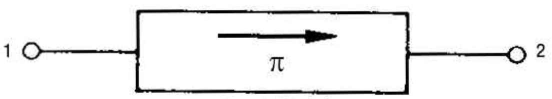
APPLICATION NOTE

No. 6512: Use of Ferrimagnetic Materials in Gyrators

Introduction

Non-reciprocal microwave devices are conveniently defined in three functional classes: (1) isolators, (2) circulators, and (3) gyrators. In general, these devices are interchangeable in circuit synthesis because each may be converted into either of the others by combining it with reciprocal elements. We have seen examples of isolators and circulators in preceding Tech Briefs; now gyrators will be described.



Gyrator Symbol

A gyrator is defined as a two port circuit element that exhibits 180 degrees of differential, or non-reciprocal, phase shift. The gyrator circuit symbol indicates that an R.F. signal transmitted from port 1 to port 2 will undergo 180 degrees phase shift (arrow direction) relative to an R.F. signal transmitted in the reverse direction. For many systems applications, devices that exhibit 45° or 90° of differential phase shift are required. This article will describe the material properties and basic geometry criterion required in the design of rectangular waveguide non-reciprocal phase shifters.

Differential Phase Shift

Recall that a magnetized section of ferrimagnetic material placed in a waveguide at a region of R.F. magnetic field circular polarization, will exhibit a permeability that is different for the two directions of R.F. signal propagation. At low values of internal static field (H_i), the losses are small and about equal but a plane wave will experience a change in phase due to the difference in μ'_- and μ'_+. The differential phase shift ($\Delta\phi$) is non-reciprocal and in general

$$\Delta\phi = (\mu'_+) - (\mu'_-) \qquad (1)$$

to avoid gyromagnetic resonance loss, values of H_i are usually restricted to the region,

$$H_i < H_{res} - 5\,\Delta H \qquad (2)$$
$$H_i > H_{res} + 5\,\Delta H$$

where H_{res} is the internal static field required for gyromagnetic resonance and ΔH is the resonance linewidth of the ferrimagnetic material employed. At low frequencies, gyrator operation above gyromagnetic resonance can be used to avoid the low field loss region.

Waveguide Devices

If a thin slab of ferrimagnetic material is placed in a rectangular waveguide, as shown in Figure 1, and biased with a static field (H_a) we can obtain differential phase shift. The internal static field (H_i) is related to H_a by Kittel's equation,

$$H_i = \{[H_a - (N_z - N_x) M_s]\,[H_a - (N_z - N_y) M_s]\}^{1/2} \qquad (3)$$

where N_x, N_y, N_z are the demagnetizing factors for the ferrite geometry employed.

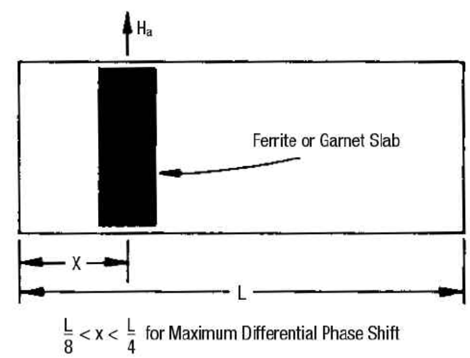


Figure 1

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The slab location is best found experimentally. It has been found that $L/8 < x < L/4$ for maximum differential phase shift. For a given ferrite the amount of phase shift depends on H_i and slab length. The scheme shown in Figure 2 can be used to increase further the differential phase shift without increasing device length. Here two slabs are placed symmetrically with respect to the center of the waveguide, but oppositely magnetized.

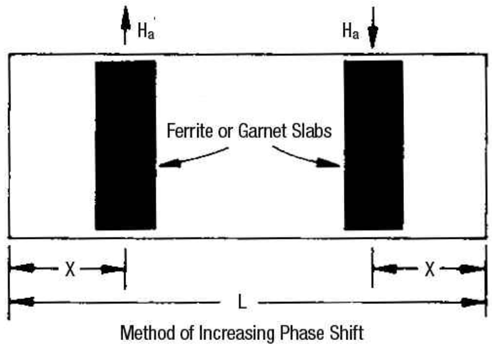

Figure 2

The frequency range of operation may be increased by placing dielectric slabs next to the ferrite or by moving the ferrite from the position of maximum differential phase shift.

For high power applications differential phase shifters are usually designed with a flat slab against the top waveguide wall. This results in increased cooling because of the large area of contact between the ferrite and waveguide wall. The optimum location for this geometry is $x = L/4$. As shown in Figure 3, more than one slab may be employed. Other advantages of this geometry are (1) decreased frequency dependence of differential phase shift, and (2) lower dielectric losses.

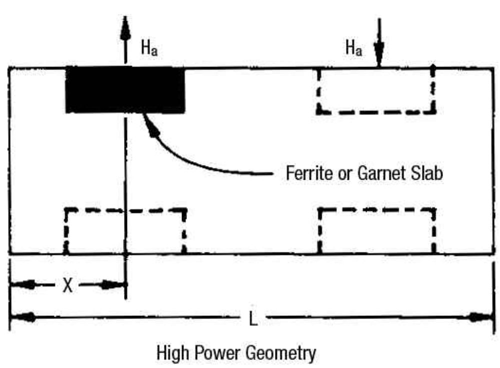

Figure 3

The ratio of differential phase shift to the total attenuation is defined as the figure of merit (F) of the device. A practical formula is:

$$F = \frac{4\omega}{\gamma_{eff}\Delta H} \qquad (4)$$

Narrow resonance linewidth materials will increase the figure of merit. The saturation magnetization ($4\pi M_S$) of the selected material should be such that low field losses do not occur at the frequency of operation.

Summary

The reader may notice a similarity between the design geometry of waveguide gyrators and resonance isolators. Indeed, if the internal static field (H_i) is adjusted for gyromagnetic resonance the gyrator geometries will exhibit good isolator properties.

The selection of the proper ferrite geometry, correct location of the ferrite slab, and choice of a ferrimagnetic material with suitable intrinsic parameters (γ, ΔH, $4\pi M_S$) for the operating frequency desired are the essential factors in gyrator design.