REC-HXI Circulator and Isolator Application Note

I. General

Circulators and Isolators are Ferrite devices used to protect sensitive RF/Microwave/Millimeter Wave Electronics Components by allowing RF Power to flow in one direction only. Usually Circulators and Isolators allow power to flow only in the clockwise direction, but they can also be configured to allow power to flow only in the counter-clockwise direction. Circulators are typically three-port devices used as Duplexers where the Transmit Signal enters Port 1 and exits Port 2 and where the Received Signal enters Port 2 and exits Port 3. Isolators are typically two-port devices used to protect amplifiers from unwanted reflected power due to varying load impedances. Isolators contain resistive terminations to dissipate any reflected power, as much as (and preferably more than) the total power incident on the load in the case of total reflection. Circulators can also be used as Isolators as long as the third port is terminated with a load sufficient to absorb the power reflected back into the Output Port.

There are two types of circulators and isolators: (a) above resonance, and (b) below resonance. The Above Resonance designs are typically under 2 GHz and are narrow band (~ 5 to 15% bandwidth), while the Below Resonance designs are above 2 GHz and can be up to an octave band for bandwidth. The above resonance designs can typically handle much higher peak and average power than a typical below resonance device.

Ferrites are generally extremely non-linear with incident power. In order to limit the non-linearities, certain dopants are used in the parent ferrite structure to sustain the required power level to suppress 2nd and 3rd harmonics. It has a direct impact on specifications such as 3rd order Intermodulation. The temperature stability and non-linearities are trade-offs to be considered when selecting the correct ferrite for the application.

Some ferrite circulators and isolators use Samarium Cobalt magnets that have high energy product (BH) ratio to produce compact designs. Some applications (DFARS clause) require these magnets to be procured by certain suppliers which affect schedule and cost.

The lower cut-off frequency for ferrite based circulators and isolators is 65 MHz. Below 65 MHz, active transistors can be used to produce an electronic circulator. However, these active circulators are narrow band and very lossy for duplexing applications.

A ferrite based circulator works on the principle of creating a TM11d mode in a circulator stripline structure, then splitting the incident wave into clockwise and counter-clockwise rotations. The counter-clockwise wave couples with the magnetic dipoles of the ferrites and decreases the velocity of the wave, while the clockwise wave is uncoupled. This rotates the null E vector to point towards the isolated port, thereby creating the circulation effect.

II. Circulator and Isolator Specifications

Circulators and Isolators are typically defined by specifications including, but not limited to Form Factor, Frequency of Operation, Isolation, Insertion Loss, VSWR(or Return Loss), Power Handling, Termination, Temperature Range, Altitude Rating, and Mechanical Dimensions.

A. Form Factor

Circulators and Isolators can be provided in form factors such as Coaxial, Drop-In, Microstrip, Surface Mount, and Waveguide.

B. Frequency of Operation

Circulators and Isolators can operate from a few MHz to over 100GHz in bandwidths as wide as 10GHz.

C. Isolation

Isolation for Circulators and Isolators is defined as the reduction in power from the Output Port to the Input Port in dB. Generally, the wider the bandwidth of operation, the lower the Isolation that can be attained and vice-versa.

D. Insertion Loss

Insertion Loss for Circulators and Isolators is defined as the reduction in power from the Input Port to the Output Port in dB. Generally, the narrower the bandwidth of operation, the lower the Insertion Loss that can be attained and vice-versa. Circulator and Isolator Insertion Loss tends to increase with decreasing temperature, but that effect is somewhat mitigated by the fact that RF/Microwave/mmWave Amplifiers have increased Gain as temperatures decrease.

E. VSWR (or Return Loss)

VSWR (or Return Loss) for Circulators and Isolators is defined the same way as for other RF/MW/mmW circuits and systems except that one value usually applies to all ports.

F. Power Handling

Circulators and Isolators can handle power from as little as 1W CW(Average) or less to Hundreds of Watts CW(Average). Forward Power refers to power traveling from the input port to the output port and Reverse Power refers to power reflected back into the Output Port from the Load due to mismatches. Reverse Power will always be less than or equal to Forward Power. Peak Power handling is equal to the CW (or Average) Power divided by the Duty Cycle. The Duty Cycle is defined as the Pulse Width multiplied by the Pulse Repetition Rate.

G. Termination

Terminations used with Isolators and Circulators dissipate power reflected back into the Output Port. They must be capable of dissipating as much power as is reflected into them. Many Isolators are designed into systems where the worst case of total reflection can be tolerated. In this case the Termination capacity must be equal to the CW Power Handling Specification. In other cases, a load VSWR is specified that will allow an amount less than the full Forward Power to be reflected back into the Output Port. In cases such as this, the Termination must be capable of withstanding the power reflected under those load conditions. For example, if a 100W CW Isolator is used in a system looking into a 3:1 VSWR, the Termination must be capable of dissipating at least 25W. The termination's efficiency will depend upon the base plate temperature on which the isolator is mounted and would have a derating linear slope above 100°C.

H. Temperature Range

Temperature Specifications for Circulators and Isolators are usually provided only for Operational use, but sometimes are also provided for Storage Conditions. Operational Temperature Specifications determine the range over which the Electrical and Mechanical Specifications are guaranteed. In some instances, Electrical Specifications will be in the form of minimum and typical quantities. In those cases, the typical specification will refer to room temperature operation and the minimum specification will refer to the high temperature operation. Storage Temperature Specifications provide the range of temperatures over which the Circulator or Isolator can be stored in a non-operational state without risk of damage. Some Qualification and Acceptance Testing Specifications require that Isolators and Circulators be subjected to the full range of Storage Temperatures and tested for compliance.

I. Altitude Rating

Circulators and Isolators used in Airborne or Space Applications must be able to operate at extreme altitudes. In order to accomplish this, they must undergo an additional manufacturing operation called Vacuum Impregnation. This allows the air to be removed from the housing and prevents arcing of the RF Power and catastrophic damage to the internal circuitry of the Circulator or Isolator. Altitude Ratings are expressed in units of feet, for example 20,000' or 20,000 FT.
For space applications, the design and material selection become more stringent to avoid Arcing, Multipaction and Outgassing effects.

J. Mechanical Dimensions

Mechanical Dimensions provide the form and fit of the Circulator or Isolator including the X, Y, and Z Dimensions; the type(s) of Connectors used(for Connectorized versions) or the Waveguide Type(for Waveguide versions) ; the height, width, and thickness of the Input/Output tabs(for Drop-In versions); the location, size, and type of mounting holes(through or threaded); and the locations and dimensions of mounting pads(for SMT versions).

III. Other Considerations

In some cases, a single Circulator or Isolator will not provide adequate Isolation for the intended application. For Narrowband applications with minimal space available and where cost is less important than performance, a Dual-Junction Circulator or Isolator may be the best solution. This will provide greater Isolation, but will also result in higher Insertion Loss. For Narrowband applications where cost is of equal or greater importance and for Wideband applications, multiple Circulators or Isolators in series may be the best solution. For these cases where physical dimensions are relaxed, separating the Circulators or Isolators by a distance equal to the width(x-dimension) of the Circulator or Isolator will provide the best performance. For these cases where physical dimensions are at a premium, the Circulators or Isolators can be staggered such that the Inputs and Outputs are not co-linear. This will prevent interactions between the internal magnets that will degrade the desired performance.

IV. Thermal Considerations

The primary function of Circulators and Isolators is to handle power reflected by a mismatched Load and circulate it into a Termination capable of withstanding all the power reflected into it, which is less than or equal to the power flowing through the Circulator or Isolator. The body of the Circulator or Isolator must be able to withstand all the power flowing through it. This power generates heat that increases the case temperature to a level greater than the ambient temperature. The heat generated must be removed to prevent moderate or catastrophic degradation of the electrical performance of the Circulator or Isolator. Therefore, heat removal could easily be considered the most critical aspect of Circulator and Isolator applications.

The first step in removing heat is properly attaching the Circulator or Isolator to the mounting apparatus. This depends on the type of Circulator or Isolator (Drop-In, Coaxial, etc.) For more information, please refer to the relevant Application Notes on the REC web site. The next step in Heat Removal depends upon how much power is being absorbed. For low to moderate power (), a heat sink with thermally conductive grease will be required. For high power (), a heat sink with thermally conductive grease will be required along with air or liquid cooling. The final step in heat removal depends upon whether a Circulator or Isolator is being used.

A. Isolators

Since Isolators have internal terminations, proper mounting of the Isolator is all that is required. However, some explanation of the types of terminations is useful. For low power () Isolators, Absorbtive Terminations are used. These are built in to the Ferrite. For medium power Isolators (), Resistive Terminations are used. For high power Isolators (), Diamond-Nickel-Chromium Terminations are used since they have Thermal Conductivity 5-8 times that of Beryllium Oxide Resistive Terminations. These are by far the most expensive and can dramatically increase the overall cost of the Isolator.

B. Circulators

Since Circulators do not have internal terminations, the user must select the most appropriate type and value of termination. For Drop-In, Microstrip, and SMT Circulators an SMT Termination is best. For Coaxial Circulators, Coaxial Terminations are best. For Waveguide Circulators, Waveguide Terminations are best. To properly affix SMT Terminations to the mounting surface, Thermally and Electrically Conductive Epoxy such as Ablefilm 5025E (made by Ablestick Laboratories) or equivalent should be utilized. Coaxial and Waveguide Terminations should utilize Thermally Conductive Grease such as () between the Termination and the mounting surface. For detailed Thermal Analysis/Design, please refer to the REC Thermal Analysis/Design Worksheet available on the REC web site.

V. Applications

A. Amplifier Protection

Isolators are primarily used to protect amplifiers from unwanted reflections that can cause irreparable damage (see Figure 1). Power entering Port 1 and reflected from Port 2 will be circulated to the Internal Termination and dissipated as heat. Circulators can also be used in this way (see Figure 2), but Port 3 must be terminated by the user with a Load that can withstand the Reflected Power.

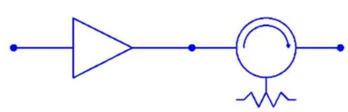

Figure 1

12 Lancaster County Road, Harvard, MA 01451 USA
Phone: 978-772-7774 ● Fax: 978-772-7775
Email: sales@rec-usa.com ● Website: www.rec-usa.com

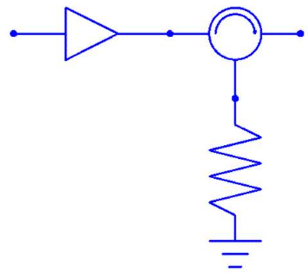

Figure 2

B. Duplexers

Circulators are primarily used as Duplexers in Transceivers (see Figures 3 and 4). The Transmitter Power enters Port 1, exits Port 2, and is radiated out of the Antenna. The Received Power enters the Antenna and Port 2 where it is circulated to the Receiver. The Circulator must have sufficient bandwidth to cover both the Transmit and Receive Frequencies.

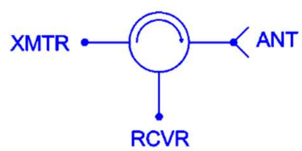

Figure 3

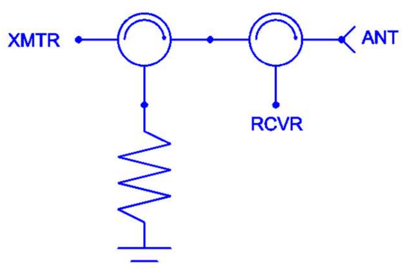

Figure 4

C. Reflected Power Monitor

Circulators can also used as Reflected Power Monitors (see Figure 5). Power enters Port 1 and exits Port 2. Any power reflected from the Load attached to Port 2 will be circulated to Port 3 and into the Power Meter attached there. This allows the effects of changing load conditions to be monitored.

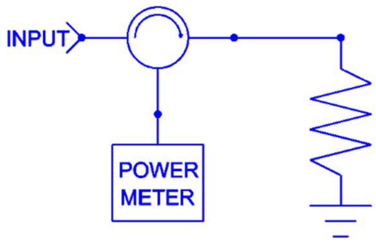

Figure 5

VI. Testing Circulators and Isolators

Testing Circulator and Isolator performance generally involves measuring S-Parameters under small signal conditions (input power levels ~10dB less than Rated Input Power), but can also require measuring Power Ratios at single frequencies under large signal conditions (input power levels at Rated Input Power). Since Large Signal Testing is a special field of study, this Application Note will focus solely on Small Signal Testing.

Unless phase information is required such as Insertion Phase, a Scalar Network Analyzer can be utilized. If phase information is required, a Vector Network Analyzer must be employed. Since Isolators have only two ports, a Two-Port Network Analyzer is sufficient for testing.