THE TWIN-FERRITE-TOROID CIRCULAR WAVEGUIDE PHASER

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Abstract

The TE_{01} mode in the circular waveguide loaded by two concentric ferrite toroids, magnetized circumferentially in opposite directions, is investigated. A method is proposed to switch the remanent magnetization of both toroids simultaneously by means of a single biasing wire. The dps (differential phase shift) shows substantial increase over that of the twin-ferrite slab phaser.

Introduction

Work on the TE_{01} mode in the circular cylindrical waveguide when loaded by a concentrically placed ferrite tube has been reported in earlier literature.[1-4] Two factors have inhibited serious thought concerning the utilization of this component in systems. This in spite of the fact that the differential phase shift per dp loss promises to be highly attractive since the ferrite completely occupies that region where the magnetic field is circularly or almost circularly polarized, and hence the material utilization is optimum. The first problem with the TE_{01} mode is that it is not dominant in the modal hierarchy. However, it has been shown[5] that dielectric loading can be effective in reordering the modal sequence and yield TE_{01} dominance. Secondly, the performance of this structure in terms of degrees of phase shift per inch per megahertz is not sufficiently improved over that for the twin slab phaser to make up for the added problem and cost of the necessary mode couplers.

To improve the figure of merit the use of two coaxial ferrite tubes, magnetized in opposite sense and located about at the two radii where circular polarization occurs for the loaded guide, was investigated.

Theory

The ferrite toroids can be magnetized at remanence by means of a single wire passing through the axis of the guide using a method similar to the so-called "partial switching" method in helical phase shifters.

Use is made of the square loop characteristic of the ferrite to achieve opposite remanent magnetizations in the concentric tubes. First both tubes may be put into state 1 (see Figure 1) by suitable pulsing. This is followed by a pulse of mangitude such that the inner tube is driven to point 3 while the outer tube is only driven to 2 due to the 1/r dependence of the field. Upon removing the excitation the the inner tube will relax to 4 while the outer will relax to 5. Reversal is obtained by first driving both to point 7 and repeating the earlier pulse sequence but with opposing polarity.

For the method to be successful the combined conditions of sufficient 'steepness' in the B-H characteristic and sufficient separation between the tube radii r_1 and r_2 must be met. Substantial values of the dps can be obtained with r_2/r_1 in the range $2 < r_2/r_1 < 3$.

In earlier work[5] the single toroidal tube was considered and, for dielectric loading of $\varepsilon_r = 80$, the differential phase shift (dps) obtained in degrees/in-GHz was maximally of the order of 15 to 20. The problem was reformulated for the two concentric tubes with dielectric loading in the inner region, i.e., to radius b1 (see Figure 2), following the earlier papers [2] and [5]. Computations were made of the dps as a function of radius of the inner ferrite tube (Figure 3), then keeping the inner radius r_1 constant the radius of the outer tube r_2 was varied with its minimum value occuring when in contact with the dielectric loading material (Figure 4). The effect of the thickness of the tubes was also considered (Figure 5) as well as the effect of the remanent magnetization on the dps (Figure 6). Throughout the computations, the waveguide radius was kept constant ($b/\lambda_o = 0.18$, λ_o = free space wavelength), and the loading dielectric had a permittivity of 80, and a radius of $b_1 = 0.356\ b$; this value was chosen to ensure maximum width of the modal inversion window using the results in [5] and then increasing it by δ (thickness of the toroids) in an attempt to offset the effect of the introduction of the toroid inside the dielectric loading cylinder. The ferrite permittivity is taken as 15, and the ferrite thickness is $\delta/\lambda_o = 0.01$, except in Figure 5, where it is varied. Through Figures 3-5 the relative remanent magnetization was taken as $|\gamma|M_r/\omega = \pm 0.3$.

It is to be observed from Figure 2 that, holding r_2 constant, a maximum in the dps occurs for $r_1/\lambda_o \cong .033$ when the outer ferrite tube is placed at the position of circular polarization for the dielectric loaded guide. Figure 4 gives the results for r_1/λ_o held at its optimum value and r_2 varied. The dps increases momotonically as r_2 is decreased with the calculation interrupted when the outer ferfite tube comes into contact with the dielectric loading. In Figure 5 we observe the dps as the thickness of the ferrite tubes is changed and observe that beyond a thickness of δ/λ_o of approximately .018 no commensurate increase in dps is obtained. Finally, in Figure 6 we observe the increase in dps with remanent magnetization. As is to be expected the increase is almost linear with respect to $\gamma M_r/\omega$.

Conclusion

In conclusion it was observed that with the proper selection of parameters a five-fold increase in dps can be obtained, for a structure with dimensions suitable for a practical design, over the single toroid without dielectric loading and at least a two-fold increase over the single toroid with dielectric loading. This, in turn, means that at least a two-fold increase in dps per in-GHz is obtained over the twin slab phaser for comparable dielectric loading.

References

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Figures

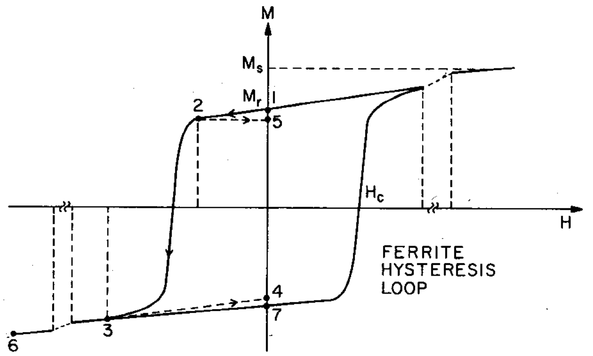


Figure 1

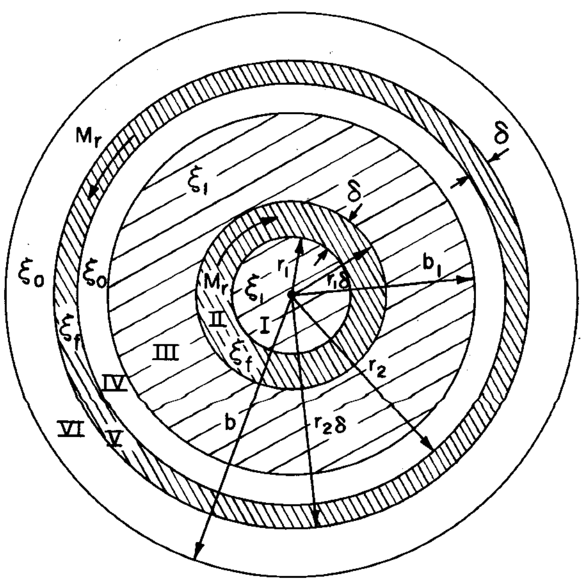


Figure 2

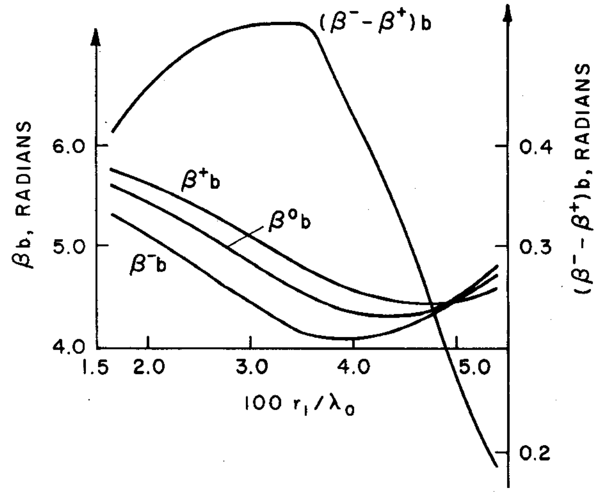


Figure 3

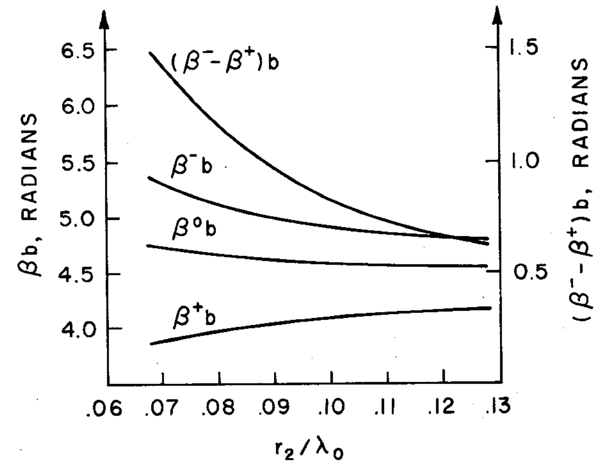


Figure 4

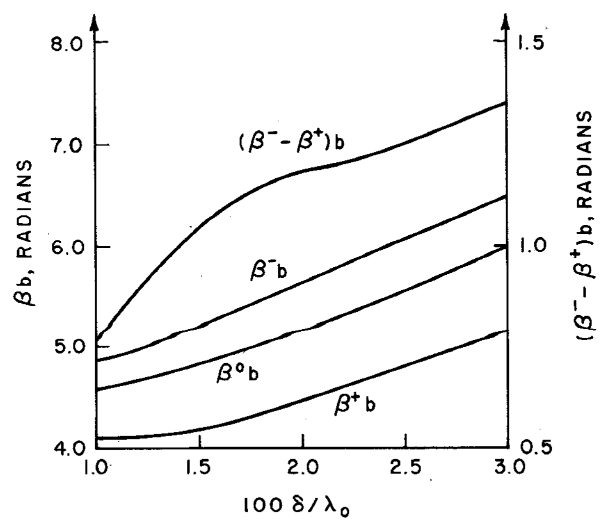
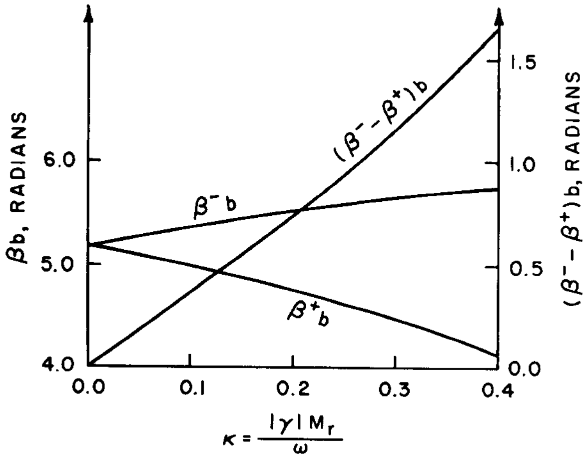


Figure 5



βb, RADIANS
$(\beta^- - \beta^+)b$, RADIANS
$(\beta^- - \beta^+)b$
$\beta^- b$
$\beta^+ b$
6.0
5.0
4.0
1.5
1.0
0.5
0.0
0.0
0.1
0.2
0.3
0.4
$\kappa = \frac{|\gamma| M_r}{\omega}$

Figure 6