APPLICATION NOTE

Factors That Influence the Power Handling Capability of Circulators

Introduction

This Application Note describes the factors that influence the power handling capability of circulators. The most common circulators are the junction type, available in stripline (coaxial, drop-in, and surface mount), microstrip, and waveguide forms.

Circulator power handling depends on several factors: power handling of coaxial connectors, power handing of the basic circulator, and power threshold of the ferrite material used. The power handling capability of circulators can be exceeded in two ways: peak power and average power. Excessive peak power leads to corona and arcing due to the high voltages that can be present. Average power failure is typically due to overheating.

Stripline and microstrip circulators operate in one of two magnetic bias regions: above resonance and below resonance.

Above resonance circulators are typically limited to an upper operating frequency of 2.5 GHz. However, with careful material selection and optimized magnetic circuit design, the upper operating frequency limit can be extended to 3.6 GHz. Below resonance circulators can operate up to frequencies of approximately 30 GHz.

Circulators That Operate Above Resonance (Magnetic)

Stripline circulators are constructed using a center conductor sandwiched between two ferrite discs or triangles. These ferrites are placed between ground planes and magnetically biased by permanent magnets outside the ground planes.

The average power rating for an above resonance circulator is a function of the circulator insertion loss, the thermal conductivities of the materials used in the construction of the circulator, and the temperature of the heat sink on which the circulator is mounted. The power dissipated in the circulator junction is calculated from the average input power and the insertion loss in dB, using the following equation:

$$Power\ dissipated = P_{IN}\left(1 - 10^{(-loss/10)}\right)$$

Average power failure in a circulator leads to overheating, which results in degraded performance that exceeds the specified circulator limits.

The peak power rating for an above-resonance circulator is a factor of the ground plane spacing and the proximity of the center conductor to the circulator housing. At excessive peak powers, voltage breakdown can occur. Maintaining a sufficient air gap between the center conductor and ground, and the use of high dielectric strength materials ensures that the peak power rating is achieved.

The peak power rating is important in pulsed power applications. Bursts (pulses) of RF with no RF present between bursts is referred to as “pulsed RF.” The most general case of pulsed RF consists of pulses of a fixed pulse width (PW) that come at a fixed time interval or period (T). The ratio of the pulse width to the pulse period is the duty cycle:

$$\frac{Pulse\ Width\ (PW)}{Pulse\ Period\ (T)} = Duty\ Cycle = \frac{Average\ Power}{Peak\ Power}$$

The peak power rating for an above-resonance circulator is a factor of the ground plane spacing and the proximity of the center conductor to the circulator housing. At high peak powers, the main concern is voltage breakdown.

Circulators That Operate Below Resonance (Magnetic)

The average and peak power ratings of a below resonance circulator are a function of the ferrite material used. High power levels in below resonance circulators result in the onset of non-linear absorption in ferrites.

The generally accepted model for explaining the phenomenon of non-linear absorption is that of spin wave build up in the material. Spin waves are excited when the RF H-field exceeds a critical value. The critical field is dependent on many factors, such as geometry, magnetization, RF power, main resonance line width, the relevant spin wave line widths, gyromagnetic ratio, and operating frequency. The theory provides for a spectrum of spin waves, some having lower critical fields than others. This accounts for the fact that as RF power is increased, absorption continues to increase as more spin waves are excited.

The insertion loss of the circulator is effectively non-linear and increases as the power level increases. The power threshold in below resonance circulators can be increased by doping the ferrite material with elements such as cobalt and holmium, which results in a marginal increase in insertion loss at low power levels.

Reduced grain size of polycrystalline ferrites and garnets increases the high power threshold without increasing the low power insertion loss. When the spin wave wavelength and the grain size are similar, the spin waves are effectively broken up and the peak power threshold is increased. The disadvantage of smaller grain size is a higher cost.