Product Information

Microwave Waveguide Switches

Background

Microwave Applications Group (MAG) is well known as a supplier of ferrite microwave phase control devices since the 1960's. The United States Air Force AWACS E-3 Sentry antenna and B-1B AN/APQ-164 offensive radar system along with many other programs have used ferrite devices developed, designed, and produced by MAG. Beginning in the 1990's, we applied our experience to microwave switching devices. These switches use the principle of Faraday rotation to achieve a unique combination of high isolation, wide temperature range, and reciprocal operation at moderately high power levels. A broad introduction to the principles involved is presented here, followed by examples of our delivered switch products. MAG's design capability extends well beyond these examples, and we invite inquiries regarding other specific applications.

Introduction to Faraday Rotation Switches

Faraday rotation is fundamental to all microwave ferrite control devices. In its simplest form, shown in Figure 1, Faraday rotation describes the phenomenon in which the polarization of an electromagnetic plane wave rotates nonreciprocally as it travels through an infinite ferrite medium that is magnetized along the direction of propagation. At a given frequency the amount of rotation per unit length depends on (1) the activity of the ferrite material, and (2) the strength of the applied magnetic bias field.

Practical devices can use a metallized ferrite rod which forms a fully-filled circular

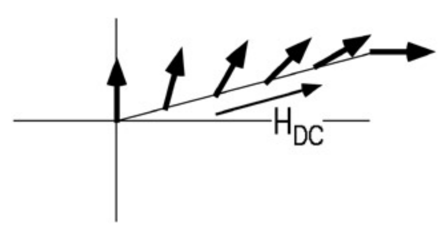


Figure 1 - Faraday Rotation Concept

waveguide. When a bias magnetic field is applied along the axis of the rod, the polarization plane of a linearly polarized TE11-mode will rotate as the wave propagates along the rod. The amount and direction of the rotation can be controlled by the magnitude and direction of the bias magnetic field; however, the relative insertion phase of the wave depends only on the magnitude of the applied bias field. A matched pair of rods both biased to produce 90 degrees of rotation will have exactly zero insertion phase difference if the rotation directions are the same, and, because of the reversal of the polarization plane, exactly 180 degrees of insertion phase difference if the rotation directions are opposite. Such a matched pair of rods can be assembled into a microwave bridge circuit using folded hybrid tees to form a reciprocal switch. High isolation between the outputs and operation at high peak and average power levels are possible with this type of switch. Figure 2 shows a block diagram of a basic switch bridge circuit configuration.

As noted above, the insertion phase difference between the matched pair of rods will remain constant; this applies even though the amount of Faraday rotation may change from the optimum 90 degree value. Such deviations may be caused by frequency and temperature variation, and result in a small amount of cross-polarized power at the output of the rotator sections. This cross-polarized power is typically absorbed in a film load or in a high power load placed in the side arm of an orthomode transducer (OMT). Thus the basic switch isolation is fairly insensitive to changes of frequency and temperature, with the main effect of shifts of rotation away from the optimum value being a small increase of insertion loss.

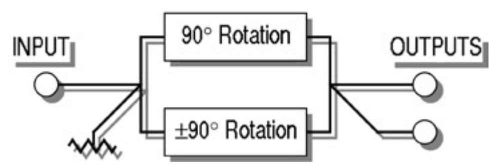


Figure 2 - Basic Switch Block Diagram

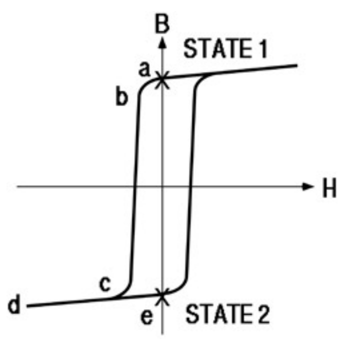


Figure 3 - Hysteresis Loop

Electronic Control

The state of each Faraday rotator is determined by the magnitude and direction of the magnetic bias flux along the axis of the rotator ferrite rod. External ferrite pieces placed in contact with the rotator rod form a closed magnetic path so that the bias flux can be maintained as a remanent condition with no continuous power required. State changes are commanded by voltage pulses applied to a coil wound around the rotator rod in the space between the rod and the external magnetic return path pieces.

The hysteresis loop shown in Figure 3 represents the B-H characteristic in the rotator rod with external return path elements. In this drawing, State 1 and State 2 are the remanent ("latched") operating points that provide equal magnitudes and opposite directions of bias magnetic flux. Note that the total magnetic flux is the flux density B integrated over the transverse-plane area of the rotator rod. These states should correspond to clockwise and counterclockwise rotations of 90 degrees in the rod. To switch between the two states, a voltage of the correct polarity is applied to the coil and the flux in the rod changes at a rate directly proportional to the instantaneous applied voltage and inversely proportional to the number of turns in the coil.

The coil current is proportional to H integrated over the length of the closed magnetic path. Since H=0 at State 1 and State 2, no steady current is needed in the quiescent case. Current will flow during the switching transient because H is nonzero. The magnitude of the current waveform versus time will generally have the shape shown in Figure 4, with the points a through e matching the designations on the hysteresis loop of Figure 3. The voltage pulse ends at point d when the current reaches a preset level.

Although one of the two rotator channels of the basic switch remains at the same state, its coil is pulsed with the same voltage polarity during each switching operation. Because the flux density level of the ferrite for this channel is already at the knee of the hysteresis loop, the current will rise rapidly to the preset value for terminating the voltage pulse. Sensing of the current rise to the preset limit in both channels is typically used as an indication that the ferrite is being switched normally, and a built-in-test (BIT) error signal is generated when the desired current limit is not sensed in a channel.

Manufacturing and Quality Controls

Products delivered by MAG must meet stringent requirements of mechanical characteristics and electrical performance. Engineering drawings define the product through various stages from raw material through final assembly. Manufacturing process and procedure documents define the detailed steps in the production flow. Acceptance test procedures define the electrical tests performed to demonstrate compliance with customer and/or MAG specifications. All documentation is reviewed and approved by MAG Engineering prior to release. Finally, MAG has a Quality System approved to MIL-I-45208A and meeting the intent of ISO 9002.

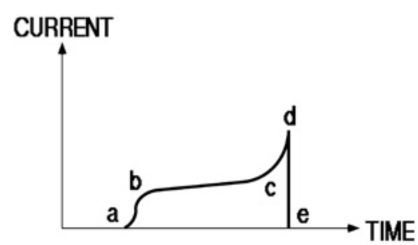


Figure 4 - Current Waveform

X-Band Basic SPDT Switch

50 kW Peak Power

0.5 dB Max Insertion Loss

17 dB Max Return Loss

25 dB Min Isolation

Less than 50 µsec Switching Time

4 KHz Switching Rate

2% Bandwidth

Operating Temperature Range -29° to +49°C

X-Band Basic SPDT Switch

The photograph to the left shows the first product example, which uses the bridge circuit described above and operates at X-Band. The specific application is an aircraft landing approach system. The switch connects a transmit-receive port reciprocally to azimuth or elevation antennas. Because the power levels are moderate, a film load is used to absorb cross-polarized error power.

Two electronic driver circuits are located on a printed wiring board incorporated into the switch housing. One of the drivers switches between two saturated states (State 1 and State 2) of the hysteresis loop as depicted in Figure 3 above. This driver controls the lower Faraday rotator in the bridge circuit of Figure 2 above, causing rotation of either +90 or -90 degrees corresponding to State 1 or State 2. The other driver is always commanded to State 1 which sets this rotator to +90 degrees. The coil current is monitored for each driver to detect magnetic saturation in the ferrite by sensing a predetermined current amplitude. Once this level is reached, the drive voltage is removed and the ferrite relaxes to the remanent “latched” state. Each driver contains BIT circuitry to verify that a current pulse has occurred. The BIT signals are ANDed to form a composite signal.

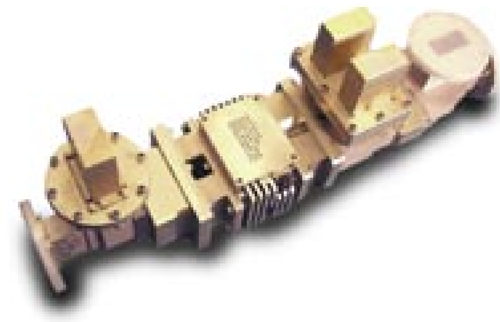
The rotators and drivers are mounted in an environmentally sealed housing. WR90 waveguide flanges and a standard bulkhead connector provide the RF and electrical connections to the switch.

C-Band High Power SPDT Switch

Our second product example is shown in the photograph to the right, and is a higher power reciprocal single input port, dual output port switch for use in C-Band Doppler weather radar systems. The switch is used to commutate the polarization of the RF energy transmitted and received by the radar system between vertical and horizontal. This feature allows the weather forecaster to form a better interpretation of the radar returns and thereby distinguish between rain, hail and snow.

The block diagram for this switch is the same as that of the X-Band single input, dual output switch described on the previous page. However, the peak and average operating power levels are much higher, and film loads are not able to handle the cross-polarized error power. Instead, orthogonal mode transducers are placed at the outputs of the Faraday rotator sections. Dummy loads capable of absorbing the error power for deviations from the ideal 90 degree rotation case are installed in the side arms of the OMT's.

As in the X-Band switch on the previous page, the Faraday rotators require no continuous power in the quiescent condition. Functioning of the electronic driver is essentially the same, with BIT signals available to verify that the proper current pulse has occurred during the transient condition.



C-Band High Power SPDT Switch

300 kW Peak Power

300 W Average Power

0.6 dB Insertion Loss

20 dB Max Return Loss

30 dB Isolation

Less than 50 µsec Switching Time

1.5 KHz Switching Rate

4% Bandwidth

Operating Temperature Range -40° to +50°C

X-Band SP3T Switch

25 kW Peak Power

250 W Average Power

1 dB Max Insertion Loss

15 dB Max Return Loss

20 dB Min Isolation

Less than 50 μsec Switching Time

1.2 KHz Switching Rate

10% Bandwidth

Operating Temperature Range -40° to +71°C

X-Band SP3T Switch

The next product example is a single input, triple output reciprocal switch for fire-control radar systems at X-Band.

Input power is split equally into two channels using an H-plane folded hybrid tee. Signals in each channel pass through two tandem one-bit, latching Faraday rotators which each impart either +45 degrees rotation or -45 degrees rotation. Based on the combination selected, the outputs of the tandem rotators will be -90, zero, or +90 degrees of rotation. The outputs of these channels are connected to OMT's. Selecting zero net rotation in both channels causes the RF signals to appear at the through arms of the OMT's and be summed at one arm of a following hybrid tee junction. Selecting ±90 degree rotation causes the RF signals to appear at the side arms of the OMT's and be summed in a following hybrid tee in one of the two output arms if the rotation senses are equal and in the other arm if the senses are opposite.

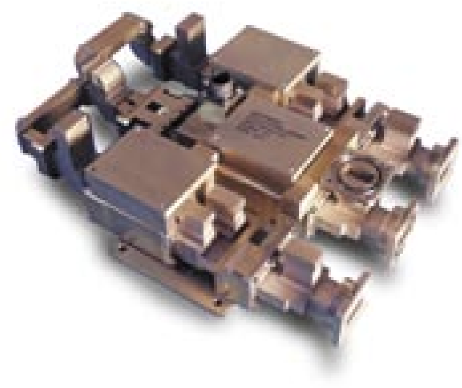
Because the magnitude of the magnetic bias field is the same in each of the tandem rotators, the overall insertion phases of the two channels will tend to track each other over frequency and temperature. However, drive compensation over temperature is necessary to avoid degradation of isolation caused by deviation of the rotation amounts from optimum. The currents in each winding are sensed for the BIT circuit and the lack of proper current in any winding will cause an error to appear at the BIT output.

X-Band DPDT Switch

The next example of a switch configuration is a duplexing, high isolation X-Band four-port unit for a naval application. This four-port device is designed for transmitted input, received output, and two selectable antenna output ports (Azimuth and Elevation), and mates with UG-138/U waveguide flanges. The complete package consists of a bridge-type four-port switchable circulator with two bridge-type reciprocal switches in the antenna output lines to increase the isolation to the unselected antenna.

The four-port circulator uses a folded hybrid tee at the input to divide the power equally into two channels. One channel contains a 90 degree waveguide twist followed by a zero degree rotator. The other channel contains a compensating length of ordinary waveguide followed by a ±90 degree switchable rotator. The reciprocal isolating switches use the basic switch block diagram of Figure 2 above, with one of the two outputs simply connected to a dummy load.

The electronic control circuits are housed integral with the RF switch housing. Two TTL logic level control signals are required for the switch. The first control signal uses a high level (5 Volts) to select one port and a low level (0 Volts) to select the other port. The other control signal is the switching pulse which initiates the switching sequence. The currents in each winding are sensed for the BIT circuit and the lack of proper current in any winding will cause an error to appear at the BIT output.



X-Band DPDT Switch

200 kW Peak Power

1.5 dB Max Insertion Loss

Less than 20 dB Return Loss

58 dB Isolation Transmitter to Idle

Less than 50 µsec Switching Time

4 KHz Switching Rate

4% Bandwidth

Operating Temperature Range -15° to +55°C

X-Band SPDT Reciprocal Switch

10 kW Peak Power

350 W Average Power

0.75 dB Max Insertion Loss

19.09 dB Max Return Loss

30 dB Min Isolation

Less than 20 μsec Switching Time

2.5 KHz Switching Rate

11% Bandwidth

Operating Temperature Range -55° to +55°C

X-Band SPDT Reciprocal Switch

This switch has a high average power requirement coupled with an impressive 11% bandwidth. The tradeoff of a higher isolation requirement, but at lower peak power levels, allows use of a resistive film load to absorb cross-polarized error signals, simplifying construction. MAG's bridge-type switch construction in an alternate packaging concept is used for this application.

This reciprocal device uses a very compact E-plane tee for the input, which equally splits the applied signal. One of the rotators is always commanded to +90 degrees, while the other is commanded to ±90 degrees depending on the output port desired. The outputs of the two rotators are combined in a very compact H-plane hybrid tee equivalent known as an ortho-tee. This configuration allows the switch to be located immediately behind the rotary joint in the particular application for this unit, requiring very little additional waveguide to interface to the two antennas.

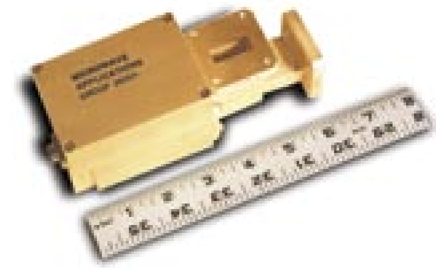
This switch uses MAG's driver compensation circuit to maintain the optimum rotation setting over a 110 degree Celsius temperature range. The driver allows the switch to provide very good isolation between the two channels over the entire temperature band. The two collocated drivers contain BIT circuitry to verify that the rotator windings receive the correct current pulse.

X-Band SPDT Tandem-Rotator Reciprocal Switch

The X-Band Tandem-Rotator Reciprocal Switch uses zero degree and 90 degree total Faraday rotation states to achieve reciprocal connections to the desired ports. This structure operates at moderate isolation levels and moderate peak and average power levels compared with MAG bridge-type switches, but provides a smaller and less expensive package. The beauty of this switch is its compact size (6.18 inches / 156.9 mm long x 2.3 inches / 58.4 mm wide x 2.84 inches / 72.1 mm high), and light weight (1.6 pounds / 726 grams).

The simplicity of this switch is achieved by using a single rotator element, thereby eliminating the need for input and output tees. The zero degree and 90 degree states drive into either port of an OMT.

The driver is a mature design with compensation to maintain proper rotation over the operating temperature range. A BIT circuit is included providing switch status information.



X-Band SPDT Tandem-Rotator Reciprocal Switch

50 kW Peak Power

100 W Average Power

0.5 dB Max Insertion Loss

17.7 dB Max Return Loss

25 dB Min Isolation

Less than 25 µsec Switching Time

2 KHz Switching Rate

12% Bandwidth

Operating Temperature Range -30° to +60°C

X-Band DPDT Circulator Switch

75 kW Peak Power

400 W Average Power

0.85 dB Max Insertion Loss

17.7 dB Max Return Loss

25 dB Min Isolation

Less than 35 µsec Switching Time

4 KHz Switching Rate

9% Bandwidth

Operating Temperature Range -40° to +85°C

X-Band DPDT Circulator Switch

This switch uses two reciprocal elements to achieve nonreciprocal operation. The device is essentially a bridge-type four-port switchable circulator. Although either input port can be used with the resultant return signal appearing at the other, this particular device is configured for VSWR monitoring of the reflected signal using just one input.

Input power is equally split into two channels using an H-plane folded hybrid tee. One channel contains a 90 degree waveguide twist followed by a ±90 degree switchable rotator. The other channel contains a compensating length of ordinary waveguide followed by a zero degree rotator. Use of the twist section achieves the nonreciprocal action desired for this application. The peak and average power requirements of the device necessitate placement of OMT's at the rotator outputs. The two OMT outputs are applied to the colinear ports of a folded H-plane tee and the two orthogonal arms act as the respective antenna interfaces. The offport of the input tee will see any received signal, but in this case it is used for VSWR monitoring of the two antennas.

Driver compensation to maintain the optimum rotation over the operating temperature for each element is utilized to avoid degradation of the isolation caused by incorrect rotation values. The current in the windings of each rotator element is monitored by a BIT circuit. As a safety mechanism, an error signal will appear at the BIT output if current is lacking at either or both windings.

Summary and Continuing Developments

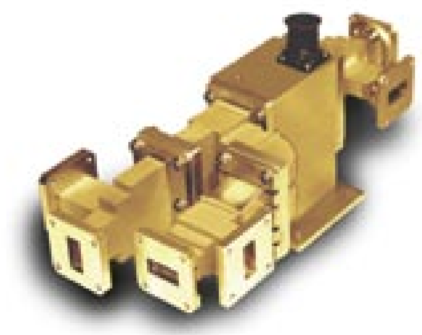
Whether constant current or latching configuration, MAG's ferrite based waveguide switches are available from Ka-Band to L-Band, and provide good channel to channel isolation and insertion loss at moderate peak and average RF power levels.

The bridge-type switch can be realized as either reciprocal or nonreciprocal with a slight length adjustment, and can operate in either a single pole or double pole configuration with only a small impact on the isolation between the two input ports. Bridge-type switches are available in DT, 3T, or 4T variations.

MAG developed compact tandem-rotator switches as a means of providing performance similar to the bridge-type switch, but at a more economical price. MAG is currently developing a switching circulator design as another alternative in a cost driven environment.

Our goal is finding cost effective solutions to meet customer specifications. Contact MAG and utilize our experience in order to fulfill the needs of your RF switch requirement.

C-Band Constant Current
SPDT Switch



X-Band Constant Current
DP4T Switch