FERRITE TRANSMISSION DEVICES USING THE EDGE-GUIDED MODE OF PROPAGATION

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Abstract

An edge-guided mode of propagation is found in wide microstrip and stripline transmission devices using ferrite dielectric slabs magnetized perpendicular to the ground plane. The theory of propagation is reviewed, and applications of the principles are described for devices such as isolators, multi-port circulators, and phase shifters.

Figure 1 shows the fields $\overline{E}$ and $\overline{B}$ for a wide ferrite microstrip line in its "dominant" mode of propagation. These fields differ significantly from these in ordinary dielectric media. When the ferrite is magnetized vertically, the RF fields are concentrated along one edge, and the equations show an exponential decay of all field quantities in the transverse direction. In a wide line, the fields may decay to negligible values at the opposite edge. The wave may be said to be "guided" along the edge. Under some conditions, the edge may be curved and the wave will follow the curve, being "stuck" there, unable to propagate in any other way.

In a published paper [1], approximate field equations are presented in some generality. There it was shown that in the special case of a weak internal H field, but with full magnetization (assuming $H_o = 0$ and $\omega_m = -\gamma M$) the propagation constant is given by

$$\beta = \omega \sqrt{\mu_o \epsilon_o \epsilon_f}$$

and the transverse decay constant is

$$\alpha = \omega_m \sqrt{\mu_o \epsilon_o \epsilon_f}$$

for an assumed lossless ferrite material. All field quantities vary as exp $(-\alpha x - j\beta y)$ for propagation in the y direction as in Fig. 1.

For an idealized geometry, these approximate equations show no dispersion over all frequencies and a constant impedance and transverse decay rate. However, under weak fields, ferrites show high losses at low frequencies which are substantially less than ω_m.

At high frequencies the ferrite medium can propagate in other modes under a wide microstrip conductor. Thus, the bandwidth of useful devices using this mode is limited by losses at the lowest frequencies and by multi-mode propagation effects at the highest frequencies. For frequencies where $\mu_{eq} < 0$, <u>only</u> the edge guided (dominant) mode can propagate in a thin zone between parallel conducting planes. For weak internal fields, $\mu_{eq} \approx 1 - \omega_m^2/\omega^2$.

In a line of width a, the cut-off frequency for the first higher-order mode is

$$\omega_c \approx \pi/a \sqrt{\mu_o \mu_{eq} \epsilon_o \epsilon_f}$$

where $\mu_{eq} > 0$, and μ and K are the familiar elements of the permeability tensor.

Practical devices using this mode include isolators, circulators and phase shifters. Fig. 2 shows the schematic principle for an isolator. Waves from the left propagate along the lower edge of the wide line as shown. Waves from the right travel along the upper edge and are absorbed in the lossy material.

Fig. 3 shows the principle applied to a phase shifter. A high-dielectric constant ceramic along one edge causes greater phase shift for waves on that side than for waves on the opposite side traveling in reverse. Reversing the magnetization will reverse the sides of propagation and shift the phase.

Fig. 4 shows the principle applied to a four-port single junction circulator. A star-shaped center conductor guides the waves along the edge as shown from port 1 to port 2, 2 to 3, etc. Reversing the magnetic field reverses the circulation direction, 1 to 4, 4 to 3, etc.

Practical devices have been built using these principles, and these will be described in the oral presentation. Fig. 5 shows the performance of a wide-band isolator. The loss was slightly less than one db from 2-4 GHz and slightly greater than one db from 4-8 GHz. By the use of very gradually tapered transducers, an impedance match was achieved as shown, and high-order-mode effects were largely suppressed, even though these modes were not cut off in the upper part of the band. Fig. 6 shows the performance of a preliminary test model of a single-junction four-port circulator. In this device, multimode effects were evident at frequencies above ~ 3 GHz. In this material ($4\pi M_s \approx 600$ Gausses) it appears that other modes are launched when the "guiding" edge is curved in this way.

One of the most interesting applications of the isolator is the DUMA, [2], [3], a microwave diode amplifier. In this device, negative resistance diodes (such as the IMPATT diode) are coupled across one edge of the wide line, and lossy material is applied to the opposite edge. Gain is obtained for forward waves and loss for reverse waves.

References

[1] M. E. Hines, "Reciprocal and Non-Reciprocal Modes of Propagation in Ferrite Stripline and Microstrip Devices", IEEE Trans., MTT-19, No. 5, pp442-451, May 1971.
[2] M. E. Hines, "A New Microstrip Isolator and Its Application to Distributed Diode Amplification", IEEE G-MTT Symposium, Diget of Papers 1970, pp304-507.
[3] R. N. Wallace and M. E. Hines, "Distributed Unidirectional Microwave Amplification", IEEE, GMTT Int. Symposium, Diget of Paper, 1970 pp88-89.

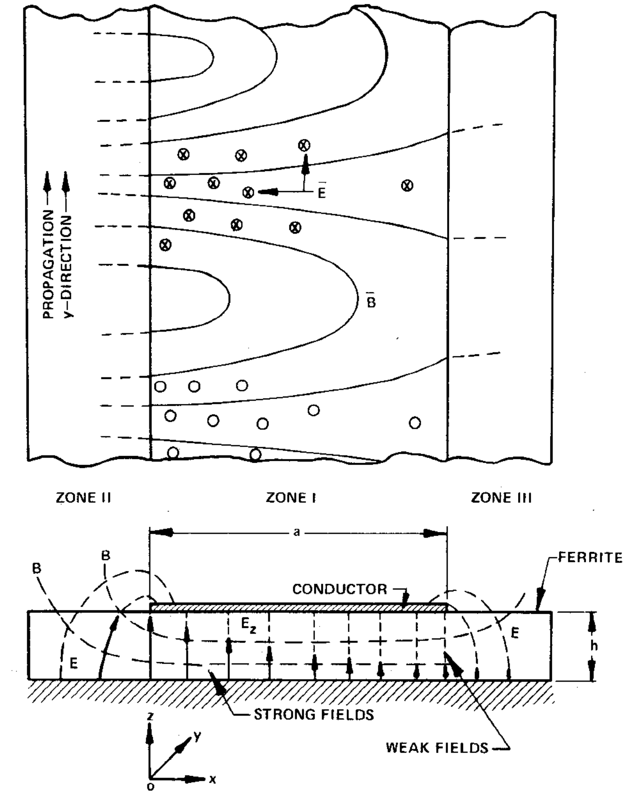

FIG. 1 MICROSTRIP LINE SHOWING RF FIELDS OF THE DOMINANT MODE. DC MAGNETIZATION IS IN THE Z DIRECTION.

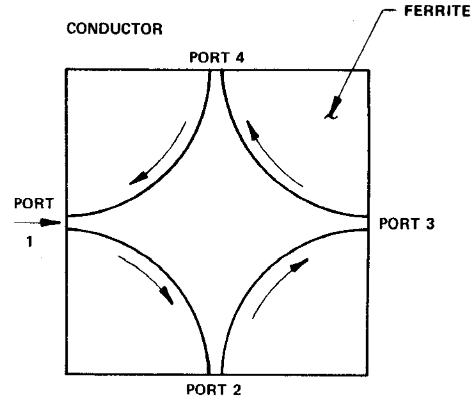

FIG. 4 FOUR-PORT CIRCULATOR USING THE EDGE-GUIDED MODE. REVERSING THE FIELD REVERSES THE DIRECTION OF CIRCULATION.

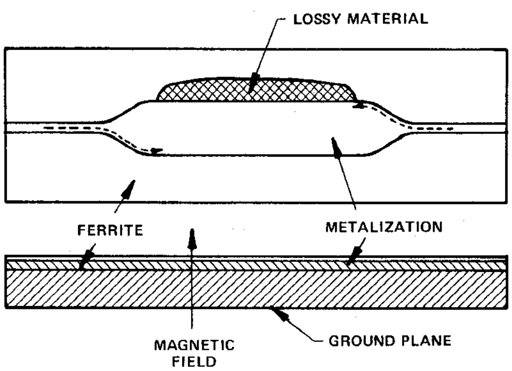

FIG. 2 LOSSY MATERIAL ALONG ONE EDGE ABSORBS POWER FROM ONE WAVE DIRECTION ONLY.

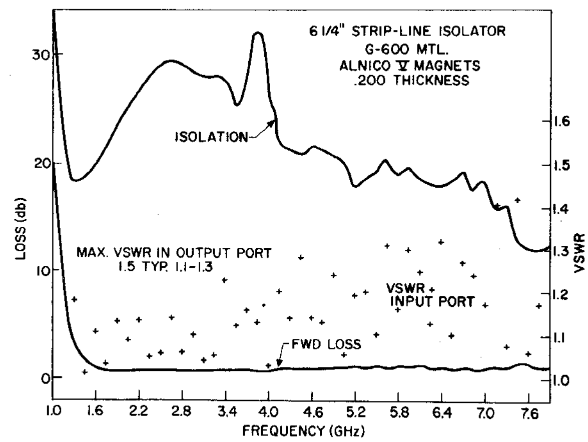

FIG. 5 BROAD BAND ISOLATOR PERFORMANCE

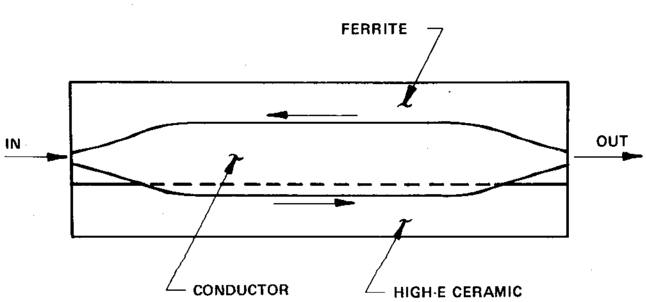

FIG. 3 PHASE SHIFT CAN BE ATTAINED BY USING A HIGH DIELECTRIC CONSTANT MATERIAL UNDER ONE EDGE OF THE WIDE CONDUCTOR. REVERSING THE MAGNETIC FIELD SHIFTS THE PHASE.

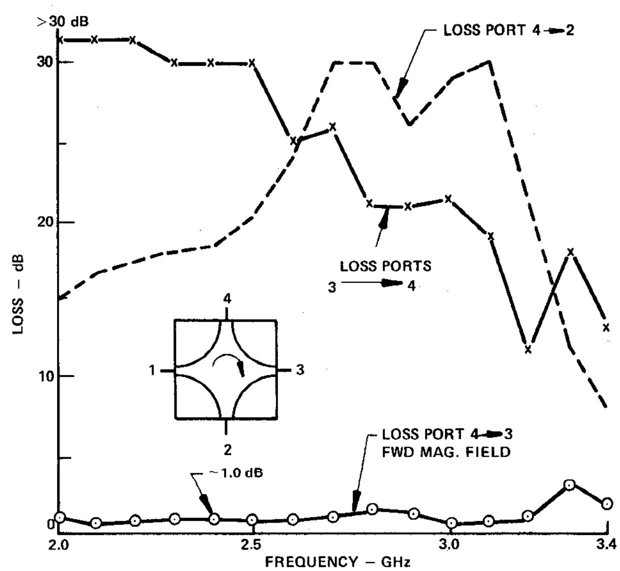

FIG. 6 FOUR-PORT CIRCULATOR PERFORMANCE