V-1. THEORETICAL ANALYSIS OF TWIN SLAB PHASE SHIFTERS IN RECTANGULAR WAVEGUIDE*

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One of the more promising device configurations for digital ferrite phase shifters is that of a rectangular waveguide containing circumferentially magnetized ferrite toroids of suitable length (Reference 1 and 2). Such a structure is shown in Figure 1. A very similar structure, which is more readily amenable to theoretical analysis is shown in Figure 2. Here the ferrite toroid has been replaced by two oppositely magnetized slabs which extend over the complete height of the waveguide. The propagation of electromagnetic waves through waveguides of the type shown in Figure 2 has previously been analyzed by Lax et al (References 3 and 4), and by Von Aulock (Reference 5).

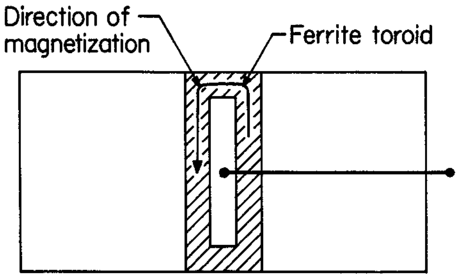

Figure 1. Phaseshifter Using Ferrite Toroid

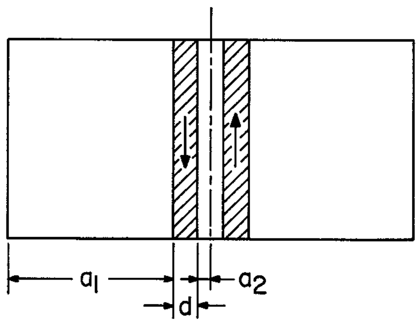

Figure 2. Phaseshifter Using Twin Ferrite Slabs

The propagation constant of the fundamental mode can be calculated from the characteristic equation. This characteristic equation is in general rather complicated. Considerable simplification can be obtained, however, by noting that in cases of practical interest the rf fields are strongly concentrated in and near the ferrite, so that the precise location of the side walls of the waveguide becomes immaterial. For the purposes of calculating the propagation constant, it is in fact frequently permissible to assume that the walls are at infinity.

The propagation constants for the two directions of magnetization have been calculated for arbitrary thickness and arbitrary but relatively close spacing of the ferrite slabs assuming that the ferrite is lossless. The results show that the differential phase shift is highest when the slabs are very close together and their thickness is approximately 1/10 of the free space wavelength, λ_o. Figure 3 shows some results for a representative set of material parameters.

If the material is lossy the propagation constant as calculated from the characteristic equation becomes complex. The attenuation constant has been calculated assuming that the two slabs touch each

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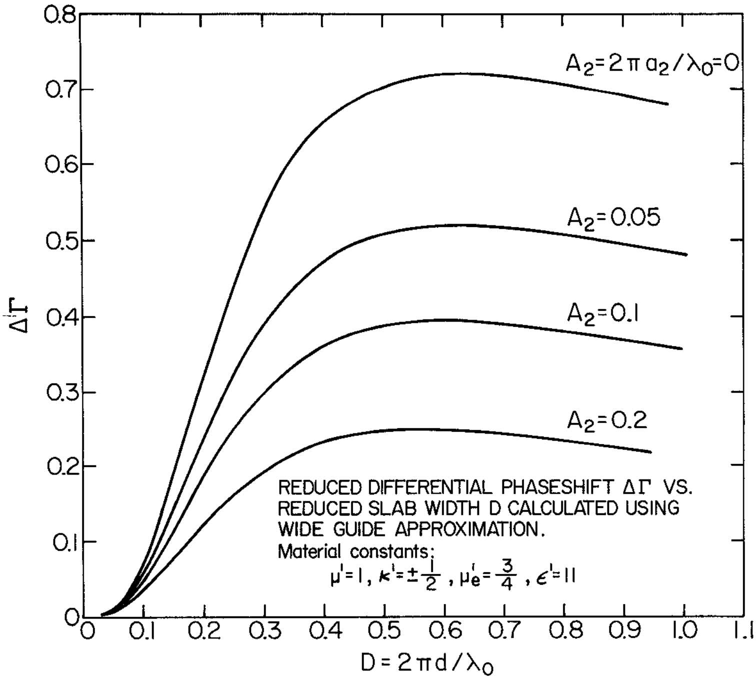

Figure 3.

other and taking only the magnetic losses into account. The calculated insertion loss of a waveguide section having a differential phase shift of 2π is plotted versus reduced slab-thickness in Figure 4, again assuming a reasonable set of material parameters. The results indicate that the lowest insertion loss for a given phase shift is realized at a slab thickness of the order of 1/25 times the free space wavelength.

The peak power handling capability of twin-slab phase shifters is limited by the onset of spinwave instability An appropriate measure of the suitability of ferrites for high power applications is given by the following figure of merit.

$$F_{hp} = \frac{\gamma^2 2\pi M h_{crit}}{\omega^2 \mu''} \tag{1}$$

where γ is the gyromagnetic ratio, ω the (angular) frequency, M the remanent magnetization, h_{crit} the critical field (as measured in a thin disc magnetized perpendicular to its plane using a linearly polarized field) and μ'' the imaginary part of the diagonal element of the permeability tensor measured at the remanence point. It can be shown on the basis of theoretical arguments that the figure of merit defined by Equation (1) cannot substantially exceed 2 unless the magnetization is very small. This has also been confirmed experimentally to some extent.

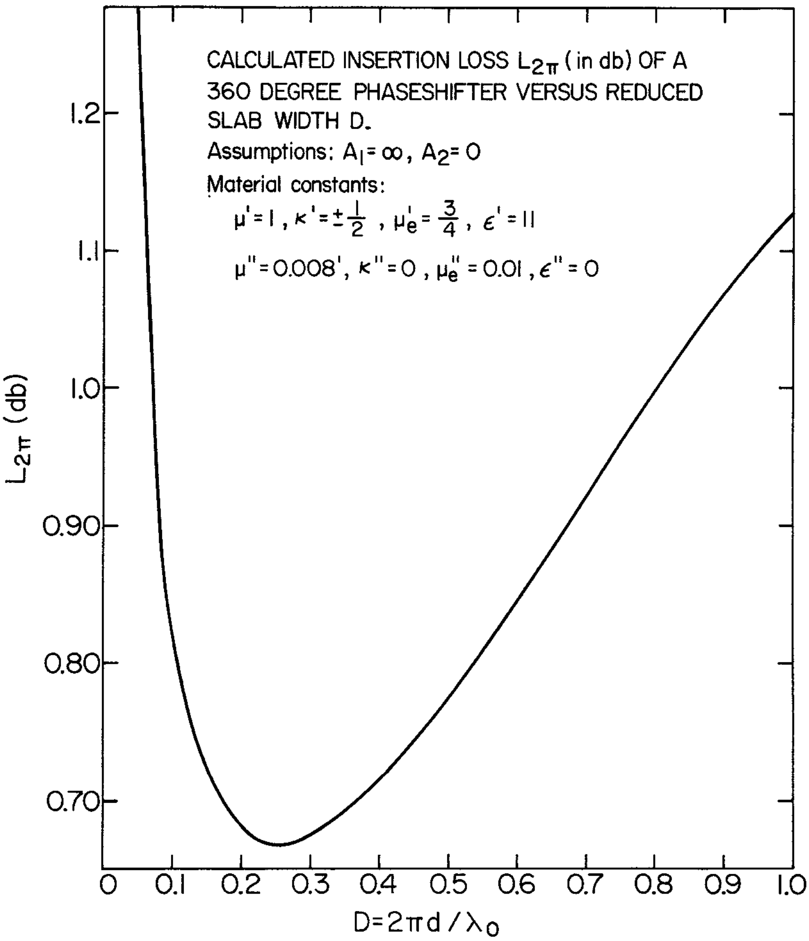

Figure 4.

The critical power level can be expressed as:

$$P_{crit} = P_o L^2_{\pi/2} F^2_{hp} \qquad (2)$$

Here $L_{\pi/2}$ is the loss (in db) of a phase shifter section having a differential phase shift of $\pi/2$. P_o depends upon the thickness of the ferrite slabs. At the slab thickness which minimizes the insertion loss (for given phase shift) P_o is approximately 4 Mw for full height waveguide. This estimate assures that the dielectric constant equals 11 and that the two oppositely magnetized slabs are in close contact. For finite spacing between the slabs P_o is likely to be somewhat smaller.

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