ISOLATORS AND CIRCULATORS FOR RADIO SIGNALS

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Introduction

This paper is an introduction to isolators and circulators used in the transmission and reception of radio signals. It discusses applications for isolators and circulators in various situations and explains how they operate. The need to use isolators and circulators as an RF system component has increased over time as more transmitters using different modulation types appear at infrastructure sites. The most popular use of an isolator is to control interference from intermodulation. The isolator also protects its transmitter's power amplifier from overheating by keeping reflected power from flowing back toward the transmitter.

Single-Stage Isolator

A circulator is a three-port device which allows one to route signals in a specific direction. An illustration of a circulator is shown in Figure 1. When a signal is applied to port 1, it will be output at port 2. Similarly, any signal applied at port 2 will travel through the circulator and will be output at port 3. Finally, any signal which enters port 3 will be output at port 1. The signal encounters some losses, typically between 0.3 and 0.7 dB, depending on the frequency of operation.

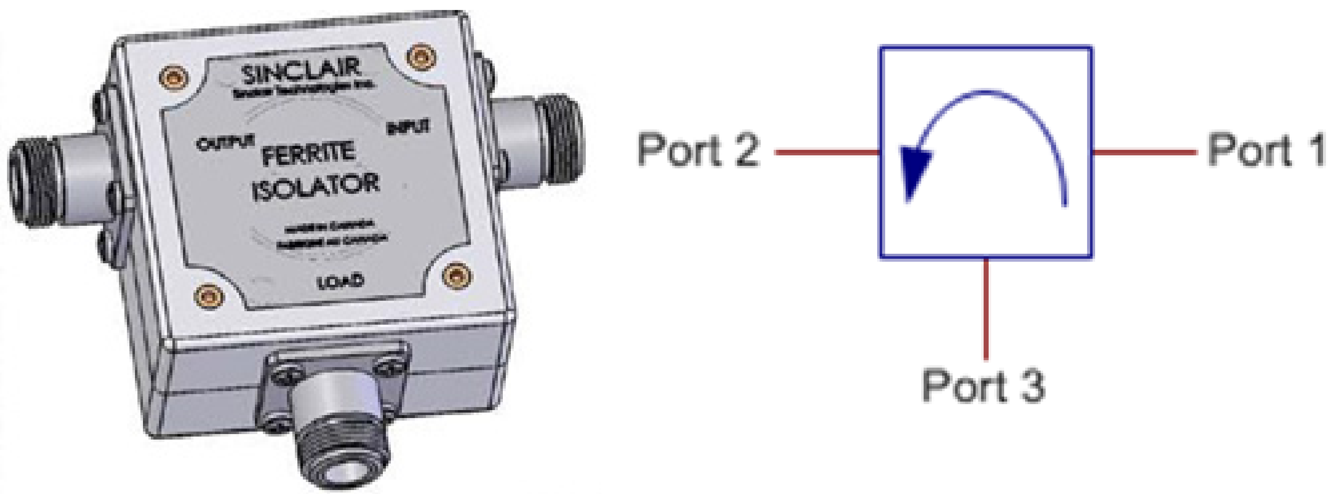

Figure 1: A single stage circulator and a schematic diagram of circulator operation

Figure 2 shows the internal parts of a circulator. The spacing between the magnets, the position of the tap points on the conducting strips, as well as the fixed and adjustable capacitators, all combine to determine the operating frequency of the isolator.

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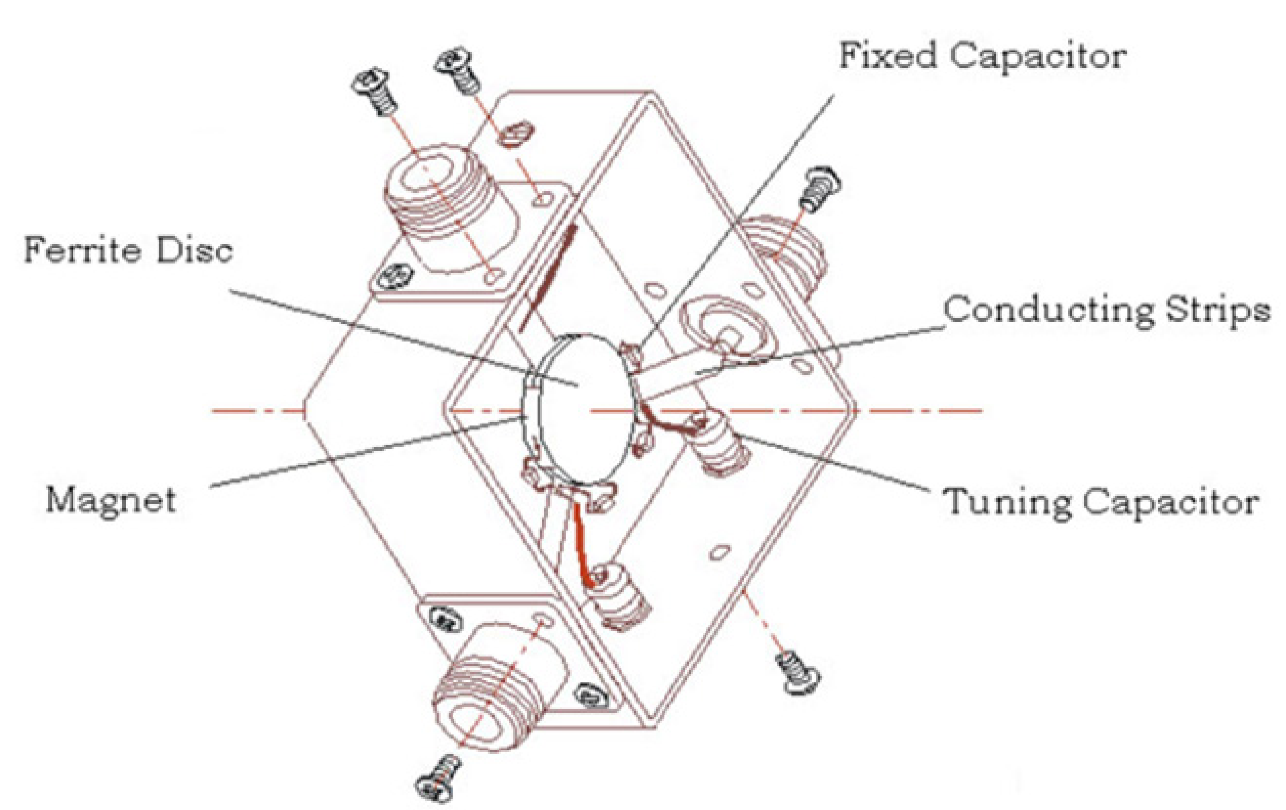

Figure 2: The internal materials of a typical ferrite circulator

During the manufacture of the circulator, magnetic spacing and the values of the internal-fixed capacitators must be adjusted to tune the units to the customer's specified frequencies. Note that the only field-adjustable parts of a circulator are its three variable-tuning capacitators, which can be tuned to a new frequency, but only within a limited range.

The conducting strips are thin and are sandwiched between the ferrite discs. This design can cause internal damage from heat build-up in high-power applications; thus it is important to consider the maximum power that will pass through the device when specifying a circulator.

One example of an application of a circulator is duplexing a transmitter and receiver. Keep in mind, when used in this way, the circulator only provides isolation, and no filtering. If one chooses to use a circulator in this application, two factors must be considered. The first consideration is power – the circulator must be able to handle the maximum power output of the transmitter. The second consideration is frequency spacing – the transmit frequency and the receive frequency must be very closely spaced. While precise maximums depend on the frequency in use, the difference must be no greater than several megahertz if adequate isolation between the transmitter and the receiver is to be obtained. Figure 3 shows a circulator used to duplex a transmitter and receiver. The receive signal enters the circulator from the antenna and is routed to the receiver. The transmit signal enters the circulator and is routed to the antenna.

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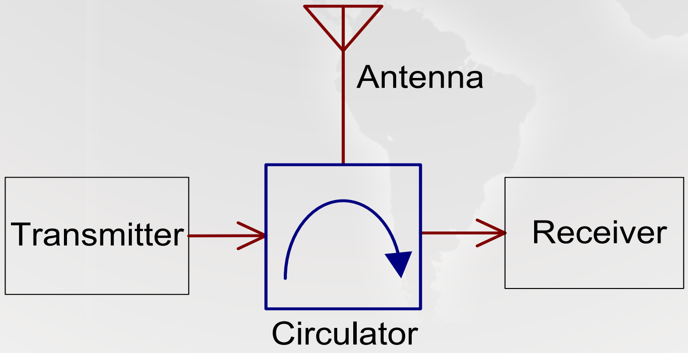

Figure 3: Using a circulator to duplex a transmitter and receiver

Although technically feasible, this duplexing set-up is recommended only in low-power applications. Recalling the operation of a circulator, this configuration reveals a potential danger. If the antenna cable breaks, the circulator has an open port on the antenna port. This open circuit will cause all the transmitter power to be reflected back to the circulator where it can enter the receiver. Thus, the full power of the transmitter is present at the receiver input, potentially damaging the receiver.

An isolator is an application of a circulator. A circulator is turned into an isolator by terminating one output with a matched, 50-ohm load as shown in Figure 4.

Figure 4: The circulator becomes an isolator when a matched 50-ohm load is added

The label isolator becomes apparent when one considers how an isolator is used to isolate a transmitter from a load. In Figure 5, the transmitter is connected to an antenna through an isolator. When everything is functioning properly, the transmitted signal reaches the antenna through the isolator. The isolator creates a small loss, but is otherwise transparent to the system.

Environmental factors can play a huge role where the use of isolators is needed. One such scenario might be when an antenna is bent by a high wind, or the antenna-feed line becomes an open circuit. An open circuit on the antenna-feed line will cause a total reflection of the transmit power back

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towards the transmitter. The signal enters the isolator which is routed to the load where it is harmlessly dissipated as heat. If the isolator was not present, the signal would have re-entered the transmitter with potentially damaging results.

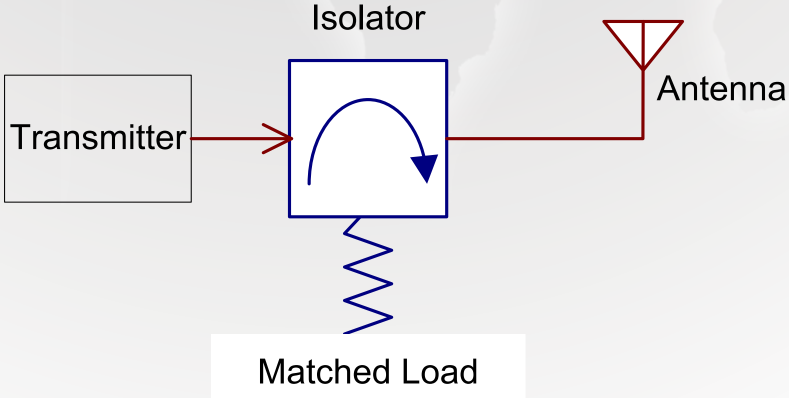

Figure 5: The isolator protects the transmitter from reflected power from antenna and transmission line

Another way the transmitter is isolated from the load is in impedance matching. If the transmitter output impedance is not matched to the load, then a reflection will occur. Although the system may start matched, varying conditions, such as antenna icing, may change the load impedance. Without the isolator, the transmitter will then see different impedances, probably affecting its output power. Using the isolator means that the transmitter power is always entering a matched 50-ohm load. Therefore, whatever happens beyond the isolator is not visible to the transmitter, which is thus isolated from the load.

Dual-Stage Isolator

In the real world, no isolator is perfect. A single-stage isolator will typically have 35 dB of isolation which may not be high enough for some applications. If system power levels are high, a dual-stage isolator may be needed.

Figure 6a: Dual isolator type “A”

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Figure 6b: Dual isolator type “B”

A dual isolator, as illustrated in Figure 6, is simply two isolators housed in the same enclosure. Sinclair manufactures two different configurations of the isolator. Figure 6a shows Sinclair’s typical configuration known as type “A” and Figure 6b shows Sinclair’s alternative version known as type “B”, where the load B port and the output ports are physically swapped. Mechanical restrictions generally dictate which version to use.

Looking at either Figure 6a or 6b, the input signal enters the first isolator at the input port and passes through the first stage. Then it enters the second stage where it passes through to the output port. A reflected signal entering the output port is routed through to the larger load attached to the load port of the second stage. Since no match is perfect, a small amount of power will enter the first stage of the dual isolator after being reflected from the larger load attached to the load B port on the second stage. This reflected signal is routed through to the smaller load connected to the load port of the first stage. As a result, the dual isolator will supply an assured higher-degree of isolation than the single isolator.

In examining the dual isolators in Figure 6a and Figure 6b, one can see that the first stage load is of a lower power rating than the second load. Since the second stage dissipates virtually all the reflected power, the first stage load sees much less of the total reflected power and therefore can be made much smaller.

Losses in a dual-stage isolator are roughly equal to twice the loss of a single-stage isolator.

A three-stage isolator can also be produced by Sinclair; however it is uncommon as there are very few situations where an extremely-high degree of isolation is required.

Main Isolator Application

An important application of isolators occurs in transmit combining. The use of isolators is highly recommended whenever two or more transmitters are combined into a single antenna. It may also be needed when other transmitters in the same frequency band are co-located on the same or nearby antenna mounting structure.

There are no perfect combining methods. Some of a transmitter’s signal will get through the combining equipment to the other transmitter(s). The signal, if not stopped, can enter the final output stage of the transmitter power amplifier. Once the signal enters this stage, it will mix with the desired signal and produce intermodulation products. These intermodulation products have the potential to occur on receive frequencies or on neighboring receive frequencies, and produce receiver interference otherwise known as receiver desense. A transmitter that has a class “C” type transmitter power amplifier is more susceptible to this phenomenon than one with a type “A” power amplifier.

The mixing can be prevented by using isolators. The isolator will route almost all of the incoming stray transmit signals to the load where it is dissipated as heat. The isolator will attenuate the stray signal to a level where it does not affect the system.

In specifying a load for an isolator, one must ensure it is large enough to dissipate all possible reflected power. Keep in mind, that a short in the antenna or the antenna-feed line can reflect a significant amount of the transmitted signal back towards the transmitter. In some cases, this reflected power can destroy the transmitter power amplifier by overheating it, if isolators are not used. If the load encounters more power than it is rated for, then it will fail. If the load fails on an isolator, it becomes a circulator. This undesirable situation will route the reflected power back towards the transmitter. It may be prudent to purchase the load with a rating to handle all the transmitter power. Some people wrongly assume that a smaller load can be used due to the fact that a portion of the transmitted power is consumed by the antenna and the feed line, and that all the transmitted power does not make its way back to the isolator. In this case, not all of the transmitted power will be reflected back to the transmitter. There is a possibility that a short can occur closer to the isolator than the feed line and antenna, in which a more significant portion of the transmitted power will be reflected and sent to the load. Purchasing the isolator is much like buying an insurance policy – the isolator costs much less than the cost of repairing or replacing a transmitter, not including other potential penalties associated to system-down time.

Isolator Specifications

Major specifications to consider when choosing an isolator are discussed in the following section. The Sinclair I2113A isolator is used as an example with select specifications listed in Figure 7.

Electrical Specifications		
Frequency Range	MHz	132 to 174
Bandwidth	MHz	5
Field Tunable		No
VSWR (max)		1.25:1
Isolation (typ)	dB	35
Connectors		N-Female
Power Input	W	125
Insertion Loss (typ) Tx to Ant	dB	0.4
Insertion Loss (max) Tx to Ant	dB	0.6
Isolation (min)	dB	25

Mechanical Specifications		
Width	in (mm)	2.5 (64)
Depth	in (mm)	1.4 (36)
Length/ Height	in (mm)	2.5 (64)
Weight	lbs (kg)	1.1 (0.5)
Actual shipping weight	lbs (kg)	2 (0.91)
Shipping dimensions	in (mm)	13x9x3 (330x229x76)

Environmental Specifications		
Temperature range	°F (°C)	-22 to +140 (-30 to +60)

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Frequency Range (MHz) – This specification shows that the unit can be factory-tuned to work anywhere between 132 to 174 MHz. Nevertheless, this specification does not indicate that it can be re-tuned to a frequency other than the frequency that it was ordered for.

Bandwidth (MHz) – This isolator has a bandwidth of 5 MHz. This specification indicates that if two or more signals were multicoupled through this isolator, they can be a maximum of 5 MHz apart and still receive the performance within the specifications. All signals must fall within the operating bandwidth of the isolator.

VSWR (Max) – This rating of 1.25:1 indicates the input matching of the device. This value is referenced to 50-ohms. A rating of 1.25:1 corresponds to a return loss of 19 dB.

Isolation (Typ) – In terms of isolation, the typical value for a single-stage isolator is 35 dB.

Power Input (Watts) – This isolator has a power input rating of 125 watts. This specification indicates that the input power of 125 watts can be safely handled by the isolator. Note that the load resistor must also handle 125 watts as power can be reflected back to the transmitter and cause damage. For example, if the antenna falls over or the feed line develops a short, then the circulator equipped with a 100 watt load connected to a 125 watt transmitter, will have most of the 125 watts reflected back to the isolator. Although the isolator can safely handle this power, the load cannot. Once the load fails, the signal is reflected back to the transmitter and it may cause damage to the transmitter.

Insertion Loss (Typ and Max) – The specification for this unit shows a maximum insertion loss of 0.6 dB. This value indicates that if 100 watts are input to this device, 87.1 watts will pass through and the remaining 12.9 watts are dissipated as heat. However, the typical value is 0.4dB which indicates less loss than 12.9 watts.

Connectors – This device is equipped with type N-female connectors.

Temperature Range – This device will perform within specifications for a temperature range of -30 to +60 degrees Celsius or -22 to +140 degrees Fahrenheit.

This completes a basic overview of isolators and circulators. Sinclair can offer all the components described in this paper and the professional services to complete an RF system design that meets a customer’s specific needs.

Please refer to www.sinctech.com for more information related to duplexer, preselector, combiner, and cavity filter products.

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