

APPLICATION NOTE

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.

This Application Note describes the material properties and basic geometry criteria required in the design of ferrite junction circulators. The three-port version, called the Y-junction circulator, is discussed in this Application Note.

The Y-junction circulator is a non-reciprocal device that provides transmission of energy from one of its ports to an adjacent port, while decoupling the signal from all other ports. The circulator symbol shown in Figure 1 indicates that the RF energy:

- Incident on port 1 emerges from port 2.
- Entering port 2 emerges from port 3.
- Entering port 3 emerges from port 1.

Two ferrite disks, one located on each side of a metallic center conductor, are used in the stripline type of circulator. The 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 Transverse Magnetic (TM) modes of opposite polarization.

Under the circulation condition shown in Figure 1 at a specific applied Direct Current (DC) field, these TM modes create a null at port 3, which is then isolated, and power is transferred from port 1 to port 2. The power entering at port 2 appears at port 3, and so on, creating the circulator action. When port 3 is terminated in a matched load, the device operates as an isolator, passing power between port 1 and 2, but absorbing power into the load when power is passed into port 2 and into the load of port 3.

Most circulators are used as isolators in a similar fashion, giving isolation in the range of +20 dB to +30 dB. The direction of circulation can be reversed by reversing the polarity of the DC field. Two or more circulator junctions can be combined to give very high isolation performance.

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

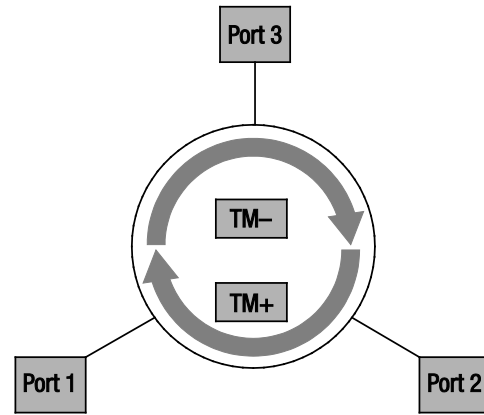


Figure 1. Y-Junction Circulator

Junction Circulators

The Y-junction circulator can be constructed in either rectangular waveguide or stripline. The waveguide type, shown in Figure 2, is used at high microwave frequencies. Although Figure 2 consists of three H-plane junctions, Electric field-plane (E-plane) circulators can also be made.

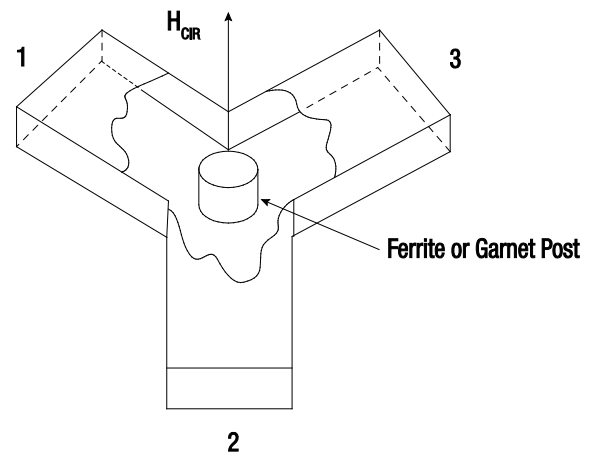


Figure 2. Waveguide Y-Junction Circulator

The stripline version shown in Figure 3 is principally applicable to the VHF and low microwave frequencies, and usually made with coaxial connectors.

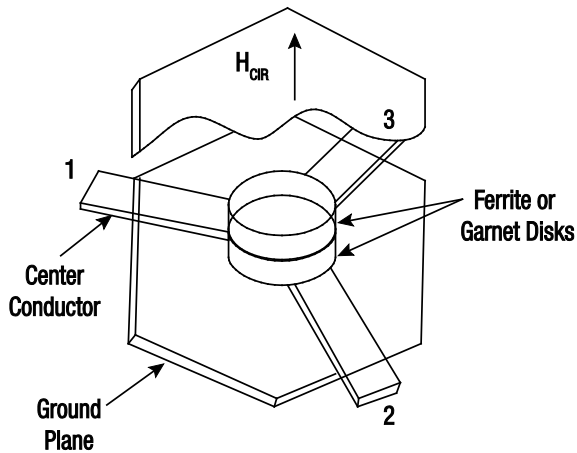


Figure 3. Stripline Y-Junction Circulator

In both types, a ferrite element is placed in the center of three symmetrical junctions that are spaced 120 degrees apart. A ferrite post is used in the waveguide version. Two ferrite disks, one located on each side of a metal center conductor, are used in the stripline version.

These devices operate in two ways to meet the circulation condition:

- Below resonance = Uses a combination of the DC field just above the low field loss (determined by $\gamma \times 4\pi M_s$ and the shape demagnetization factor), but below ferromagnetic resonance [reference 1].
- Above resonance.

Because the effective RF permeability below resonance is close to unity, the diameter is a function of the frequency determined by the TM mode, and the bandwidth by the maximum $4\pi M_s$ allowed by the low field loss requirement.

Because the permeability above resonance can be varied significantly near resonance, the size is a function of the DC bias and frequency. Considerable variation in possible size for a given frequency is possible provided very narrow line width materials are used.

Low field loss is less likely above resonance, except at very low frequencies, less than 500 MHz for most applications. For both above resonance and below resonance, it is essential that the ferrite is as magnetically saturated as possible to avoid non-linear effects like inter-modulation and harmonic distortion. This is a function of the shape as well as the bias field and $4\pi M_s$.

Using composites that consist of a ferrite surrounded with a ring of high dielectric constant dielectric helps the saturation by reducing the internal field uniformity created by magnetic return paths, ineffective magnets, and pole pieces, resulting in improved non-linear behavior.

Operating Principles

Network theorems tell us that reciprocal multiport junctions cannot be matched, but that we can match non-reciprocal multiport junctions. Trans-Tech, Inc. (TTI) has found that a non-reciprocal, loss-less, matched, multiport junction is a perfect circulator. These theorems led to the development of ferrite Y-junction circulators. Much of the original device design has proceeded on an empirical basis. Recently, circulator action has been described in terms of electromagnetic field theory, and is available in design software form. 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} , μ_{eff} , ϵ') [references 2, 3, 4].

References

- [1] *Test for Line Width and Gyromagnetic Ratio Application Note*, TTI, Document Number 202837.
- [2] H. Bosma, *On Stripline Y-Circulation at UHF*, IEEE Transactions on Microwave Theory and Techniques, Volume MTT-12, January 1964, pp. 61–72.
- [3] C. E. Fay and R. L. Comstock, *Operation of the Ferrite Junction Circulator*, IEEE Transactions on Microwave Theory and Techniques, Volume MTT-13, January 1965, pp. 15–27.
- [4] D.K. Linkhart, *Microwave Circulator Design*, Artech House, 1989.

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