APPLICATION NOTE

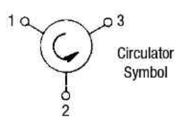
No. 6511: Use of Ferrimagnetic Material in Circulators

Introduction

The realization of non-reciprocal microwave ferrite devices stems from the gyro-magnetic behavior of the elementary magnetic dipoles, or uncompensated electron spins, of the ferrite material as discussed in preceding Tech Briefs.

In this article we will describe the material properties and basic geometry criteria required in the design of ferrite junction circulators. We will deal with the three-port version usually called the Y-junction circulator.

The Y-junction circulator is a non-reciprocal device providing transmission of energy from one of its ports to an adjacent port while decoupling the signal from all other ports. The circulator symbol shown indicates that R.F. energy incident on port 1 emerges from port 2, R.F. energy entering port 2 emerges from port 3, and R.F. energy entering port 3 emerges from port 1.



The Y-junction circulator can also be used as an isolator or as a switch. It is simple in construction, compact, and lightweight. Units have been built to operate in frequency bands of approximately 5 to 35 percent from 0.1 Gc to greater than 140 Gc. Good results have been obtained over wide ranges of peak and average power. At VHF, circulators have been operated at about 1 megawatt peak and at greater than 2 Kw average power.

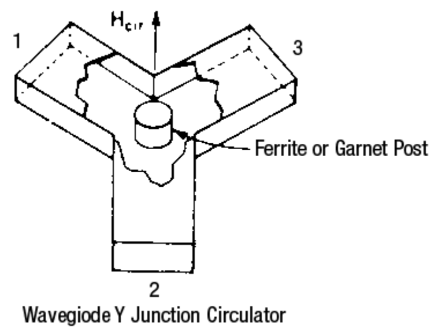


Figure 1a

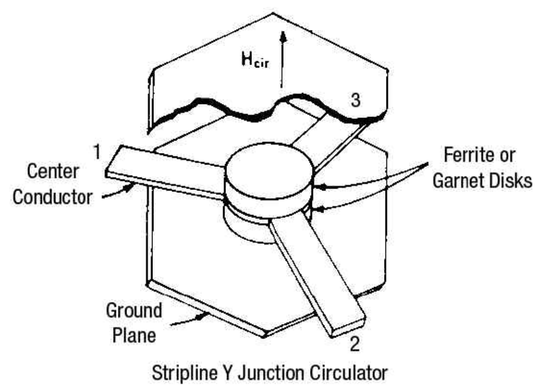


Figure 1b

Junction Circulators

The Y-junction circulator can be constructed in either rectangular waveguide or stripline. The waveguide type, shown in Figure 1a is used at high microwave frequencies. It consists of three H-plane junctions although E-plane circulators can also be made. The stripline version shown in Figure 1b is principally applicable to the VHF and low microwave frequencies. It is usually made with coaxial connectors. In both types, a ferrite element is placed in the center of three symmetrical junctions spaced 120 degrees apart. A ferrite post is employed in the waveguide version.

Two ferrite disks, one located on each side of a metallic center conductor, are used in the stripline type.

Circulator action is obtained by biasing the ferrite element in the axial direction with an internal static field (H_{cir}) of proper magnitude. The circulator can operate at two values of H_{cir}. One is small in magnitude and less than the internal d-c magnetic field required for gyromagnetic resonance. The other is larger than that required for resonance. This property enhances the versatility of ferrite Y-junction circulators.

In general, circulator action is controlled by either of two pairs of independent variables, (1) ferrite post or disk diameter and magnetic field, or (2) saturation magnetization and magnetic field. The operating range can be increased by placing dielectric matching sections in the junction. The direction of circulation is reversed by reversing the static magnetic field.

Operating Principles

Network theorems tell us that reciprocal multiport junctions can not be matched but that we can match non-reciprocal multiport junctions. Also, we find that a non-reciprocal, lossless, matched, multiport junction is a perfect circulator. These theorems led to the development of ferrite Y-junction circulators. Much of the device design has proceeded on an empirical basis. Recently circulator action has been described in terms of electromagnetic field theory.

A cavity type resonance of the ferrite element appears to be an essential feature of circulator operation. The lowest frequency resonance mode of the stripline disk structure is shown in Figure 2a. The R.F. electric field vectors are perpendicular to the plane of the disk and the R.F. magnetic field vectors are parallel to the plane of the disk. This mode is excited by an R.F. signal entering port I and zero applied static magnetic field. The R.F. signals are 180 degrees out of phase at ports 2 and 3, and about half the input signal magnitude.

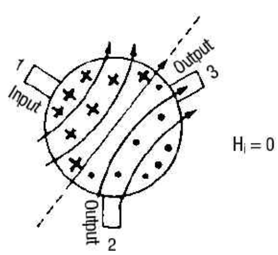


Figure 2a

When a static magnetic field is applied into the plane of the page, the standing wave pattern will rotate clockwise, as shown in Figure 2b. An R.F. signal null will appear at port 3 for a certain value of internal static field (H_{cir}). The R.F. signal at port 2 will about equal the input signal at port 1. We can represent the standing wave by two contra-rotating field patterns. The R.F. magnetic fields lie in the plane of the disk. They are circularly polarized at the disk center and linearly polarized at the disk edge. Permeabilities can then be defined for the positive and negative sense of rotation. The positive sense is clockwise when viewed along H_{cir}.

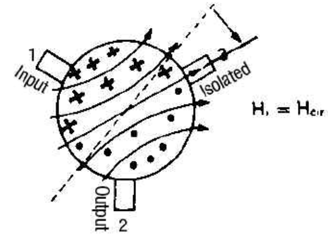


Figure 2b

The required disk or post diameter increases as the operating frequency decreases. For operation above gyromagnetic resonance the static magnetic field H_{cir} increases as $4\pi M_S$ increases. For operation below gyromagnetic resonance H_{cir} decreases as $4\pi M_S$ increases.

At low frequencies, circulator operation below gyromagnetic resonance can cause high device insertion loss as a result of the ferrite not being fully magnetized. By operating the circulator above gyromagnetic resonance the ferrite usually will be fully magnetized and the low field loss region avoided.

Design equations exist that relate the ferrimagnetic element size and circulator operating characteristics to the intrinsic material properties ($4\pi M_S$, ΔH, γ_{eff}, $\tan\delta$, ε'). Although very tractable, they are rather long and are not given here. The reader is referred to the references given below.

References

H. Bosma, "On Stripline Y-Circulation at UHF", IEEE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-12, pp. 61-72; January 1964.

C. E. Fay, and R. L. Comstock, "Operation of the Ferrite Junction Circulator", IEEE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-13, pp. 15-27; January 1965.