THE EDGE GUIDED MODE NONRECIPROCAL PHASE SHIFTER

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Summary

Results of a theoretical study are presented for a model of non-reciprocal dielectric-ferrite loaded stripline phase shifter employing the edge guided dynamic mode.

One of the fundamental structures which support the edge-guided mode is a ferrite loaded stripline with the d.c. magnetic biasing field oriented normal to the ground plane. This geometry, since its introduction by Hines[1] has been explored extensively by a number of authors with the objective of obtaining broad band non-reciprocal isolation.[2-4]

In this short paper we present the results of a theoretical study of the differential phase shift and insertion loss for a parallel plate model with a ferrite region loaded on one side by a dielectric slab of high permittivity while on the other side of the ferrite, and on the far side of the dielectric slab, we have free space or regions of relatively low permittivity (Figure 4).

The structure supports a multiplicity of modes with the primary one being the field displaced dynamic mode which relates directly to the no-cut-off mode for the isotropically loaded stripline. In addition, a magnetostatic mode is observed in the range of frequencies where the effective permeability is negative but it suffers field displacement in the opposite sense to that of the dynamic mode.

Courtois has discussed some experimental and theoretical results obtained using a parallel plate model containing up to two ferrite regions terminated on one side by a dieletric region and on the other by a magnetic wall, i.e., an infinite impedance boundary condition.[5]

Calculations were performed for a material with a saturation magnetization of 1780 Gauss and a resonant line width of 45 Oersteds while the internal d.c. magnetizing field was taken to be 200 Oersteds. The dispersion characteristics, and particularly the differential phase shift, were examined as a function of the width of the ferrite and the width and relative permittivity of the dielectric region. Also of interest is the frequency at which the onset of the first higher order mode occurs since this will limit the effective bandwidth of the device unless provision is made to suppress this mode. The range of values of the parameters for which these various device attributes were examined were: width of the ferrite region from 1 to 10 mm, width and relative dielectric constant of the dielectric region from .1 to 5 mm. and 4 to 95, respectively. The optimum device would be non-dispersive, i.e., a linear ω-β characteristic for both β_+ and β_-, low and equal attenuation constant for both directions of propagation and thus also constant differential phase shift as a function of frequency. The operation of the device depends on electrical asymmetry which is attained through structural asymmetry. This means that for one direction of propagation significant energy is carried by the ferrite region while for the reverse direction the dielectric region plays the major role.

The most promising results were obtained for relatively narrow ferrite regions and for dielectric regions with a permittivity value which lies substantially above that of the ferrite. Some results illustrating the device performance as a function of the permittivity of the dielectric region are shown in Figures 2 and 3. It is evident that increasing the dielectric loading increased the differential phase shift but substantially reduced the bandwidth of the device while at the same time increasing the insertion loss. Decreasing the loading to $\varepsilon_d \approx 16$ will yield 60 degrees differential phase shift per cm with deviations of approximately ±2 degrees over the entire X band and with an associated insertion loss of less than .05 db/cm in the forward direction and less than .1 for the reverse direction. However the upper end of the X band is not available due to the onset of the first higher order mode at 10.9 GHz.

Inspection of the field distribution confirms that at the low end of the band, for the case ε_d = 96 where the field displacement effect is maximum, the dominant part of the energy is concentrated at the left hand side of the ferrite slab with a substantial fraction carried by the lossless region where $\varepsilon_1 = 1$. As the frequency is allowed to increase the effective permeability is less negative, the field displacement is weaker, and a more substantial part of the energy is carried by the region of high dielectric constant. As a result, a greater part of the energy is contained within the ferrite region and the differential phase shift increases but also the loss increases considerably. At still higher frequencies the dielectric region becomes dominant and most of the energy is carried there with the result that losses decrease rapidly as does the differential phase shift. For dielectrics with lower permittivity the same effect is observed but is moderated. When we reach a permittivity of the dielectric about equal to that of the ferrite, the losses are almost uniform over the band while the differential phase shift varies little over almost an octave.

In Figure 4, the width of the ferrite is halved while the width of the dieletric region is also reduced so as to increase the cut-off of the higher order modes. We observed that for a relative dielectric constant of 32 cut-off is well above X band and a a differential phase shift of 73 degrees (±3°) gives us an operating band from approximately 8 GHz to 13 GHz. Allowing ±5° phase deviations gives a bandwidth from 7.5 to 14 GHz or almost an octave. The insertion loss in the forward direction increases from .02 db/cm to about .13 db/cm and for the reverse direction it decreases monotonically from a high of .10 db/cm at the low frequency end of the band to about .04 db/cm. Decreasing the relative dielectric constant to 24 causes the differential phase shift to drop to 60°/cm (±5°/cm) over the X and Ku bands and leads to insertion losses of less than .03 db/cm in the forward, and .07 db/cm in the reverse direction. Suppression of the next higher order mode would extend operation into the K band and yields an octave and a half of bandwidth for an allowed phase deviation of ±5°/cm.

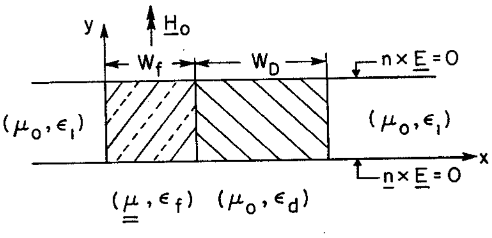

Figure 1. Model Geometry

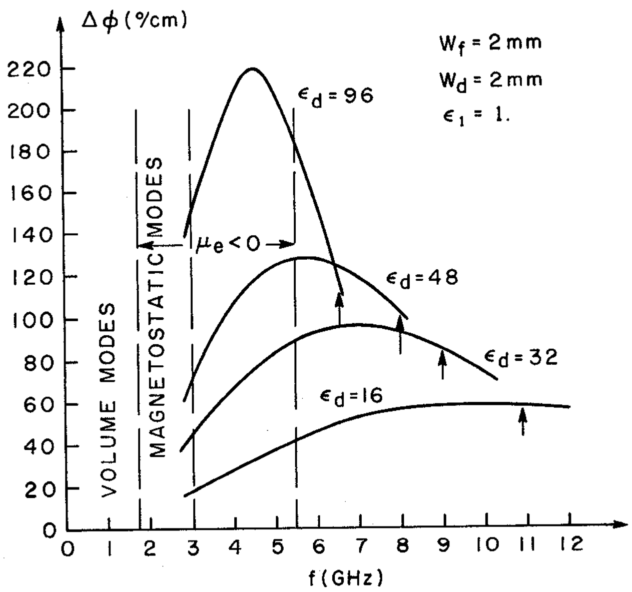

Figure 2. Differential phase shift as a function of frequency for a ferrite material of $4\pi M_s$ = 1780G., ΔH_0 = 45 Oer., ε_f = 15, with H_0 = 200 Oer., ε_d variable and ε_1 = 1. Ferrite width 2mm., dielectric width 2mm. Arrows indicate onset of first higher order mode.

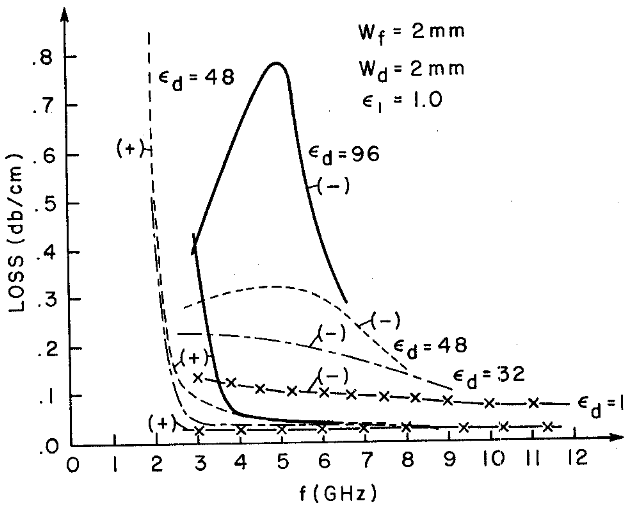

Figure 3. Insertion loss as a function of frequency. (Parameters as for Figure 1.)
——— ε_d = 96, -------- ε_d = 48
-·-·-·- ε_d = 32, ×—×—× ε_d = 16.

(-) and (+) indicate direction of propagation associated with insertion loss characteristic.

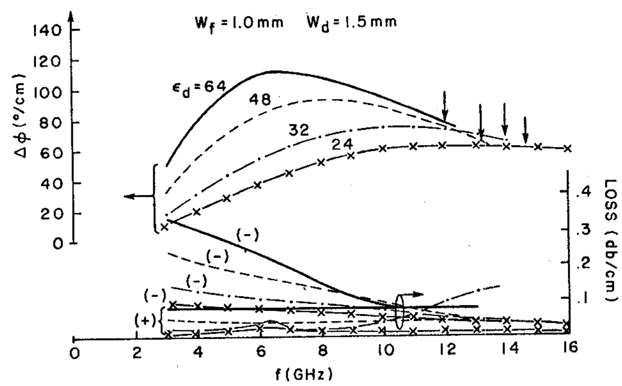

Figure 4. Differential phase shift and insertion loss for reduced width ferrite and dielectric sections. Electrical parameters as for Figure 1.
——— ε_d = 64, - - - - ε_d = 48,
·-·-·-·- ε_d = 32.

References

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