THE EDGE GUIDED MODE ON FERRITE LOADED STRIPLINE

Donald M. Bolle
Division of Engineering
Brown University
Providence, RI 02912

Abstract

The dispersion characteristics and modal structure of the edge guided or peripheral mode on ferrite loaded striplines are described as a function of the various electrical and geometric parameters.

Introduction

Since the introduction by Hines[1] in the late 1960's of devices utilizing the field displacement effect on the ferrite substrate microstrip line, considerable effort has been expended by workers in the United States as well as France[2], Italy[3] and Japan[4] on extending the analysis beyond an approximate heuristic treatment and in pursuing further the promising broad band behavior of devices based on the edge-guided mode.

Furthermore, a debate concerning the relationship between the edge-guided mode and other mode types, particularly surface modes, has been joined.

To resolve this debate, in part, this paper will present some basic results for surface modes on a ferrite-dielectric interface and will compare these results to those obtained for the edge-guided modes of the ferrite loaded stripline.

A study was made of the geometry shown in Figure 1a which shows two parallel perfectly conducting planes separated by a distance d and loaded for x>0 by ferrite and for x<0 by dielectric. Of interest to us is the nature of the surface modes that may exist on the ferrite-dielectric interface.

The next phase of the analysis consisted of considering the ferrite loaded stripline shown in Figure 1b. The assumption was made that the width of the strip be such that interaction between the strip edges could be ignored. This consideration plus the implicit symmetry of the stripline led to the canonical structure shown in Figure 1c, where we have a conducting ground plane at y=0 and a semi-infinite conducting plane at y=d for x>0. For these surfaces the boundary condition $\underline{n}\times\underline{e}=0$ pertains, whereas for the surface y=d, x<0 the condition $\underline{n}\times\underline{h}=0$ holds.

A study of the modes existing on the ferrite-dielectric interface of Figure 1a and the modes which occur on the structure given by Figure 1c will allow discrimination between modes characteristic of the ferrite-dielectric interface and the mode types to be associated with the edge of the stripline.

Theory

Figure 1 shows the basic geometries to be considered in this paper. The ferrite loaded regions are shown hatched and will be subjected to a d.c. biasing field oriented normal to the ground plane. In this case the field components are most conveniently expressed in terms of e_y and h_y which satisfy coupled p.d.e.'s.

Following Van Trier[5] the p.d.e.'s are decoupled generating a pair of scalar potentials. All field components are expressed in terms of these potentials. In the dielectric regions the same procedure is followed except that here the p.d.e.'s are not coupled. For the ferrite region we obtain expressions of the form:

$$e_y = \sum_{n=o}^{\infty}\left[a_n e^{-\alpha_{1,n}x_o} + b_n e^{-\alpha_{2,n}x_o}\right]\cos \delta_n y ,$$

$$-jh_y = \sum_{n=1}^{\infty}\left[a_n\zeta_n e^{-\alpha_{1,n}x_o} + b_n\xi_n e^{-\alpha_{2,n}x_o}\right]\sin \delta_n y ,$$

where

$$\zeta_n = \frac{\kappa}{1+\chi}\,\delta_n/D_+ ,$$

$$\xi_n = \frac{\kappa}{1+\chi}\,\delta_n/D_- ,$$

$$D_\pm = \frac{1}{2}(\gamma_{1,n}^2 - \gamma_{2,n}^2) \pm \left[\frac{1}{4}(\gamma_{1,n}^2 - \gamma_{2,n}^2)^2 + (\frac{\kappa\delta_n}{1+\chi})^2\right]^{1/2} ,$$

and

$$\delta_n = n\pi/k_f d, \quad e^{+j(\omega t - \beta z)},$$

where

$$\gamma_{k,n}^2 = 1 - \frac{\delta_n^2}{1+\chi} , \quad \gamma_{2,n}^2 = 1 + \chi - \frac{\kappa^2}{1+\chi} - \delta_n^2 ,$$

$$x_o = k_f x , \quad k_f = \omega\sqrt{\varepsilon_f}/c , \quad \eta_f = \eta_o/\sqrt{\varepsilon_f} ,$$

$$\underline{h} = k_f\,\eta_f\,\underline{H} , \quad \underline{e} = j\,k_f\,\underline{E} .$$

The approach taken was to write harmonic functions satisfying the necessary boundary conditions at y=0 and y=d in the ferrite and dielectric regions, respectively. The remaining unknowns are then obtained through insisting on the continuity of the tangential electric and magnetic field intensity components across the interface at x=0. Four sets of linear equations are obtained in the case of Figure 1c. These are manipulated to yield a determinantal equation which, upon solution, yields the dispersion relation for the structure. In the case of Figure 1a this process gives a trancendental equation which may be readily solved to yield dispersion data as well as the field structure.

Results

Figure 2a and 2b shows two typical results obtained for the geometry of Figure 1a. Surface modes exist whenever the effective permeability $\mu_o[1+\chi - \kappa^2/(1+\chi)]$ is negative. In the case of Figure 2a the lowest order mode ($N=0$, $\frac{\partial}{\partial y} = 0$) covers the C band for $4\pi M_s$ = 1750 Gauss and H_{dc} = 1000 Oersteds. The response is shifted to the X band upon increasing the saturation magnetization to 4250 Gauss and the d.c. bias to 1400 Oersteds. It is to be observed that substantial differential phase shifts become available in the upper part of the band.

The modes are bidirectional but non-reciprocal.

Figure 3 illustrates typical field distributions as these pertain to the parameters of Figure 2a. It may be noted that the energy tends to be excluded from the ferrite when the effective permeability is large and negative but gradually shifts into the ferrite region as the effective permeability increases and approaches zero. The broken lines in Figure 2a show the limits of the regions within which surface modes are to be found. Figure 4 illustrates the results obtained for the next higher order surface mode (N=1). The parameters used here were $4\pi M_s$ = 1750 Gauss and H_{dc} = 0 → 2000 Oersteds. Note that in this case modes exist except in those regions where the permeability $\mu_o/\overline{(1+\chi)}$ is negative.

Let us compare these results to results obtained for the canonical stripline structure.

Figure 5 shows some typical results for a structure where d = .5mm, $4\pi M_s$ = 4250 Gauss and H_{dc} = 0 → 3000 Oersteds (ε_f = 16., ε_d = 1.0). It is immediately evident that propagating modes exist only when the effective permeability $\mu_o[(1+\chi) - \kappa^2/(1+\chi)]$ is negative. Furthermore, the modes are uni-directional. These modes exhibit, therefore, the observed characteristics of the edge-guided peripheral mode on the microstrip. These results were obtained using expansions containing eight coefficients. This leads to a matrix equation of 16×16 where each of the entries within the matrix was summed to twenty terms. Convergence of the results was tested and a typical example of a 'worst case' is shown in the table.

N	PMAX	β rads/mm
8	20	-6.044
12	30	-6.308
12	50	-6.428
16	60	-6.434

A maximum error of 5% in the results was accepted so that the size of the determinant used in the dispersion calculations could be restricted to 16×16.

It is to be pointed out that Figure 5 gives only the lowest order modes. In each case higher order modes do occur. Figure 6 illustrates a typical example of the disperson characteristics for the higher order modes. The field structure of the four lowest order modes was obtained at the intersections of the broken line with the dispersion curves. The results are shown in Figures 7. Displayed are the field components tangent to the ferrite dielectric interface as a function of the y coordinate. Two points can be made: first, the edge-guided modes do form a hierarchy. This is clearly evident in the e_z component, for example. Secondly, the broken curves are the results of calculations applicable to $x=0^-$ while the solid curves were obtained from the expansions for $x=0^+$. Readily observed is the accuracy with which the boundary conditions at the interface are met for a sixteen term expansion of the field components. The Fourier series, as expected, is not adequate to the representation of the singular behavior at the guide edge located at x=0, y=d (= .5mm). Using the same electrical and geometric parameters that were used to obtain the results displayed in Figure 6, the behavior of the lowest order mode as a function of the dielectric constant of the region x<0 was investigated. The results obtained for a variation of relative dielectric constant from 1 to 64 are shown in Figure 8.

Conclusion

Using harmonic function expansions the edge-guided mode on ferrite loaded stripline was rigorously modeled and compared with the surface modes on a ferrite-dielectric interface. The canonical geometries were so chosen that the only difference in the two structures was the occurence of the edge in the former case.

It was concluded that the only similarity between the modes obtained for the two structures is that for the lowest order surface mode (N=0) the effective permeability is the same as for the edge-guided mode and both are band limited over that region where the effective permeability is negative. The behavior of the next higher order surface mode is not mirrored in the higher order edge-guided modes. We must conclude that no direct relationship exists between the two mode types and that the edge-guided or peripheral modes form a distinct hierarchy. The observed effective permeability is the one that occurs whenever an electromagnetic field propagates through ferrite subjected to a d.c. bias field oriented normal to the direction of propagation.

The bandwidth of the edge-guided mode is limited by the frequencies $F_1 = \sqrt{F_o(F_n+F_m)}$ and $F_2 = F_o+F_m$, where $F_o = \gamma H_{dc}$ and $F_m = \gamma 4\pi M_s$. ($\gamma \cong$ 2.8GHz/KGauss). However, the mode becomes highly dispersive towards the upper end of the band -- thus, to cover the X band parameter, representative values of $4\pi M_s$ = 4250 Gauss and H_{dc} = 1400 Oersteds were chosen and yield F_1 = 7.875GHz and F_2 = 15.82GHz.

References

1. M. E. Hines, "Reciprocal and nonreciprocal modes of propagation in ferrite stripline and microstrip devices", IEEE Trans. MTT, Vol. MTT-19, No. 5, pp. 442-451, May 1971.

2. L. Courtois, et al, "Propagation dans une lame de ferrite aimantee: Application a de nouveaux dispositifs non-reciproques a large bande", Cables et Telecommunications, No. 4, pp. 417-435, October 1973.

   L. Courtois, et al, "A new edge mode isolator in the u.h.f. range", 1974 IEEE International Microwave Symposium Digest, Atlanta, June 12-14, 1974.

3. P. deSantis, "Edge guided modes in ferrite microstrip with curved edges", Applied Physics, Vol. 4, No. 2, pp. 167-174, August 1974.

4. K. Araki, et al, "A new type isolator using the edge-guided mode", IEEE Trans. MTT, Vol. MTT-23, No. 3, pp. 321, March 1975.

5. A. A. Th. M. Van Trier, "Guided electromagnetic waves in anisotropic media", Appl. Sci. Research, Vol. 83, p. 305, 1953.

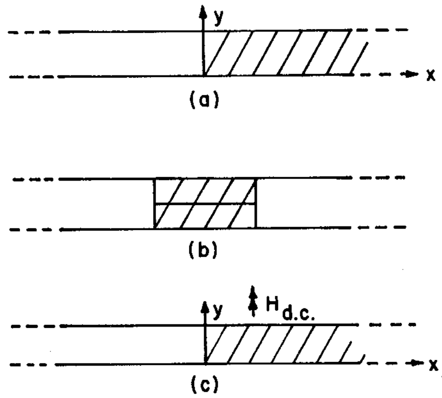

Figure 1.

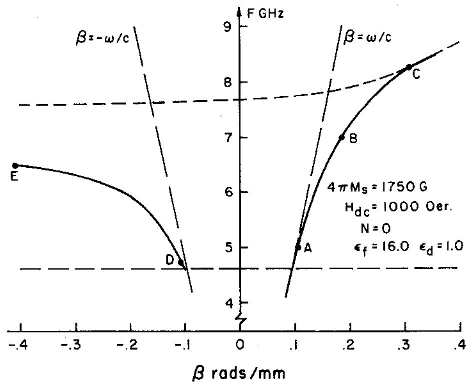

Figure 2(a).

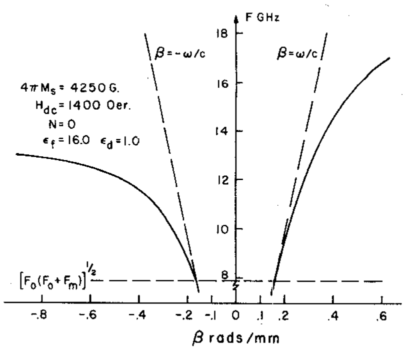

Figure 2(b).

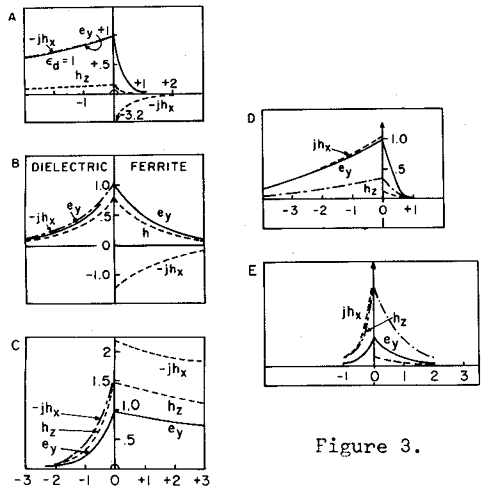

Figure 3.

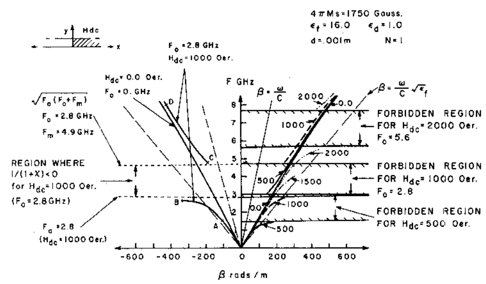

Figure 4.

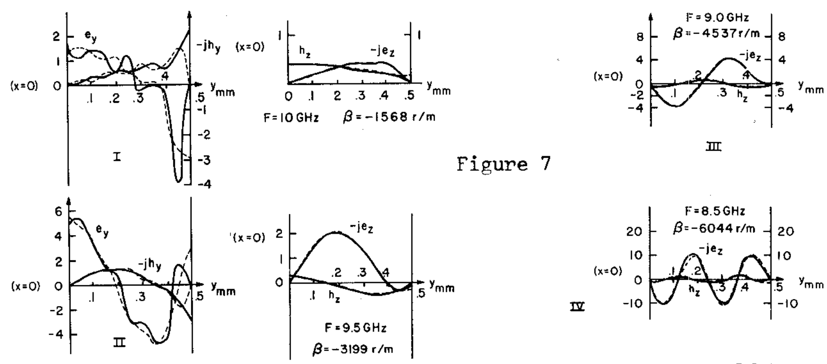

Figure 7

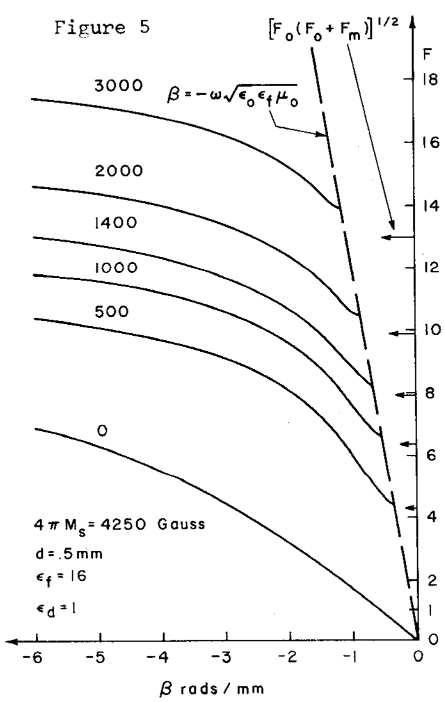

Figure 5

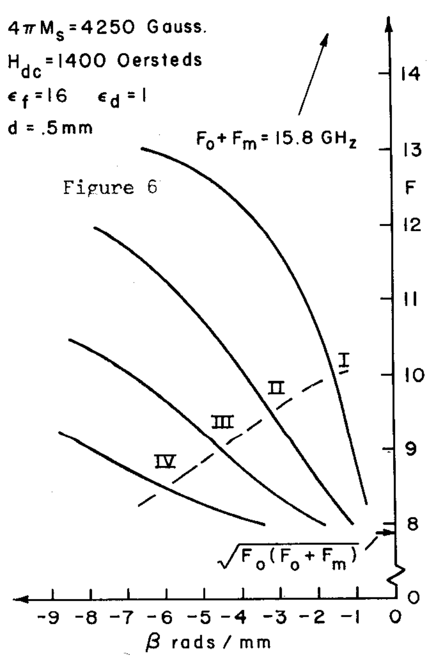

Figure 6

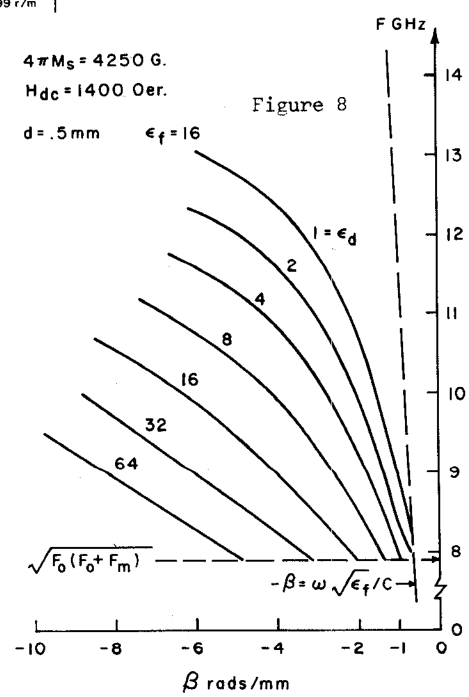

Figure 8