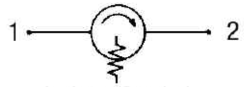
APPLICATION NOTE

No. 6510: Use of Ferrimagnetic Material in Isolators

Introduction

It has been found convenient to define three functional classes of non-reciprocal microwave ferrite devices as: (1) isolators, (2) circulators, and (3) gyrators. The realization of these devices stems from the gyromagnetic behavior of the elementary magnetic dipoles, or uncompensated electron spins, of the ferrite material as discussed in preceding Tech Briefs. This article will describe the intrinsic material properties and basic geometry criteria required in the design of rectangular waveguide resonance isolators. An isolator is defined as a two port circuit element that exhibits differential, or non-reciprocal, attenuation. The isolator circuit symbol indicates that an R.F. signal may be transmitted with little loss of energy from port 1 to port 2, but will experience substantial attenuation when transmitted from port 2 to port 1. The great value of isolators is in their ability to decouple energy sources from their loads with little reduction in available output power.



Isolator Symbol

Resonance Isolator Theory

Recall that the main features of the gyromagnetic behavior of a ferrite in the presence of an internal static magnetic field (H_i) and a correctly positioned R.F. magnetic field include:

(a) the magnetic dipoles precess at a frequency that is proportional to the magnitude of the static internal field:

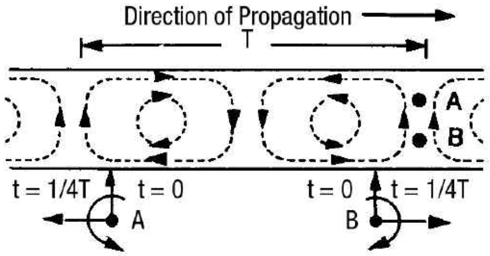
$$\omega = \gamma H_i, \qquad (1)$$

(b) the direction of precession depends on the direction of the static field, and the positive sense is clockwise when viewed in the direction of H_i.

From these conditions it is observed that resonance absorption of propagating electromagnetic energy can take place when the frequency and rotation of the R.F. magnetic field corresponds to that of the elementary magnetic dipoles. For rotations of the R.F. magnetic field in the opposite direction, little, if any, absorption occurs.

Waveguide Isolators

In rectangular waveguide propagating the dominant TE_{10} electromagnetic mode there are geometric locations where the R.F. magnetic field exhibits circular polarization. Figure 1 represents the R.F. magnetic field observed looking down on the broad face of the waveguide. In effect, the fields at points A and B rotate in the directions shown as a function of time. The rotation at points A and B has a positive sense for a static magnetic field (H_a) out of and into the plane of the page



RF Fields of the TE_{10} Mode in Retangular Waveguide

Figure 1

If a thin ferrite slab is located at a distance corresponding to point A from the side wall and biased with a static field (H_a) of proper magnitude, the ferrite will exhibit directional absorption. With H_a directed out of the page and the microwave signal propagating from left to right, the electron spins rotate in the same direction as the R.F. magnetic field. The,microwave signal will give up energy to the spin system. If the microwave signal propagates from right to left, the R.F. magnetic field will rotate in an opposite sense to the electron spins and no interaction will occur. These two cases correspond to attenuation in one direction and little or no attenuation in the other.

Note that if the ferrite is moved from point A to point B, the direction of isolation is reversed. If the ferrite is not moved from point A, but the external field is reversed, the isolator acts in the same way as if the ferrite had been moved from A to B. Consequently, reversing the field corresponds to turning the isolator around.

The plot of R.F. magnetic fields in Figure 1 is valid only for an unloaded waveguide. Insertion of a ferrite slab causes distortion which tends to elliptically polarize the fields. The position of the ferrite is best adjusted experimentally to give an optimum ratio of reverse-to-forward attenuation.

It is appropriate here to describe several elements of resonance isolator design. From equation (1), it is apparent that the static magnetic field required for resonance increases with frequency. Kittel's equation, shows that the internal field can be varied over a wide range by choosing the correct shape factors. Since it is desirable to design the isolator to work with the smallest and cheapest external magnet possible, a geometry should be achieved where the demagnetizing factors boost the external field inside the ferrite.

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

The geometry shown in Figure 2 yields demagnetizing factors of $N_x = 4\pi$; $N_y = 0$; $N_z = 0$. Inserting these values in Kittel's equation, we obtain

$$H_i = [H_a^2 + 4\pi M_s H_a]^{1/2} \qquad (3)$$

Thus by determining H_i from equation (1), the required H_a from a solution of equation (3) can be found.

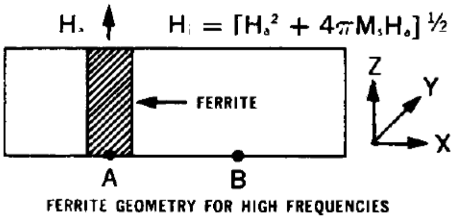


Figure 2

If a wideband isolator is desired, a ferrite with a large linewidth should be chosen; however, this usually results in a lower ratio of reverse-to-forward attenuation. The ratio of the forward attenuation to the reverse attenuation when measured in decibels is defined as the figure of merit (R) of the resonance isolator. A practical formula for any resonance isolator is:

$$R = \left(\frac{4\omega}{\gamma_{eff}\Delta H}\right)^2 \qquad (4)$$

It can be seen that the figure of merit is directly proportional to the square of frequency and inversely proportional to the square of the line width and the gyro-magnetic ratio. This figure of merit represents the theoretical limit of performance. In practice lower values are obtained. There exists a frequency region below which high device insertion losses occur as a result of the ferrite not being fully magnetized. It is called the low field loss region, and has for its upper limit the frequency

$$\omega_L = \gamma (H_{anis} + 4\pi M_s) \qquad (5)$$

where H_{anis} is the anisotropic field associated with the crystal structure; for most microwave ferrites it is of the order of 100 oersteds or less.

If the operating frequency of the isolator is low, the magnetic field required for resonance may be too low to saturate the ferrite. Resonance isolators for operation at low microwave frequencies require either a ferrite material with a saturation magnetization less than (ω_L/γ), or a geometry where a high magnetic field is required for resonance. One useful geometry is shown in Figure 3. Here the internal field is always less than the external field.

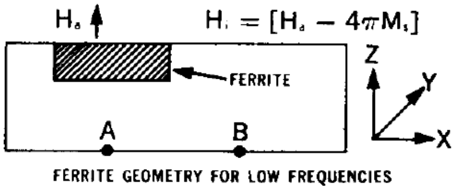


Figure 3

Summary

The essential factors in resonance isolator design are the selection of the proper ferrite geometry, correct location of the ferrite specimen, and the choice of a ferrimagnetic material with suitable intrinsic parameters (γ, ΔH, $4\pi M_s$) for the operating frequency desired. Kittel's equation allows us to readily handle the complex demagnetizing effects resulting from the finite ferrite specimens employed.

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