FERRITE PHASE SHIFTERS AND MULTI-PORT CIRCULATORS IN MICROSTRIP AND STRIPLINE

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Theoretical and experimental results are presented for new ferrite stripline phase shifters and new multiport microstrip circulators, utilizing the edge-guided mode of propagation.

This work is an extension of that presented at the 1970 G-MTT symposium[1], and recently published[2]. The new devices utilize the "edge-guided mode" of propagation in wide ferrite stripline and microstrip lines. We described here a new phase shifter and some experiments with multiport circulators.

The basic principle of the edge-guided mode in a ferrite microstrip is shown in Fig. 1. Here we show a line with a wide region in the central section and tapered impedance transformers in and out. When vertically magnetized, RF energy is concentrated along one edge for one direction of propagation and along the other edge for the opposite direction. An isolator is made by resistively loading one edge in the wide region. Nonreciprocal phase shift is obtained by reactively loading the two edges in an unsymmetrical way. Multiport circulators can be made by coupling stubs to the edge of the wide line or by tapered curved transitions as illustrated in Fig. 6. The device has also been utilized for unidirectional diode amplification[1,3].

Fig. 2 illustrates a stripline phase shifter using this principle. Here, one edge of the line protrudes into air dielectric for a narrow zone. The other edge is capacitively loaded by serrating the conductor with fine comb teeth. When the wave is concentrated along the low-dielectric side, the phase velocity is high. When along the serrated side, the capacitive loading slows the wave, giving greater phase delay.

Fig. 3 shows data for the phase shift as a function of magnetic field, here taken as the current in the magnetizing coil. Three different frequencies are plotted for the S-band range. It is seen that the phase change with magnetic field is approximately proportional to frequency, as the change in effective "electrical length" is nearly independent of frequency. This device used Trans-Tech G-610 material, and was ~6 inches in total length, with an active zone 4.75 inches long.

A variation on this principle is shown in Fig. 4. In this stripline phase shifter, the center conductor is deposited as a thin film on one of the two substrates. This line is loaded on one or both edges with fine comb teeth of significant length, somewhat less than 1/4 wavelength. Phase shift and magnetization are controlled by passing DC current through the RF center conductor. The magnetic circuit is closed except for a minute air gap between the two ferrite slabs, which are separated only by the thin film conductor. Thus, latching is possible through the remanent flux lines which encircle the center conductor.

Fig. 5 shows experimental data for an X-band device. This used two 1.0 inch long ferrite substrates, each .025" thick. For this data, a current of two amperes was first passed in one direction. Then current pulses were applied in the opposite direction with progressively increasing amplitude, up to two amperes. The phase during each current pulse is shown, and the remanent or "latching" phase shift when the current was reduced to zero, between successive pulses. This device is undesirably dispersive, but, has the advantages of simplicty, small size, and low driving energy. It is expected to be switchable at high speed.

It has also been found that a circulator can be "introduced" along the edge of a wide microstrip line. A branch microstrip line brought up perpendicular to the edge can, in particular ways, be "matched" so that a wave approaching along the edge may be taken out, or a new wave inserted via this branch line. This has been done in two ways as shown in Fig. 6. The stub may be gradually tapered into the line, or may be simply butt-connected. In the latter case, it was necessary to use a "matching" stub or transformer in the side line.

This principle of circulation requires that the wide "straight-through" line propagate only in the edge-guided mode in the frequency band of interest. If the magnetic field is uniform, it must have a value such that $\mu_{eff} = (\mu^2 - K^2)/\mu$ is negative. This is useful only over a restricted band of frequencies with most materials, but may be "tuned" by varying the magnetic field. Use of non-uniform fields has given broader band operation. The magnetic field in this case is gradually increased laterally, being more intense in the region where the lossy material is applied. This is accomplished with wedge-shaped pole pieces. Fig. 7 shows the performance curves of such a circulator.

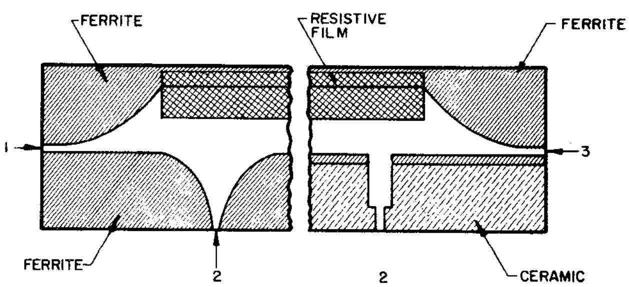

Fig. 6 Two Types of Microstrip Multiport Circulator. Nonuniform Magnetic Field was Used, Maximum in the Resistive Film Zone.

ACKNOWLEDGEMENT

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REFERENCES

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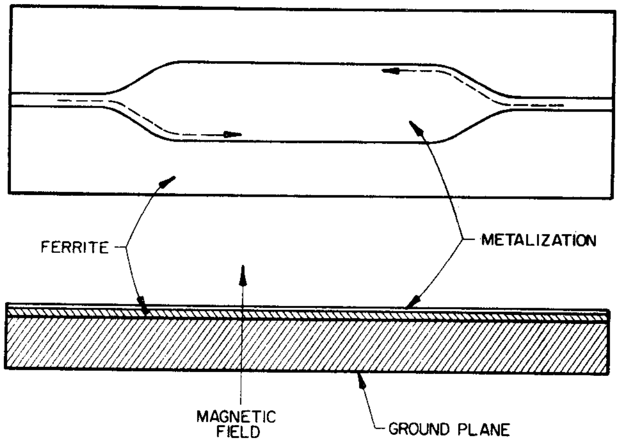

Fig. 1 Principle of Edge-Guided Wave Propagation Along Wide Microstrip Lines on a Ferrite Substrate. Energy is Concentrated Near One Edge.

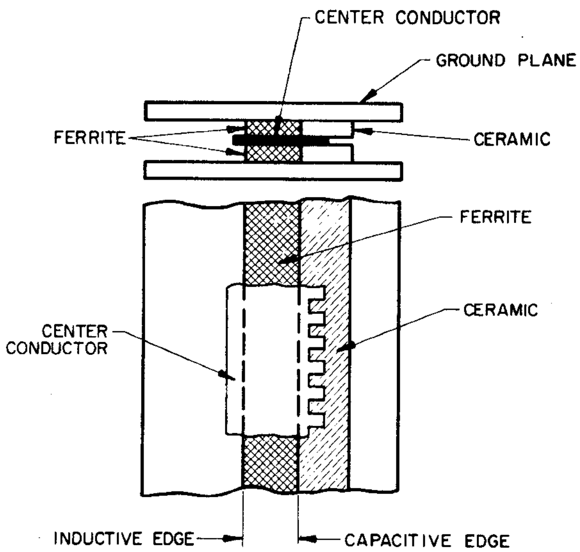

Fig. 2 Strip-Line Edge-Guided Phase Shifter.

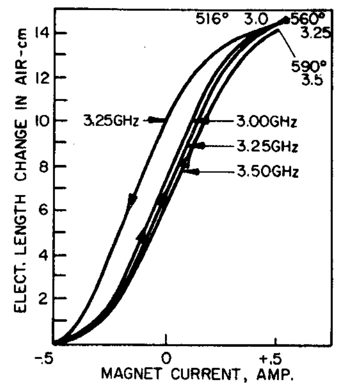

Fig. 3 Data Obtained With an Experimental S-Band Phase Shifter. Over this Frequency Range, the Change in "Electrical Length" is Plotted as the Magnetic Field is Varied. Hysteresis Effect is Largely Caused By the Steel Magnetic Structure Used.

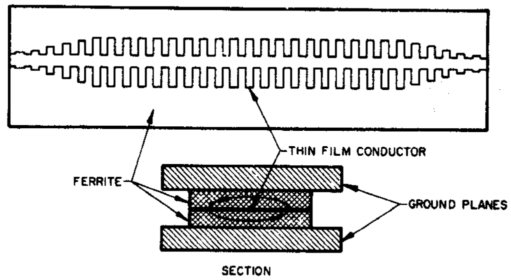

Fig. 4 "Feather Edge" Phasor. Actual Fingers are Much Narrower than Shown.

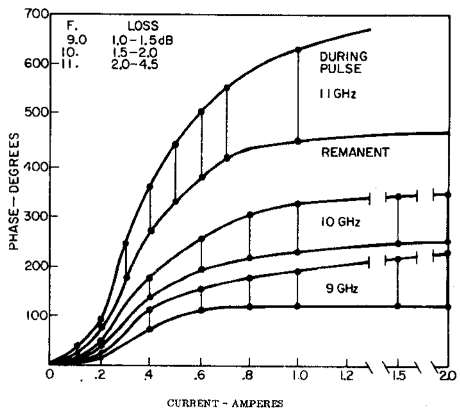

Fig. 5 Phase and Loss of X-band "Feather-Edge" Phasor.

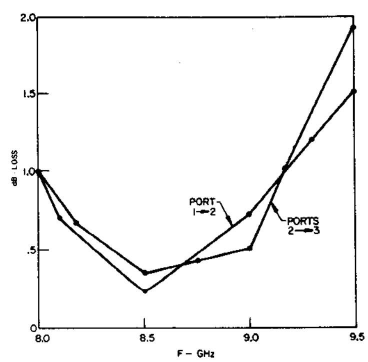

Fig. 7 Loss of Stub Type Circulator of Figure 6.