolator exists in above resonance. So, our type isolator is slightly different from a gyromagnetic resonance type, and quite different from a conventional E.G.mode isolator that is classified into a feild displacement type.

2.1 Experimental Results

Typical experimental results is shown in Fig.2,3 and 4. For a narrower line width of this transmission line, forward loss is increasingly large. And the longer the length of the shorted section is, the larger backward loss is. Reflection coefficients at input and output are small about -15 to -20 dB. Above $\omega_2(=\omega i+\omega m)$ and below ωi where μeff>0, the difference between forward and backward loss is not large.

The upper and lower limits of the available frequency range are nearly equal to ω_2 and $\omega_1(=\sqrt{\omega_i(\omega_i+\omega_m)})$, respectively.

2.2 Analysis

[Forward loss] The "open-open" boundary line is a symmentrical structure so that forward wave and backward wave can exist for any mode. But, the "open-short" boundary line shows an unidirectional propagation. Especially, the only propagating mode is the E.G.mode for μeff <0. Its propagation constant is given by eqs. (1)(2).

$$\beta = \mu/\kappa\alpha\coth(\alpha a) \qquad (1)$$

$$\beta^2=\alpha^2+\omega^2\mu eff\varepsilon \qquad (2)$$

The attenuation constant of the E.G.mode in the "open-short" line due to ferrite loss, is calculated in Fig.5 and corresponding to the experimental value of the forward loss.

[Reflection at the discontinuity] The E.G. mode of ferrite stripline is completely displaced to the one edge, which depends on the propagation direction and the D.C. magnetic field. So, it is understandable that a reflection at the discontinuous junction where the "open-open" boundary line (tapered sections in Fig.1) is connected to the "open-short" line, is very small when the "open edge" is continuous along the line and the R.F. field of the E.G.mode is concentrated at this "open edge". This case is called as a forward direction. In the other case, where the R.F.field comes to the "short edge", it may be expected that a large reflection occurs. But fortunately, there occurs a very small reflection, and almostly the same as for forward direction. This is also confirmed by numerical analysis.

The modal expansion method were used in numerical analysis. The incident wave is the E.G.mode of the "open-open" line. The reflected wave and the transmitted wave are expanded by the modes in the "open-open" line and the "open-short" line, respectively. The continuity of the electric and magnetic field at the junction, determines the expansion coefficients.

$$Ez0(x)+\sum_{n=0}^{\infty}AnEzn(x)=\sum_{n=0}^{\infty}BnE\acute{z}n(x) \qquad (3)$$

$$Hx0(x)+\sum_{n=0}^{\infty}AnHxn(x)=\sum_{n=0}^{\infty}BnH\acute{x}n(x) \qquad (4)$$

Unfortunately, there does not exist the orthogonality of the modes. Therefore, the explicit represantations of the expansion coefficients can not be obtained and the calculation is carried out by computar.

The calculated values are plotted in Fig 6.

3. New type E.G.mode circulator

The E.G.mode circulator is also wide band. For an example, M.Blane et al. showed that the E.G.mode circulator can operate from 4 GHz to 13 GHz with 20dB isolation and 1.5-2.5 dB insertion loss.[4)]

20 dB isolation is enough for the usual use of the circulator. For the use to a negative resistance amplifier, however, higher isolation is desirable, if possible.

In the present stage, the isolation of the circulator is not high enough and so an isolator is added to the one port of the circulator to obtain the higher isolation as in Fig.7. The scattering matrix of such circuit of Fig.7 will be written in the following form.

$$S_0 = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 0 \end{bmatrix} \quad (5)$$

We will propose and discuss a very simple circuit of which scattering matrix is given as eq.(5).

3.1 Fundamental and principle of new circuit

A circulator of which scattering matrix is given in eq.(6) is widely used in many devices such as reflection type amplifier, phase shifter, switch and so on.

$$S_1 = \begin{bmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \end{bmatrix} \quad (6)$$

In many cases, however, (1-3) element of the matrix in eq.(6) is not necessary to be 1. Even if it is zero, the circuit can be used for the above devices and it is furthermore preferable.

So, it would be considered to be worth while if the circuit of eq.(5) could be composed simply. Let's call this circuit as quasi circulator.

The new circuit-quasi circulator which we are now proposing is a modification of the new E.G.mode isolator and shown in Fig.8. This operation can be explained simply with the knowledge about the edge guided mode and our isolator.

When an incident wave at 1 (2), then it propagates along the edge a (b) and it will come out at the port 2 (3).

When an incident wave is at the port 3, however, it can not propagate along the shorted part and it is not reflected there but absorbed through the loss of the ferrite.

Therefore, very few power will come out at the port 1. This means the (1-3) element of the eq.(6) becomes very small near to zero.

3.2 Experimental results

Experiments were performed with the ferrite of $4\pi M_s$= 1310 Gauss and ΔH= 80 Oe and with the external magnetic field 2300 Oe.

Fig.9 shows the characteristics of the proposed circuit of Fig.8. Due to the great effect of the shorted part , the transmissions from port 3 to port 1, from port 3 to port 2 and from port 2 to port 1 are very small, compaired to the usual circulators.

The isolation from port 1 to port 3 is not so large as the one from port 3 to port 2 and from port 2 to port 1. This is because of the matching at port 2. This will be improved by the design of the transition from coaxial to strip line at the port 2.

These isolation values are the largest ones among so far reported, as far as the authers know.

This quasi circulator will be of great value to the negative resistance amplifier.

4. Conclusion

The propagation characteristics of the "open-short" boundary line are examined. And, as an application of a nonreciprocal propagation, new type E.G.mode isolator is proposed here. Furtheremore, the circuit of which scattering matrix is expressed in eq.(5) has been simply made through the use of the new E.G.mode isolator. These isolations are fairly large compaired to the usual ones.

References

[1] M.E.Hines; "Reciprocal and Non-Reciprocal Modes of Propagation in Ferrite Stripline and Microstrip Devices" IEEE Trans.,MTT-19 pp.442-pp.451, May 1971.

[2] P.de Santis and F. Pucci; "Experiments on the Optimization of a Novel M.I.C. Symmentrical Three-Port Circulator" IEEE PG-MTT, 1972 International Microwave Symp. Digest, pp.238-pp.240, May 1972.

[3] L.Courtois; "A New Edge Mode Isolator in the V.H.F. Range" 1974 Int. Microwave Symp. Digest, pp.286, May 1974.

[4] M.Blanc, et al.;"Etude de la Fonction Isolation Tres Large Bande Utilisant Les Matriaux Ferrite" 1st International Seminar about Microwave Ferrite, March 1972.

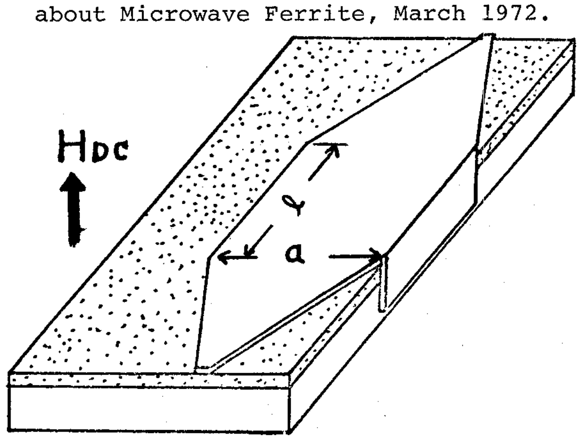

Fig.1 The circuit structure of the new type E.G.mode isolator.

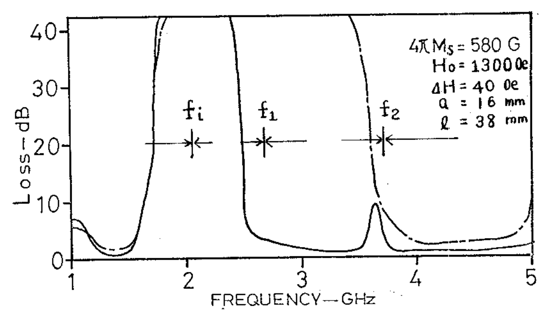

Fig.2 The characteristics of the new type E.G.mode isolator over all frequencies.

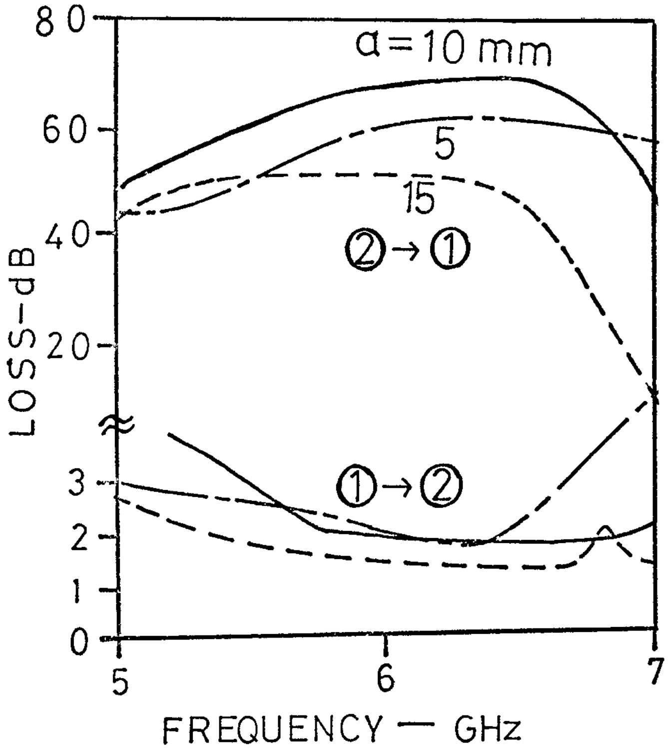

Fig.3 The transmission vs. the line width.

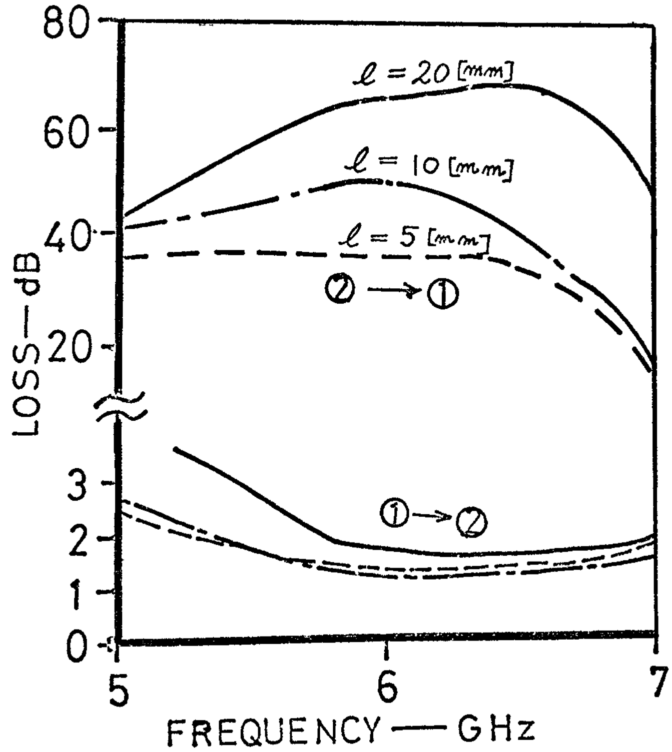

Fig.4 The transmission vs. the shorted section length.

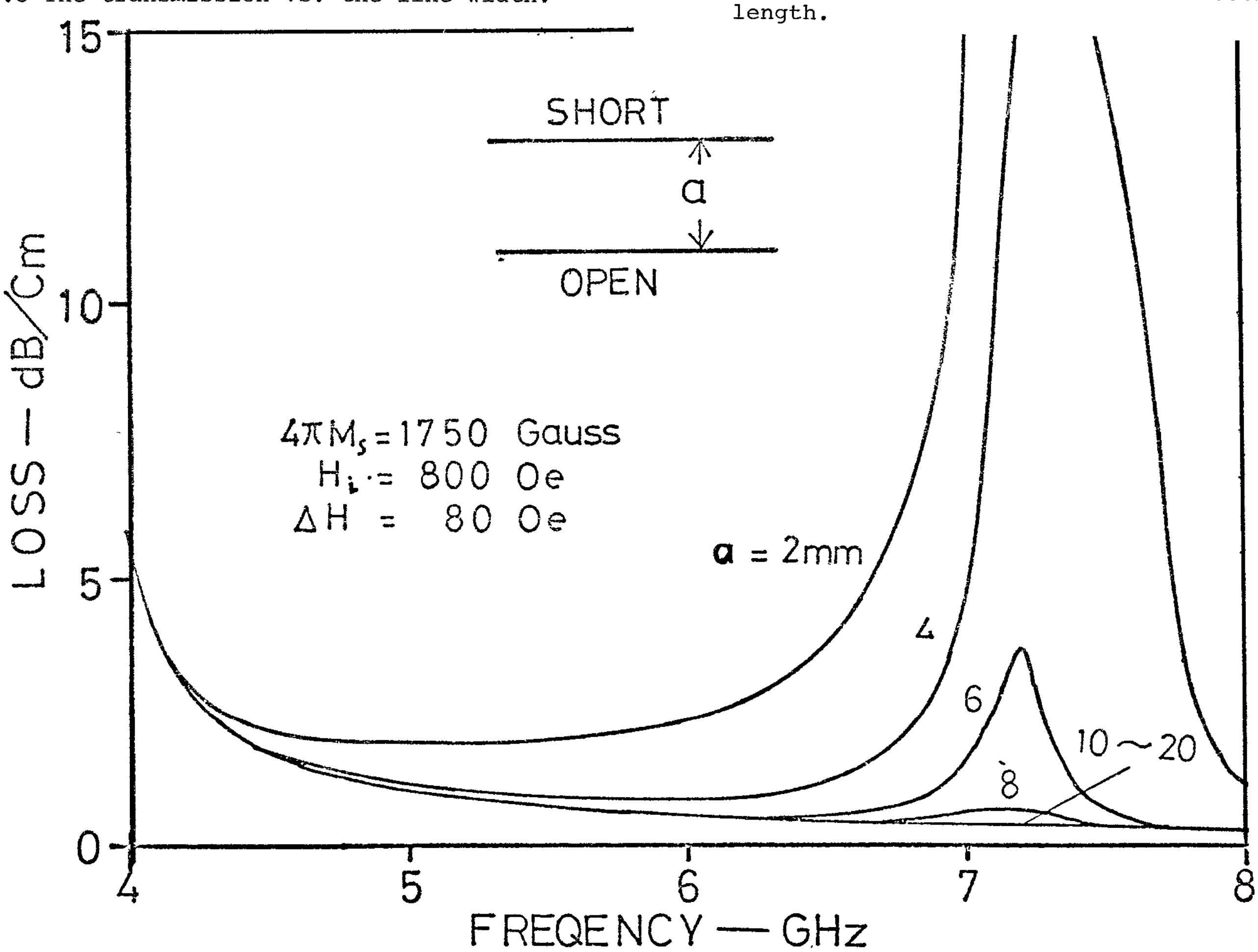

Fig.5 The attenuation constant of the E.G.mode in the "open-short" line.

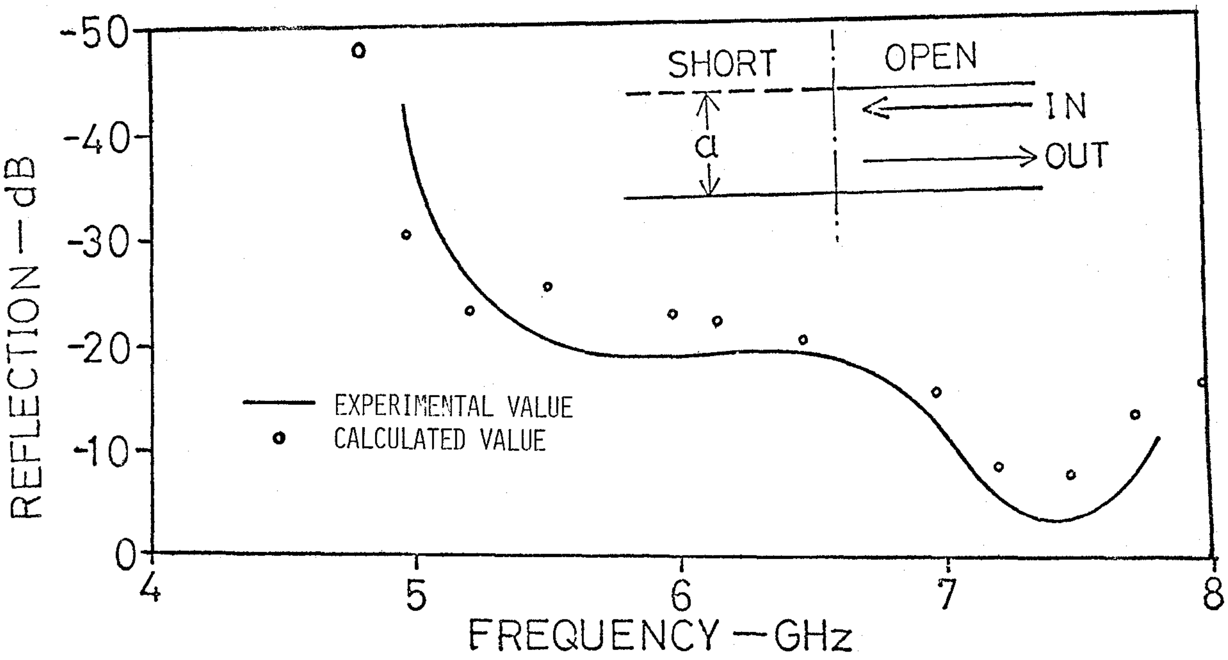

Fig.6 The reflection at the transmission line discontinuity.

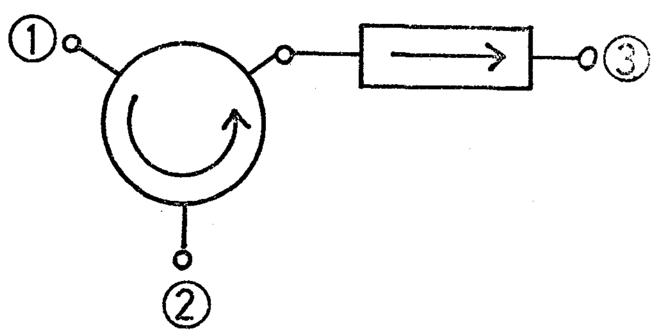

Fig.7 The microwave circuit for a reflection type amplifier.

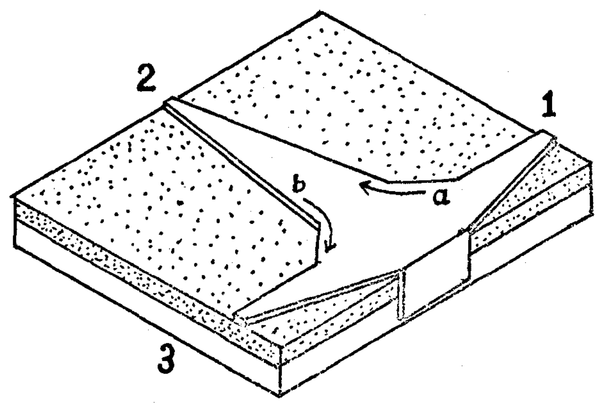

Fig.8 The circuit structure of the quasi-circulator.

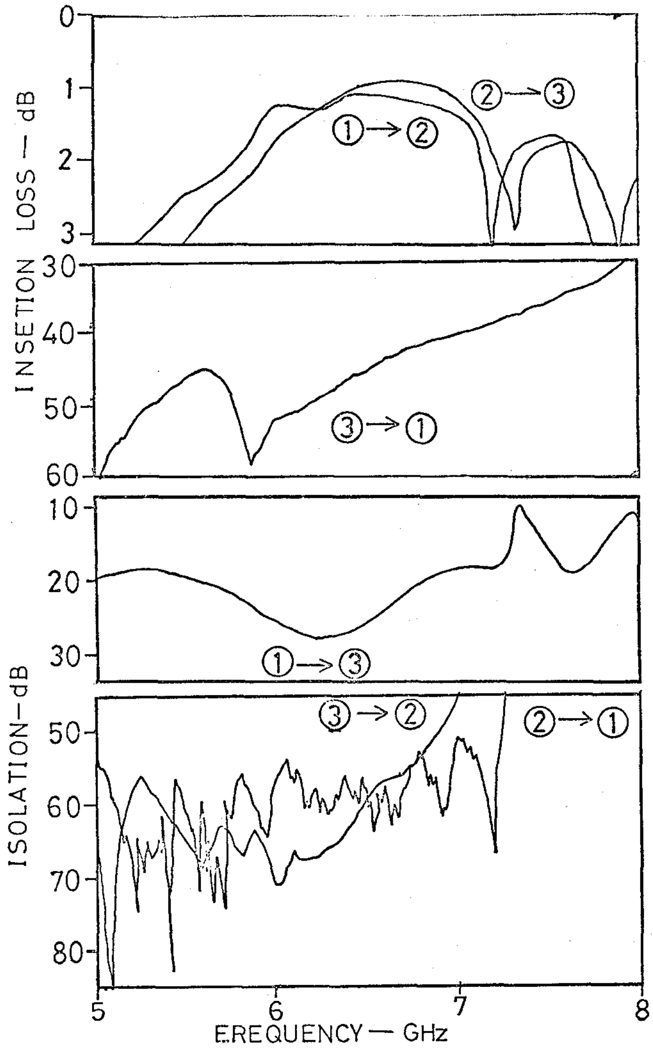

Fig.9 The characteristics of the quasi-circulator.