IV-7 FERRITE MICROSTRIP PROPAGATION

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The object of this program has been to evaluate the utility of ferrite microstrip devices which use externally applied magnetic fields as opposed to latched remnant fields. Although the latched devices call for less average magnetic field current, devices with externally applied fields show promise of greater figure of merit. Since Reggia-Spencer devices can achieve figures of merit in excess of 1000°/dB, it was decided to investigate the potentialities of externally magnetized devices in an attempt to increase figure of merit and bandwidth, and to reduce size and weight compared to the Reggia-Spencer device.

Propagation in ferrite-filled TEM structures can be compared to two special cases: (1) ferrimagnetic medium of infinite spatial extent, and (2) a ferrite-filled parallel plane guide. For the first case, the following expression gives the farady rotation per unit length:[1]

$$\frac{\theta}{1} = \frac{\omega\sqrt{K_e}}{2c}\left[\left(1 + \frac{\omega_m}{\omega+\omega_o}\right)^{1/2} - \left(1 + \frac{\omega_m}{\omega-\omega_o}\right)^{1/2}\right] \qquad (1)$$

This is nearly independent of frequency, and approximately proportional to ω_m/ω when we consider ω fixed. The parallel plane case is analyzed by Van Trier, who through a numerical boundary value solution for the fields, gives phase constant β approximately proportional to ω_m/ω. It was thought that ferrite microstrip should give results lying between these two special cases. The experiments did not bear this out, the microstrip phase shift being somewhat less than the parallel plane calculations.

Straight sections of microstrip circuit were evaporated in TT390 and TT101 (Trans-Tech Inc., Gaithersburg, Maryland) ferrite slabs of various thickness. Transmission resonance and guide wavelength for these samples were measured in C-band and X-band in order to establish ω-β diagrams. Wavelength measurements were taken by mounting the microstrip samples in a slotted line carriage and picking up the signal with a voltage probe.

Similar data were taken as a function of magnetostatic field applied parallel to the microstrip conductor. Resonant frequency versus external magnetic field is shown in figure 1. These curves do not follow the magnetization curves of the material (TT1-390) accurately due to the fact that the magnetization distribution through the rectangular samples was nonumiform. ω-β diagrams for a 0.020-inch and 0.012-inch copper microstrip on a 0.030-inch-thick sample of TT1-390 ferrite are shown in figures 2 and 3. At full saturation, these curves cut off ($\beta = 0$) at a frequency corresponding to $\gamma 4\pi M$, and therefore exhibit considerable dispersion in this frequency range. Similar data were obtained with a 0.020-inch microstrip on a 0.014-inch-thick ferrite.

A 3-inch-long sample of TT1-390 with 0.012-inch microstrip was matched directly to the ferrite to less than 1.4:1 from 8.2-11GHz, and tested as a phase shifter. The samples were placed in a long solenoid capable of producing fields up to about 90 oersteds, with a central uniform region of about 5 inches in length. The magnetic field distribution in the sample was estimated by using an axial-type Hall probe set adjacent to the ferrite and making use of the boundary condition of continuity of tangential field over the air-ferrite boundary. Such a field plot was uniform to within 10 percent over the central 2/3 of the ferrite length.

Figure 4 shows phase shift versus frequency with applied field, uncorrected for demagnetizing effects, as a parameter. These curves have the same general frequency dependence, as reported by Hair. Similar data were observed for 0.023-inch microstrip on 0.060-inch-thick ferrite, supporting the theory that the aspect ratio of the microstrip cross section is of prime importance. These curves are similar to those plotted by Hair.

The observed phase shifts are of the order of 50°/cm of microstrip transmission line, compared to the theoretical 129°/cm computed from equation (1) for the infinite medium with 100 oersteds applied field.

Losses were estimated by recording the resonant Q values of the microstrip samples. Coupling to the microstrip samples was continuously reduced until the resonant ransmission curves no longer narrowed. Unloaded Q's were estimated from the 3dB points of these curves. The attenuation coefficient is then given by

$$\alpha = \frac{\beta}{2Q} \tag{2}$$

Since figure of merit can be expressed as β/α in radians/neper, we can write

$$F = 13.2\, Q \frac{\Delta\beta}{\beta} \,, \tag{3}$$

giving F in units of degrees per dB. For example, from figure 2, at 9 GHz, $\Delta\beta/\beta = 0.073$, $Q \simeq 180$, and $F = 173$ deg/dB. In a later test, a phase shifter of 0.0307-inch microstrip on a 0.030-inch-thick ferrite yielded a $\Delta\beta$ of about 1 radian/cm, corresponding to a figure of merit of about 470 degrees/dB.

To account for these Q values, magnetic losses must be taken into account. The attenuation coefficient for a copper microstrip line with substrate dielectric constant $\epsilon_o \epsilon_r$, is given by

$$\alpha = \frac{7.25 \times 10^{-5}\sqrt{f_{mc}\,\epsilon_r}}{h(\text{inch})} \ (\text{dB/foot}) \tag{4}$$

For the 0.030-inch line on 0.030-inch-thick ferrite, converting to neper/cm

$\alpha = 0.0033$ neper/cm.

Setting $\beta \cong 7$, and using (2) we get

$Q = \beta/2\alpha = 1060$,

almost a factor of 10 larger than observed values. α has been estimated from an assumed magnetic loss tangent value of 0.005 to be about 0.0189 neper/cm. The corresponding Q value is 185, close to measured values.

It is interesting to compare these results with the Reggia-Spencer phase shifter[3] comprising a round ferrite rod centered in an X-band waveguide. They have recorded values of phase shift and guide wavelength for various rod diameters from which we can calculate values of $\Delta\beta/\beta$. At 9.1 GHz, $\Delta\beta/\beta$ values run from 0.059 to 0.66 for rod diameters running from 0.2 inch to 0.325 inch. The maximum $\Delta\beta$ values correspond to in excess of 100 degrees/cm phase shift per unit length, between two and three times the values recorded for the microstrip devices studied here. Thus, the difference in F must be due to some combination of conductor losses and field concentration effects.

It was thought that the metallic ground plane created a boundary condition that would tend to prevent field rotation. A phase shifter was constructed with a sheet of teflon separating the ferrite from the ground plane. Phase shift data were about 10 percent less than the case where the ground plane was in contact with the ferrite. It is therefore evident that field concentration effects predominate. Further experiments along this line will be discussed.

Since the ferrite samples are of rectangular shape, the demagnetizing field is nonuniform, and some residual magnetization and phase shift are noticed. This effect will be considered in terms of sample shape and applied field geometry.

Finally, a single period meander line phase shifter will be discussed, in which about 1000 degrees phase shift has been recorded. Preliminary data are shown in figure 5.

High power saturation effects were looked for in the case of the 0.030-inch microstrip on 0.030-inch TT1-390 ferrite. Trailing edge pulse droop was looked for for as evidence of high power saturation. The time duration prior to onset of spin wave instability should be roughly equal to $1/\gamma\Delta H_k$ where ΔH_k is the spin wave line width, which for TT1-380 has been quoted as about 3.9 oersteds. This time then about 100ns, which was looked for in 500ns X-band pulses amplified by a T.W.T. Up to 20 watts, no such effects were noticed. This experiment will be refined, and data on a variety of circuit cross section geometries presented.

1. B. Lax and K. Button, "Microwave Ferrites and Ferromagnetics" McGraw-Hill Inc., N.Y., 1962, p. 302.
2. A.A. Th. M. Van Trier, "Guided Electromagnetic Waves in Anistropic Media," Applied Science Research, Vol III B, 1953, p. 305.
3. F. Reggia and E. Spencer, Proceeding of the IRE, Vol. 45, P-1515.

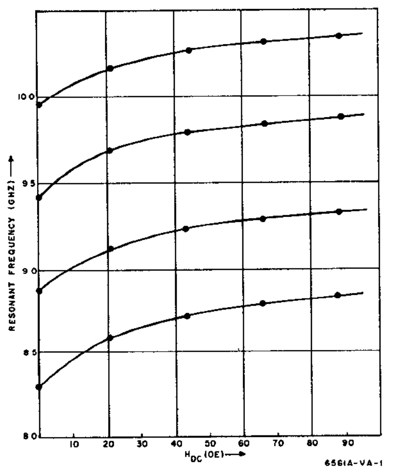

FIG. 1

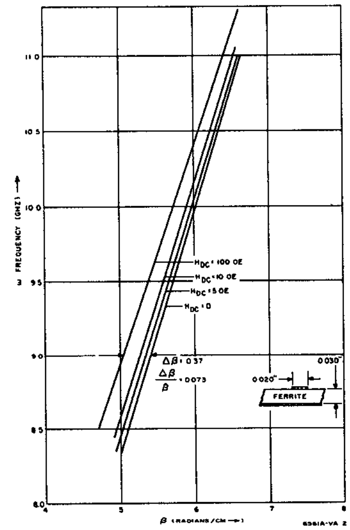

FIG. 2

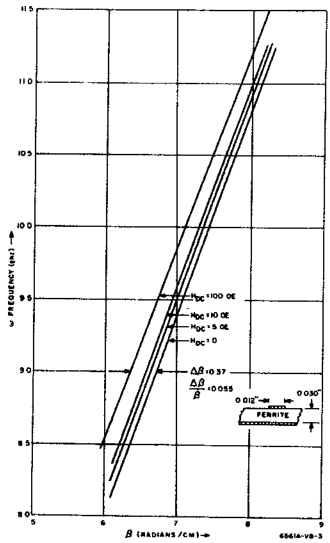

FIG. 3

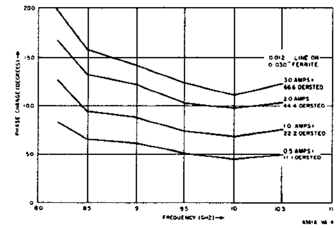

FIG. 4

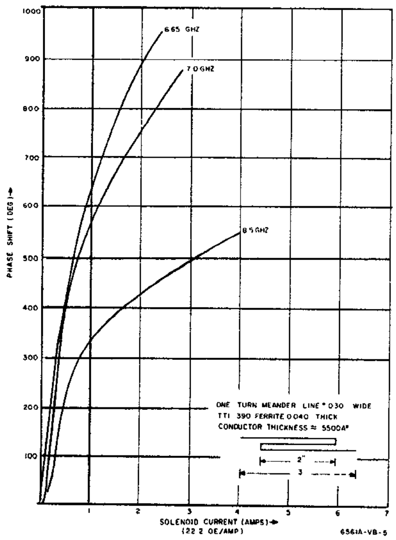

FIG. 5

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