MICROWAVE APPLICATIONS GROUP

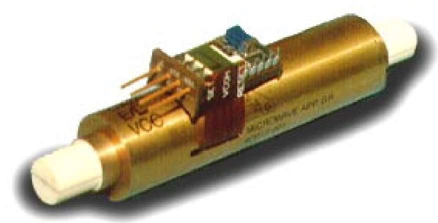
Dual-Mode Phase Shifters

Data Sheet

C-Band to Ka-Band • Efficient • Economical

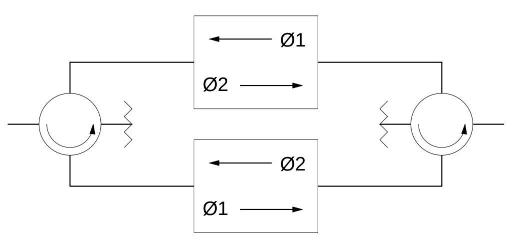
MAG's Dual-Mode phase shifters are the only latching, reciprocal ferrite phase shifters successfully produced in large quantities, and are ideal for passive phased array antenna applications. These units, available in frequencies from C-Band to Ka-Band, allow Electronically Steerable Arrays (ESA's) to be deployed at reasonable cost with good power handling capabilities. One successful application is in the United States Air Force B-1B offensive radar system. MAG designed and built more than 130,000 units for this program.

MAG's Dual-Mode phase shifters use a quadrantally symmetric ferrite rod so that circularly polarized energy will propagate through it without change of field distribution. The name "Dual-Mode" comes from the fact that the structure supports opposite-sense circularly polarized modes in the transmit and receive directions so that phase changes resulting from command state changes will be reciprocal. External latching yokes fitted to the ferrite rod provide a closed magnetic path for latching operation. Resistive films, incorporated in dielectric sections both ends of the rod, absorb undesired cross-polarized fields. See back of sheet for typical data at various frequency ranges.



PARAMETER	FREQUENCY				
	C-BAND	XL-BAND	X-BAND	Ku-BAND	Ka-BAND
Percent Bandwidth	9	6	8	5	4
Insertion Loss (dB)	1.0 avg.	1.0 avg.	1.0 avg.	1.0 avg.	1.25 max.
Insertion Loss Modulation (dB)	±0.2	±0.2	±0.2	±0.2	±0.2
Maximum Return Loss (dB)	-15.0	-17.0	-13.98	-17.69	-15.56
Peak RF Power (Watts)	250 min.	200 min.	1000 min.	28 min.	100 min.
Average RF Power (Watts)	10 min.	10 min.	6 min.	4 min.	4 min.
RMS Phase Error (Degrees)	6	5	6	10	4
Reciprocity (Degrees)	±3	±3	±3	±3	±4
Switching Time (Microseconds)	75	120	160	80	60
Switching Rate (Hz)	2000	526	2000	200	1000
Size (Inches)	4.3 x Ø .82	4.8 x Ø .64	3.8 x Ø .53	2.2 x Ø .35	2.2 x Ø .32
Weight (Ounces)	3.0	2.4	1.4	0.4	0.3
Operating Temperature Range (Degrees C)	-20 to 70	-10 to 65	20 to 85	-20 to 49	-25 to 55

This diagram depicts a reciprocal device realized using nonreciprocal ferrite components.



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3030 Industrial Parkway • Santa Maria, California 93455 • (805) 928-5711
www.magsmx.com • sales@magsmx.com

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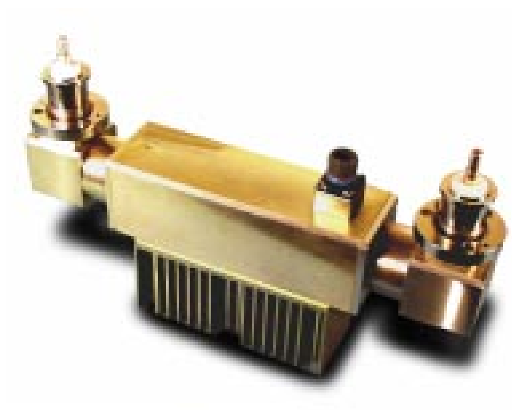
Rotary-Field Phase Shifters

Data Sheet

L-Band to Ku-Band • Unlimited Phase Shift • Highly Accurate

MAG Analog Rotary-Field Ferrite Phase Shifters are uniquely designed to provide unlimited phase shift with modulo-360 degree phase control characteristics that are independent of frequency, temperature, power level, and ferrite material parameters. These units, available in frequency ranges from L-Band to Ku-Band, are capable of handling high power levels while maintaining rms phase error to less than one degree. A very successful application of these units is the low sidelobe, single-axis scanning antenna of the E-3 Airborne Warning and Control System (AWACS).



Rotary-Field Phase Shifter geometry consists of a transducer from rectangular to circular ceramic filled waveguide, a linear to circular polarizer, a rotatable half-wave plate, a circular to linear polarizer, and a transducer back from circular to rectangular waveguide. The phase shift angle is proportional to twice the angle of rotation of the half-wave plate, controlled electronically by digital or analog drivers. Major design choices involving ferrite material type and size, quarter-waveplate, matching transformer, and driving yoke are optimized for specific system requirements. See back of sheet for typical data at various frequency ranges.

Rotary-Field Phase Shifters

PARAMETER	FREQUENCY				
	L-BAND	S-BAND	C-BAND	X-BAND	Ku-BAND
Percent Bandwidth	15	12.7	8.8	10.5	5.0
Average Insertion Loss (dB)	1.2	0.6	0.6	0.7	0.7
Insertion Loss Modulation (dB)	0.2	0.3	0.3	0.3	0.3
Maximum Return Loss (dB)	-13.98	-14.0	-15.6	-17.7	-17.0
Peak RF Power (Kilowatts)	8	40	25	4	2
Average RF Power (Watts)	400	600	250	60	40
Typical RMS Phase Error (Degrees)	4.0	1.0	1.0	1.0	1.0
Switching Time (Microseconds)	250	300	250	200	200
Switching Time with Boost (Microseconds)	250	100	100	100	100
Coil Current (Milliamperes)	2400	900	500	230	160
Coil Resistance (Ohms)	1.0	1.0	3.0	9.5	14.0
Size (Inches)	2.5 x 7.0 x 13.4	2.0 x 6.6 x 8.0	2.0 x 3.0 x 4.8	1.25 x 1.25 x 3.2	1.0 x 1.25 x 2.0
Weight (Ounces)	282	62	30	6	4
Operating Temperature Range (Degrees C)	0 to 55	0 to 50	-20 to 50	-40 to 70	-40 to 90

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Synthetic Aperture Radar Components

Data Sheet

Synthetic Aperture Radars provide extremely high resolution imagery from long ranges in all types of weather, day or night. Microwave Applications Group (MAG) provides components for several well-known Synthetic Aperture Radar systems. Among these components are MAG's Rotary-Field Phase Shifters and MAG's low-cost Dual-Mode Phase Shifters.

MAG Rotary-Field Ferrite Phase Shifters are uniquely designed to provide unlimited phase shift with modulo-360 degree phase control characteristics that are independent of frequency, temperature, power level, and ferrite material parameters. These units offer the advantage of continuously variable phase scanning and are capable of handling high power levels while maintaining rms phase error to less than one degree.

MAG Dual-Mode Phase Shifters are the only latching, reciprocal ferrite phase shifters successfully produced in large quantities, and have successfully been applied to numerous military and commercial applications. These units have been proven to be much more robust and significantly less costly than active array elements, and are capable of handling moderate levels of power.

MAG provides components for the following Synthetic Aperture Radar systems:

- ***U.S. Air Force U-2 Aircraft ASARS-2 Advanced Synthetic Aperture Radar System;***
- ***U.S. Air Force RQ-4 Global Hawk UAV Synthetic Aperture Radar;***
- ***U.K. Ministry of Defence ASTOR Sentinel R1 Airborne Stand-Off Radar;***
- ***U.S. Air Force RQ-1 Predator UAV TESAR Synthetic Aperture Radar.***

The use of ferrite phase shifters in Synthetic Aperture Radars allows electronic steering of the antenna beam. The use of Rotary-Field Phase Shifters with continuously variable phase capability allows real time slewing of the antenna beam at a moderate rate.

Typical data is shown below for the specific programs listed, however MAG's ferrite phase shifters are readily available from S-Band to K-Band.

Parameter	X-Band Rotary-Field	Ku-Band Dual-Mode
Bandwidth	10%	8%
Insertion Loss	0.7 dB avg.	1.0 dB avg.
Return Loss	-17.69 dB	-17.69 dB
Peak RF Power	4 kW	28 W min.
Average RF Power	60 W	4 W min.
RMS Phase Error	1 Degree	6 Degrees
Switching Time	100 Microseconds	50 Microseconds
Weight	3 Ounces	0.4 Ounce

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1. Introduction

Early versions of the latching ferrite phase shifters used discrete lengths of ferrite to provide phase quantization. Thus, a four-bit phase shifter consisted of cascading four sections of ferrite (of length *l, 2l, 4l, 8l*) separated by dielectric spacers which provided magnetic isolation. Each individual bit operated at the maximum remanent magnetization (plus or minus) so that a simple electronic circuit was adequate to control the phase shifter. However, machining and assembly of discrete ferrite sections is expensive. Furthermore, variations of remanent magnetization with temperature and frequency cannot be compensated easily with this type control. Most phase shifters are now constructed from a continuous section of ferrite with the phase shift quantization, frequency compensation and temperature compensation allocated to the electronic driver. The driver accomplishes these tasks by operating the ferrite in a partially magnetized state. As the magnetization varies from negative saturation to positive saturation, the relative permeability of the ferrite is controlled by adjusting the magnetic flux density in the ferrite core. The flux change cycle consists of a "reset" portion plus a "phase set" portion, as indicated by the sketches of Fig. 1. The purpose of the reset portion is to establish a reference limit-condition of magnetization of the ferrite. The phase-set portion of the cycle meters the change of flux away from this reference. It is important to establish the reference point in a repeatable manner, since the precision of phase setting is directly dependent on this condition. Phase shift is then accomplished by changing insertion phase from the reference point. The "memory" property of the ferrite material hysteresis loop is essential in allowing remanent-flux operation at a desired phase state, but tends to work against establishing a repeatable reset reference. Experience has shown that there is a tendency for the apparent reset phase state to wander in a manner dependent on the previous phase-set history of the unit. An improvement in the reset accuracy can be achieved by restricting all flux change operations to movements around the major hysteresis loop. Reset from a given remanent point is accomplished by first driving to the longest phase shift end of the hysteresis loop ("full set") and then driving to the opposite end of the loop

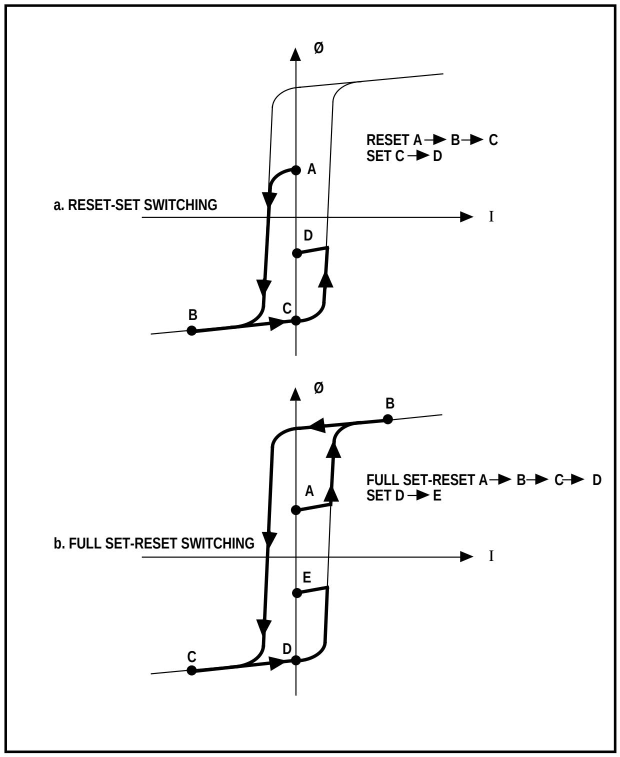


Figure 1. *Flux Change Cycles.*

("full reset"). Using this approach, adequate accuracy is possible with the peak current level as the criterion for terminating the full set and full reset pulses.

The phase-set portion of the cycle uses the level-set signal information to achieve a particular remanent flux state which corresponds to the desired insertion phase level for the phase shifter. Setting of the remanent flux state can be done by direct open-loop construction of a driving pulse from the level-set signal or by a feedback arrangement in which information about the voltage amplitude and duration of an applied pulse is accumulated, compared with the level-set signal, and used to terminate the drive at the appropriate time. The simplest relationship of either type is one in which the Volt-time integral of the driving pulse is made to be proportional to the desired phase shift angle. In practice, it is necessary to calibrate the Volt-time integral to fit the actual phase shifter characteristics, and even to change this calibration as a function of operating frequency and temperature.

2. Phase Shifter Control Characteristics

A typical control characteristic of a latching phase shifter and its electronic driver is shown in Fig. 2. The control characteristic will vary from phase shifter to phase shifter. Also, changing the r-f frequency or the ambient temperature will cause changes in the control characteristic. In order to accurately set the phase shifter, calibration curves for each device at various operating frequencies and temperatures are measured and stored either in the beam steering computer or in PROM at the driver itself. Errors of the order of three degrees rms are achievable for a 7-bit device over a ten percent frequency range and a temperature range of 90 degrees Celsius.

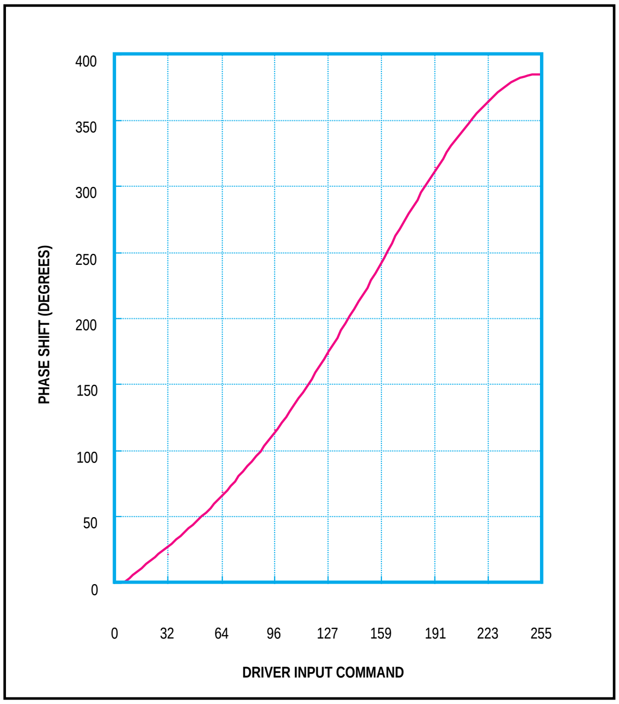


Figure 2. *Control Characteristic of a Latching Phase Shifter.*

3.1 MAG Driver Developments

For the past few years, MAG has been investigating methods of reducing driver cost. Removal of the requirements to mount the driver directly to the phase shifter has allowed us to bundle several drivers into one hybrid package with the very desirable effect of reducing both cost, size and weight.

To accurately establish to state of a ferrite phase shifter, the magnetic flux in the microwave ferrite is set by measuring the volt-time product associated with the phase shifter SET pulse. Although the supply voltage is approximately constant, variations affect phase shifter performance unless compensation is provided. The MAG driver provides this compensation by sampling the phase shifter control voltage and digitally integrating the sampled voltage to provide accurate characterization of the volt-time product.

Using the digital integration described above, a new logic chip was developed using 5 Volt CMOS standard cells. The Application Specific Integrated Circuit (ASIC) chip provided the logic necessary to control four phase shifters. Built-in-test (BITE) was also incorporated into the driver to allow diagnostic testing of the driver and phase shifter. To prove the design, a breadboard was built using LSTTL logic. After verification of the design, the chip was physically realized in September 1988.

3.2 Driver Features

The driver provides the usual control waveforms for latching dual-mode ferrite phase shifters, e.g., a saturated reset pulse followed by a timed set pulse. The time of the set pulse is determined by the data word and the voltage applied to the phase shifter drive coils. The driver provides these waveforms for all channels simultaneously in the case of multichannel drivers.

Special features incorporated into the driver are:

Built-in-test circuits which provide for the sensing of the set and reset currents in each channel and provide an indication of a failure.

If a particular channel does not receive a new data word (parallel) or receives data word zero (serial), the output drivers are not activated during the switching cycle.

Automatic shutdown of the driver limits the maximum set current, which protects the set output circuit if the phase shifter saturates.

The driver requires two power supplies. The first is the logic supply of 5 Volts which must be well regulated since this voltage is also the reference voltage for the A/D converter used in the ASIC to measure volt-time product. The supply must furnish 25 mA current to each ASIC connected to it. The second supply – which may have poor regulation – is the supply used to provide switching energy to the phase shifter. Since the phase shifter is a latching device, it only requires drive energy when it is desired to change the phase state. To reduce the peak current demands on the second power supply, local energy storage is provided by a capacitor located at the driver. Typically, the second power supply operates at 15 Volts. The current from this supply is dependent upon the geometry of the phase shifter being controlled and the switching rate of the phase shifter. The driver can be switched at rates up to 2 KHz.

The driver operates by sensing the reset current and turning off the voltage once the reset current has reached a given value – typically in the range 1.2 to 1.8 Amp. The set current is also sensed and the set circuit is protected by shutting off the driver whenever this current exceeds a predetermined limit. The threshold currents for the BITE circuits are 750 mA for the reset and 150 mA for the set.

Data is supplied to the driver via digital input signals. The logical low is between 0 and 1.5 Volts while the logical high is between 3.5 and 5.0 Volts. The input current in either the low or high state is less than or equal to 10 microamperes. Data may be entered using either a parallel or serial mode.

The parallel mode uses an 8-bit data bus and an address bus whose size is commensurate with the number of drivers connected to the data bus, i.e., a 4-bit address bus is sufficient to separately address 16 channels. Data on the data bus will be loaded to the address specified by the address bus upon the application of a signal to the data load (DL) line. The timing diagram is given in Fig. 3a. The maximum rate that data may be loaded is 5 MHz. The reset-set switching cycle is initiated by application of a signal to the output enable (OE) line.

The serial mode of operation requires the data to be entered into a latch on the driver via a clock signal. The maximum clock frequency is 5 MHz. The reset-set switching cycle may be initiated by the coincidence of the clock and the data or by a signal on an output enable (OE) line as shown in Fig. 3b.

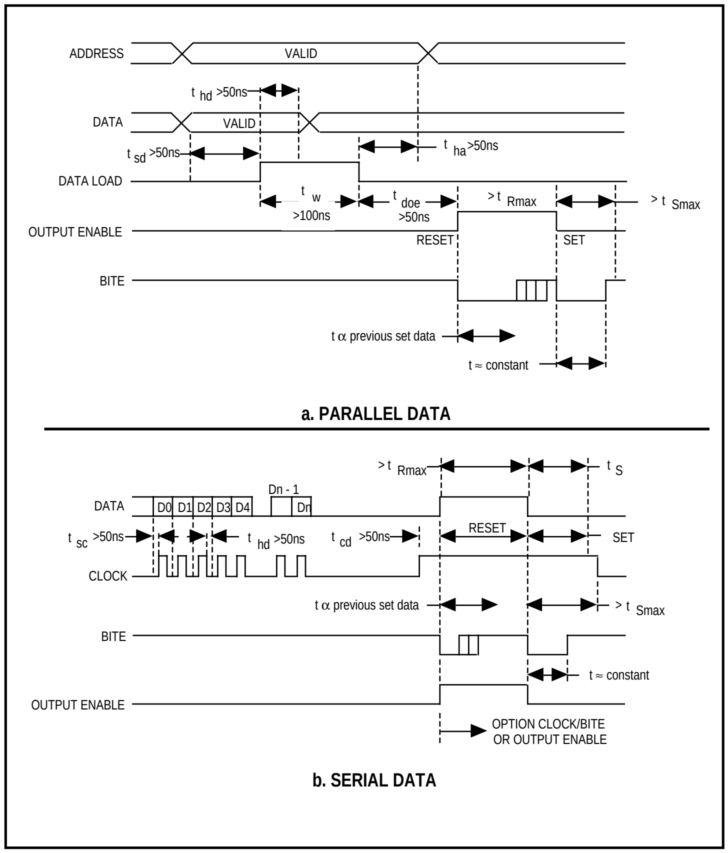


Figure 3. *Timing Diagrams.*

3.3 Driver Packaging

MAG has developed several techniques for packaging the logic chip and the associated power stages. The least costly of these uses discrete components mounted on a circuit board. The ASIC is mounted in a package which is hermetically sealed. Fig. 4 shows a realization of a four-channel driver which uses a parallel interface and Fig. 5 shows a four-channel driver using a serial interface. It is obvious that the serial interface results in a significant reduction in size at the cost of increased data loading time. What is not so obvious is the fact that the serial configuration results in increased reliability because of the fewer connections involved.

A phased array antenna will normally have a beam steering computer (BSC) which allows for temperature and frequency compensation required by the phase shifter. However, in some cases it is desirable to include memory on the driver to provide the necessary compensation. The single-channel driver shown in Fig. 6 uses discrete components and PROM storage to provide frequency and temperature compensation.

The hybrid microelectronic circuit shown in Fig. 7 is a driver which controls eight phase shifters. Two ASICs as well as the crystals, resistors, capacitors and transistors are located on a substrate inside the hermetically sealed package. The size and weight reduction realized by this packaging technique is achieved with a significant cost penalty – particularly for small volume production.

A photograph of a driver containing 8 ASICs and capable of controlling 32 phase shifters is shown in Fig. 8. MAG has used this packaging extensively in phased arrays developed and delivered to the Naval Air Warfare Center at China Lake, California. The high density packaging results in the lowest possible costs.

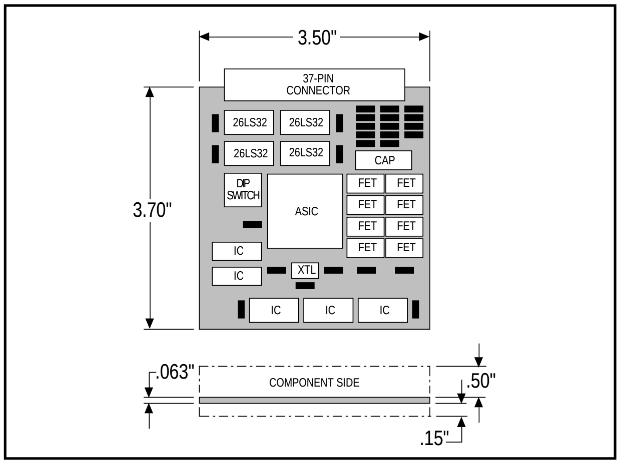


Figure 4. *Four-Channel Driver, Parallel Mode.*

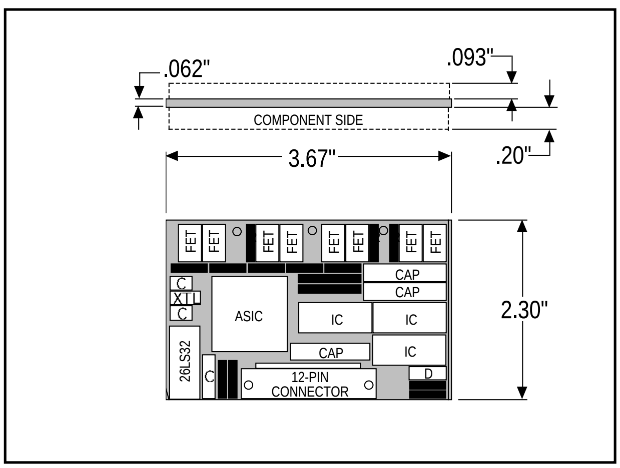


Figure 5. *Four-Channel Driver, Serial Mode.*

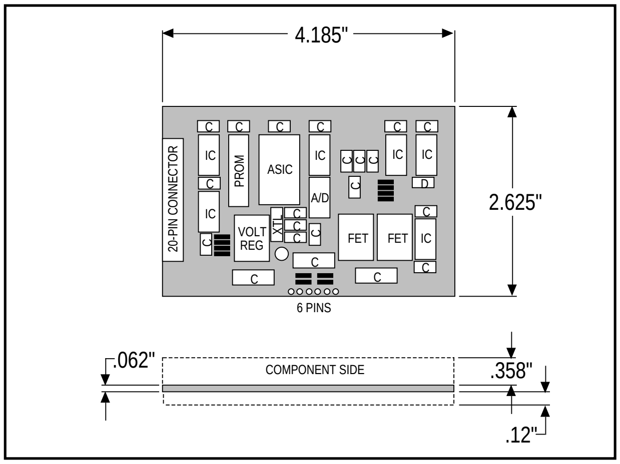


Figure 6. *Single-Channel Driver Incorporating a PROM for Frequency and Temperature Compensation.*

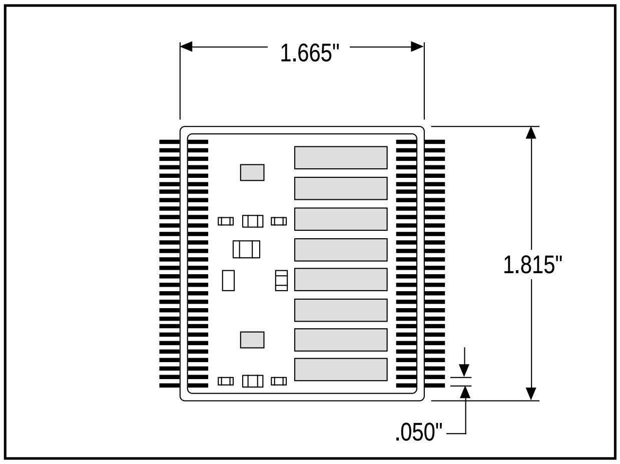


Figure 7. *Eight-Channel Driver Hybrid Package.*

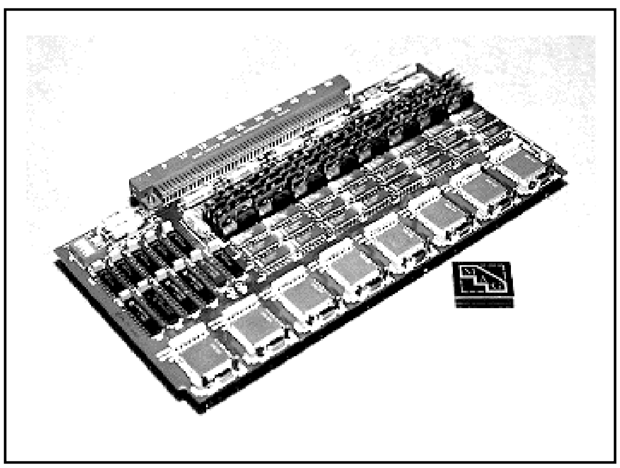


Figure 8. *Photograph of 32-Channel Driver Board.*

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

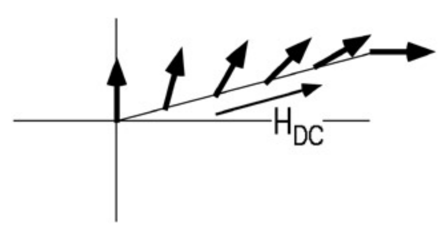


Figure 1 - Faraday Rotation Concept

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.

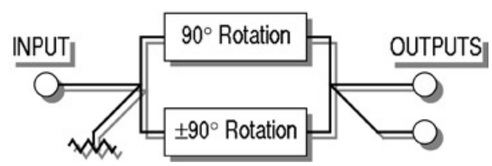


Figure 2 - Basic Switch Block Diagram

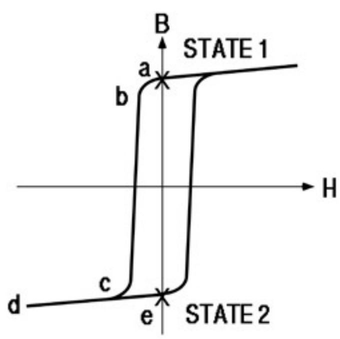


Figure 3 - Hysteresis Loop

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.

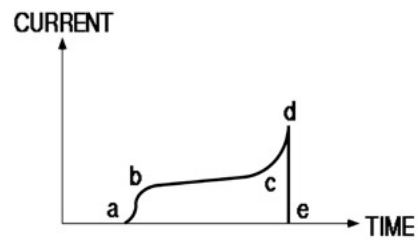


Figure 4 - Current Waveform

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.

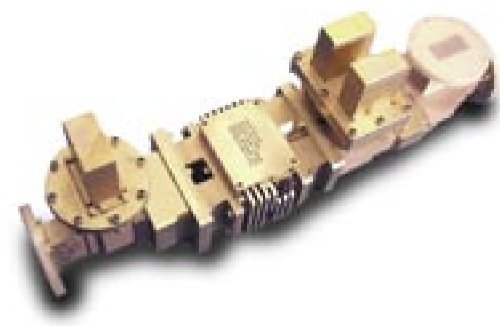
The rotators and drivers are mounted in an environmentally sealed housing. WR90 waveguide flanges and a standard bulkhead connector provide the RF and electrical connections to the switch.

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

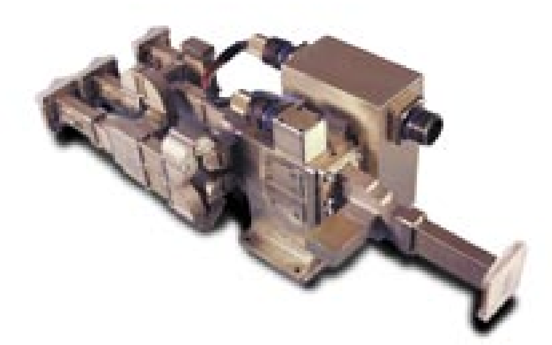
30 dB Isolation

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.

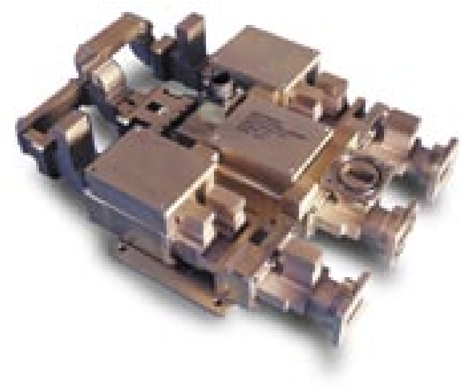
Because the magnitude of the magnetic bias field is the same in each of the tandem rotators, the overall insertion phases of the two channels will tend to track each other over frequency and temperature. However, drive compensation over temperature is necessary to avoid degradation of isolation caused 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.

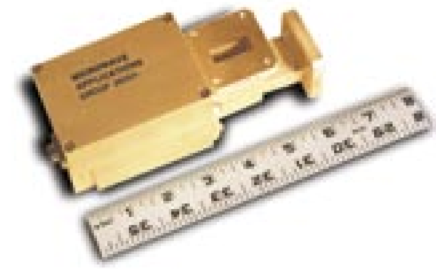
This switch uses MAG's driver compensation circuit to maintain the optimum rotation setting over a 110 degree Celsius temperature range. The driver allows the switch to provide very good isolation between the two channels over the entire temperature band. The two collocated drivers contain BIT circuitry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

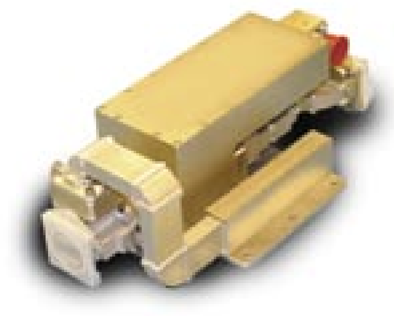
25 dB Min Isolation

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

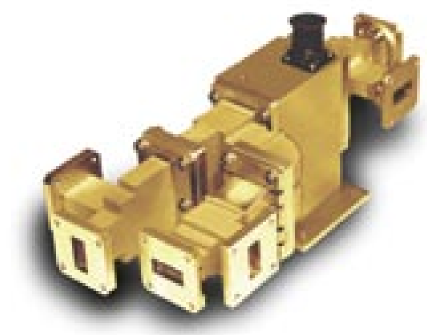
Whether constant current or latching configuration, MAG's ferrite based waveguide switches are available from Ka-Band to L-Band, and provide good channel to channel isolation and insertion loss at moderate peak and average RF power levels.

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

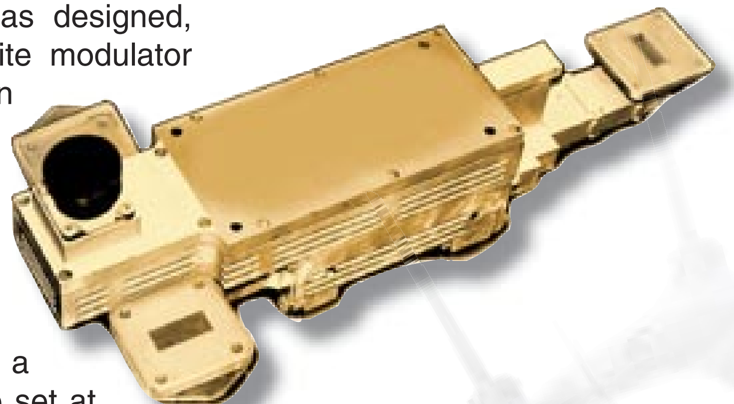


X-Band Constant Current
DP4T Switch

Roll Resolvers

Product Information

Waveguide Ferrite Modulator Control Devices

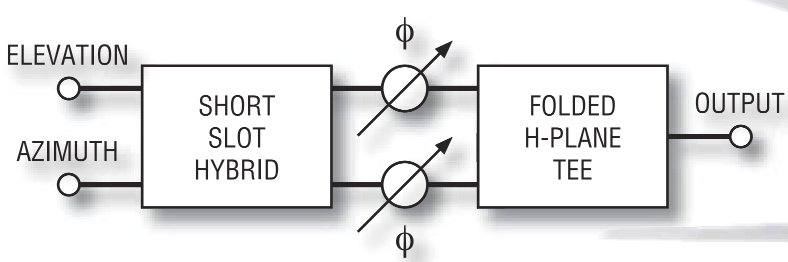


Microwave Applications Group (MAG) has designed, produced, and delivered waveguide ferrite modulator control devices to compensate for motion while an aircraft is in flight and its radar system is in use. Commonly referred to as a “Roll Resolver,” these units are in service currently on two well-known platforms.

The Roll Resolver functions by performing a rotation of coordinates from the reference set at the input of the network to a rotated set at the output of the network. This is accomplished using the circuit shown below. When one phase shifter is set to angle ϕ and the other to the angle $-\phi$, the output of the circuit (OUT) expressed in terms of the input at the elevation port (EL) and the input at the azimuth port (AZ) may be shown to be

$$OUT = EL \cos(\phi) - AZ \sin(\phi).$$

This is the true vertical signal from the monopulse antenna, which has undergone a roll of ϕ degrees. The true horizontal signal may be found by setting the phase shifters to command angles $\pm\phi\pm\pi/2$.



The phase shifters shown in the schematic diagram are realized using MAG designed and produced Rotary-Field phase shifters. This type of ferrite phase shifter has very good phase accuracy and exhibits low insertion loss and insertion loss modulation. A matched set of phase shifters and the electronic circuitry required to control the phase shifters are assembled into an aluminum housing. The short slot hybrid and the folded H-plane tee are bolted to the housing to form a rugged assembly shown in the photograph on the front page. The depicted unit is representative of the Roll Resolvers which continue to operate successfully on board the U.S. Air Force's B-1B bombers. A similar device is in use with the Air Force's B-2 bomber fleet.

Microwave Applications Group has a proven record of creativity and innovation in microwave component and subsystem design for government, military, and commercial applications. MAG has been at the forefront of electronically-steered radar technology, especially in the area of ferrite-based devices. Programs utilizing MAG designed and produced products over the last 30 years are well-known and continue to operate successfully. Examples of products developed and supplied by MAG are:

- *Precise analog ferrite phase shifters for use at high peak and average power levels;*
- *Reciprocal, latching, ferrite phase shifters with weight and size parameters compatible for use in phased array antennas;*
- *Compact, high performance phase shifters for use in sequential lobing of array antennas;*
- *High performance waveguide isolators, variable power dividers, and polarization controllers;*
- *Ferrite switches that achieve a unique combination of high isolation, wide temperature range, and reciprocal operation at high power levels;*
- *Electronic drivers, function generators and interface equipment for real-time computer control of processes;*
- *Planar phased array antennas and linear array modules, complete with phase shifters, drivers, antenna controller, radiating elements and feed assembly;*
- *Multi-channel driver packages with the capability to drive a set of phase shifters.*

MAG continues to develop new products using proven ferrite technology, and looks forward to advancing the state of the art of microwave components and subsystems.

MICROWAVE APPLICATIONS GROUP
3030 Industrial Parkway • Santa Maria, California 93455 • (805) 928-5711
www.magsmx.com • sales@magsmx.com

MICROWAVE APPLICATIONS GROUP

Electronic Scanning Antennas

Product Information

Microwave Applications Group (MAG) has a proven record of creativity and innovation in microwave component and subsystem design for government, military, and commercial applications. MAG has been at the forefront of electronically-steered radar technology, especially in the area of ferrite-based devices. Programs utilizing MAG designed and produced products over the last 30 years are well-known and continue to operate successfully. In more recent years, MAG has designed and built Electronically Scanning Antennas, utilizing years of component-level experience combined with engineering expertise. The following pages provide data on these antennas produced by MAG:

Phased Array Antenna System (PAAS), C-Band, X-Band, Ku-Band

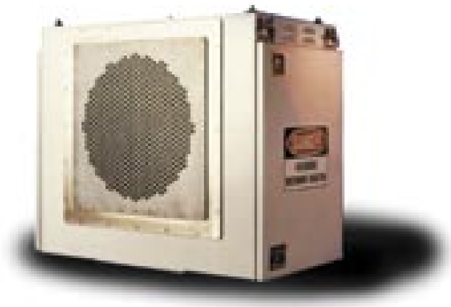
I-30 Expedient Antenna System, X-Band

Terminal Guidance Antenna, Ku-Band

Planar Phased Array Antenna, Ku-Band

Millimeter-Wave Antenna, Ka-Band

Phased Array Antenna System (PAAS), C-Band, X-Band, Ku-Band



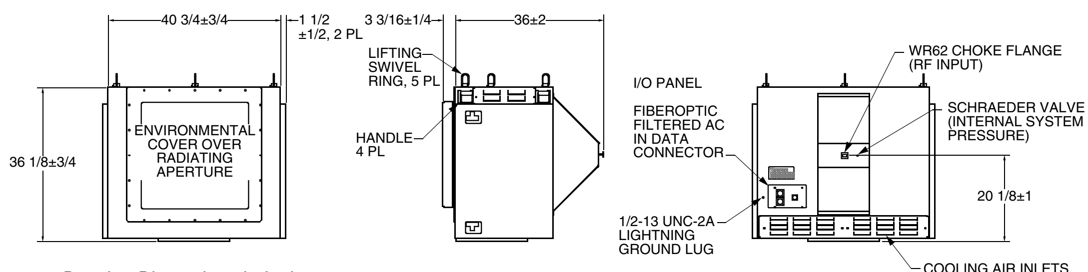
Designed for test range instrumentation applications, the Phased Array Antenna System (PAAS) is a family of ruggedized, low-cost electronically scanning antennas.

The antenna portion of the system is made up of a phased array transmission lens (bootlace lens) with a space feed. The lens consists of aperture and feed plates with ferrite phase shifters contained between the two plates. Radiating elements integrated into the aperture and feed plates are distributed on an equilateral triangular grid. The element spacing is selected to ensure that grating lobes do not occur in visible space when the beam is scanned to its limits, and the triangular grid geometry is used to minimize the number of elements.

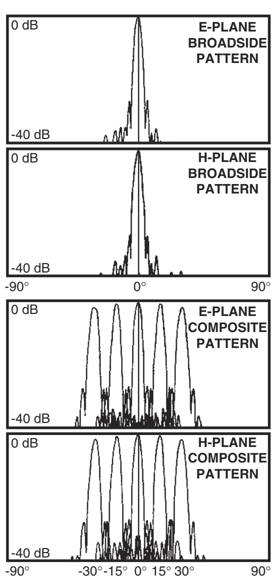
In addition to the antenna portion, the system also consists of a beam steering controller (BSC). The BSC accepts signals from the system controller and points the antenna main beam in a specified direction within a 60 degree cone about the antenna normal. Digital communication between the BSC and the antenna is accomplished via a fiberoptic network.

The mechanical and electrical characteristics, physical dimensions and interface data, as well as measured patterns are presented for the Ku-, X-, and C-Band PAAS antennas.

Ku-Band

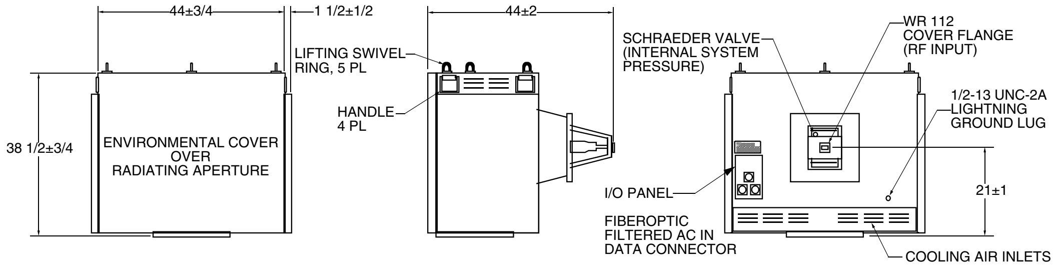


Drawing Dimensions in Inches

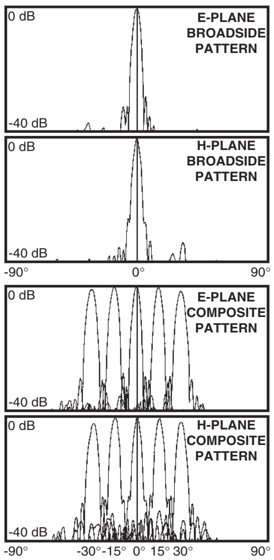


CHARACTERISTIC	DESCRIPTION
Frequency	Ku-Band, 7%
Instantaneous Bandwidth	100 MHz
Polarization	Circular, RHCP or LHCP Selectable
VSWR	1.40 : 1 max
Gain (Broadside)	30 dB min
Peak Power	30 KW
Average Power	1500 W
Beamwidth (Nominal)	Pencil Beam, 3.7 Degrees
Beam Pointing Accuracy	±0.3 Degrees max
Beam Resolution	0.6 Degrees max
Beam Broadening	0.9 Degrees max
Peak Sidelobe Level	-25 dB max
Beam Switching Time	120 Microseconds
Load Time	3.24 Milliseconds max
Operating Temperature	-20 to +50 Degrees C

X-Band

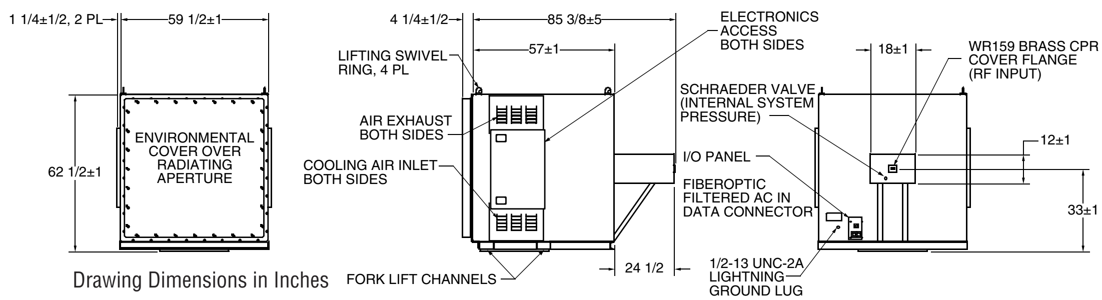


Drawing Dimensions in Inches

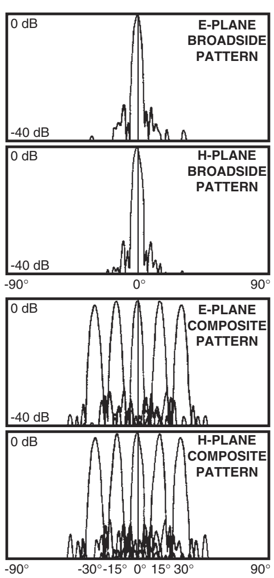


CHARACTERISTIC	DESCRIPTION
Frequency	X-Band, 7%
Instantaneous Bandwidth	50 MHz
Polarization	Linear and Circular Models
VSWR	1.50 : 1 max
Gain (Broadside)	30 dB min
Peak Power	50 KW
Average Power	3 KW
Beamwidth (Nominal)	Pencil Beam, 1.9 Degrees
Beam Pointing Accuracy	±0.3 Degrees max
Beam Resolution	0.6 Degrees max
Beam Broadening	0.9 Degrees max
Peak Sidelobe Level	-25 dB max
Beam Switching Time	120 Microseconds
Load Time	3.24 Milliseconds max
Operating Temperature	-20 to +50 Degrees C

C-Band



Drawing Dimensions in Inches



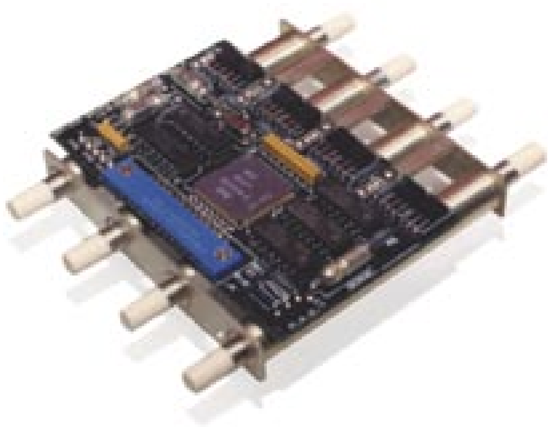
CHARACTERISTIC	DESCRIPTION
Frequency	C-Band, 17%
Instantaneous Bandwidth	100 MHz
Polarization	Circular, RHCP or LHCP Selectable
VSWR	1.40 : 1 max
Gain (Broadside)	30 dB min
Peak Power	25 KW
Average Power	10 KW
Beamwidth (Nominal)	Pencil Beam, 3.7 Degrees
Beam Pointing Accuracy	±0.3 Degrees max
Beam Resolution	0.6 Degrees max
Beam Broadening	0.9 Degrees max
Peak Sidelobe Level	-25 dB max
Beam Switching Time	200 Microseconds
Load Time	3.24 Milliseconds max
Operating Temperature	-20 to +50 Degrees C

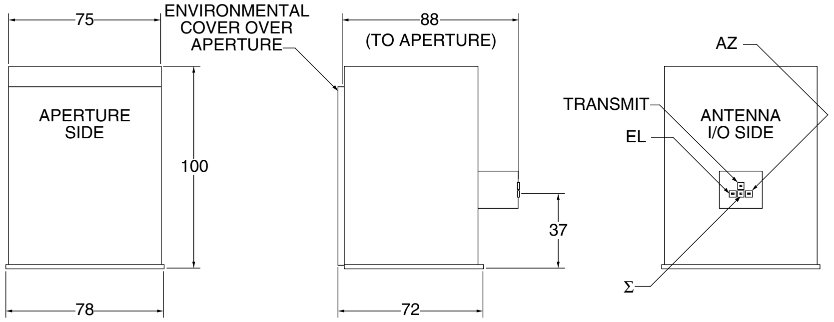
I-30 Expedient Antenna System, X-Band

The I-30 Expedient Phased Array Antenna is an electronically steerable antenna designed for test range instrumentation applications.

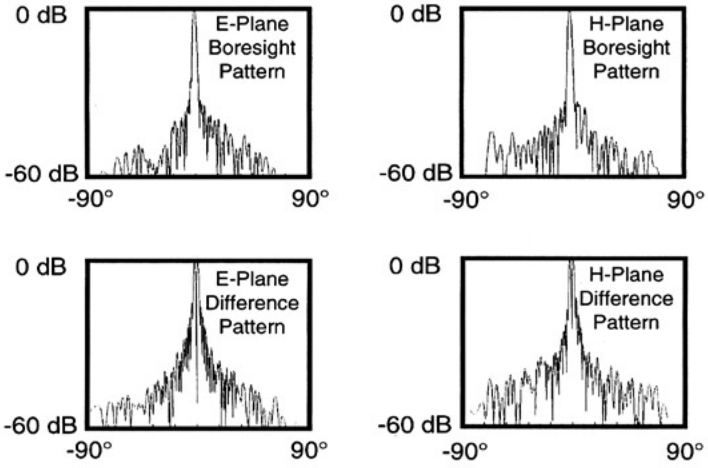
The antenna consists of a phased array transmission lens (bootlace lens) with a space feed, a beam steering computer (BSC), and associated power supplies. Nonreciprocal ferrite phase shifters operating in a circularly polarized mode are contained between an aperture plate and a feed plate. Radiating elements are formed when dielectric transformers on each end of the ferrite phase shifters are inserted into circular cavities bored in the feed and aperture plates. Since the single-bounce target return is desired, the received circular polarization is opposite the transmitted circular polarization and commutation of the phase shifters is not required. Accordingly, the phase shifters are switched at the beam scan rate rather than at twice the radar pulse repetition frequency which minimizes power supply requirements.

The feed provides monopulse operation with either sense of circular polarization on receive as well as the duplexing function between the transmit and receive modes. Flare angle changes in a square multi-mode pyramidal horn generate higher order waveguide modes to obtain equal E and H plane primary patterns providing for efficient lens illumination and low spillover loss. The BSC accepts signals from the system controller and points the antenna beam in a specified direction. The BSC and power supply are housed separately in rugged, compact cases.





Drawing Dimensions in Inches



CHARACTERISTIC	DESCRIPTION
Frequency	X-Band, 7%
Instantaneous Bandwidth	50 MHz
Polarization	Circular
VSWR	1.50 : 1 max
Gain (Broadside)	36 dB min
Peak Power	100 KW
Average Power	8 KW
Beamwidth	Pencil Beam, 1.9 Degrees Nominal
Beam Pointing Accuracy	0.25 Milliradians
Beam Resolution	0.25 Milliradians
Beam Broadening	0.3 Degrees max
Peak Sidelobe Level	-25 dB max
Beam Switching Time	100 Microseconds
Load Time	500 Microseconds max
Operating Temperature	-15 to +46 Degrees C

Terminal Guidance Antenna, Ku-Band

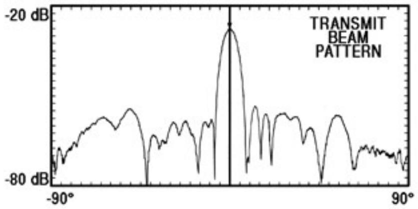
This small Ku-Band antenna is designed to provide electronic scanning capability for the terminal guidance system of a ground-to-air missile. Two-axis monopulse tracking is provided over an instantaneous frequency band of 500 MHz.

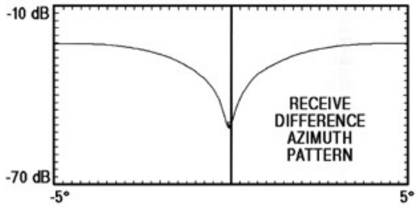
The RF portion of the antenna consists of the lens and feed assemblies and fits within a nine-inch diameter. The electronics portion consists of the phase shifter drivers, a phase shifter controller, and a PC-based beam controller.

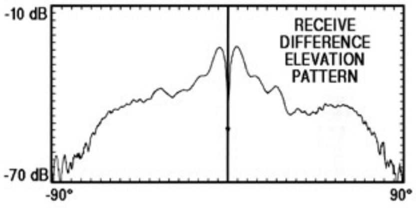
The lens assembly consists of 396 reciprocal dual-mode ferrite phase shifters arranged in an equilateral triangle pattern, contained between a feed network and a radiating ground plane. The phase shifters accept linearly polarized RF energy from the feed by means of a nonhomogeneous rectangular waveguide transition, provide variable phase shift, and radiate the same sense of linear polarization into space by use of a homogeneous circular waveguide radiating element integrated with the phase shifter. The radiating aperture consists of an aluminum ground plane with through holes which accept the radiating elements.

The feed assembly consists of the monopulse network, 5-way unequal power dividers, 6-way unequal power dividers and equal 4-way power dividers. The input power is divided into four equal parts by the monopulse network; this quadrant output is connected to the 5-way unequal power dividers used to feed the rows of the antenna. The outputs of the 5-way unequal power dividers are connected to the 6-way power dividers; each of these outputs is connected to a 4-way equal power divider; these outputs are connected to the phase shifters.

The phase shifter drivers use the MAG ASIC mounted to printed wiring boards; the phase shifter controller is a single board computer; the beam controller is either a desktop or laptop PC.







CHARACTERISTIC	DESCRIPTION
Frequency	Ku-Band, 6%
Instantaneous Bandwidth	500 MHz
Polarization	Linear
VSWR	1.50 : 1 max
Gain	29 dB
Peak Power	100 KW
Average Power	8 KW
Beamwidth	5.5 Degrees
Peak Sidelobe Level	-25 dB max
Beam Switching Time	35 Microseconds
Load Time	500 Microseconds max

Planar Phased Array Antenna, Ku-Band

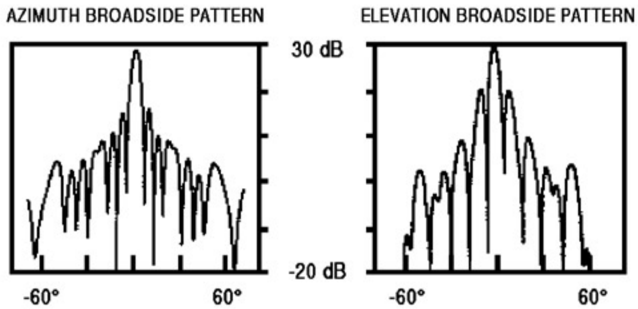
The MAG Planar Phased Array Antenna is a subsystem within a target auxiliary system which provides high power radar emitter simulation for training purposes.

The antenna portion of the subsystem consists of an array of eight radiating horn elements, each with a phase shifter providing a minimum of 360 degrees of phase shift, fed by an eight-way equal line-length corporate feed. This arrangement, along with the horn size, provides maximum utilization of the available aperture, and results in an element spacing which prevents grating lobes from entering the desired scan volume.

In addition to the antenna portion, the subsystem also includes a controller, which converts the analog input data into the required drive signals.

The unit's unique mechanical design allows for operation of the antenna in both a steerable mode utilizing the eight ferrite phase shifters, or in a stand-alone mode with the eight horns directly attached to the corporate feed.

CHARACTERISTIC	DESCRIPTION
Frequency	Ku-Band, 8%
Polarization	Linear Horizontal
VSWR	2.0 : 1
Gain	28.7 dB max
Peak Power	100 KW
Average Power	100 Watts
E-Plane Scan	±10 Degrees
H-Plane Scan	±5 Degrees
Beam Switching Time	100 Milliseconds
Operating Temperature	-54 to +71 Degrees C
Antenna Dimensions	12"w x 6"d x 12"h
Antenna Weight	10 lbs.



Millimeter-Wave Antenna, Ka-Band

The MAG Millimeter-Wave Antenna Subsystem is phase scanned in both azimuth and elevation planes. Monopulse capability is provided in the elevation plane, and the antenna is capable of switching from one beam position to any other within 30 microseconds. Instantaneous system bandwidth is 500 MHz.

The antenna consists of 216 MAG reciprocal ferrite phase shifters arranged on an isosceles triangular grid. The center-to-center element spacing is .258 inch within each row of 36 phase shifter elements, arranged into six rows with .180 inch spacing.

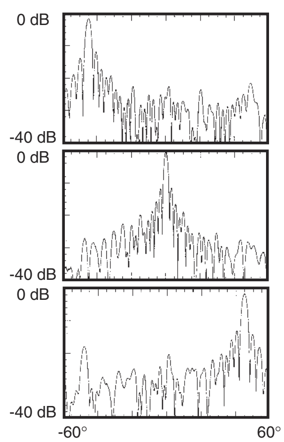
The radiating aperture is made up of circular dielectric-loaded waveguides in a metal ground plane. This type of element has broad patterns in both elevation and azimuth planes.

Electronic drivers use the MAG logic chip, and have built-in-test capability. Easy driver board replacement is made possible through access panels in the unit.

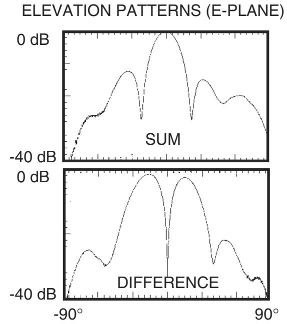
The array package is a self-contained, environmentally controlled unit. Blowers within the unit ensure a phase shifter temperature rise of less than 10 degrees C over ambient, alleviating the need for differential temperature compensation of phase shifter insertion phase.

CHARACTERISTIC	DESCRIPTION
Operating Frequency	Ka-Band
Instantaneous Bandwidth	500 MHz
Polarization	Vertical
Azimuth Scan Coverage	±45 Degrees
Elevation Scan Coverage	±35 Degrees
Azimuth Boresight Beamwidth	2±.2 Degrees
Elevation Boresight Beamwidth	18.5±1.0
Antenna Boresight Gain	25.0 dBi
Elevation Monopulse Null Depth	-30 dB
Elevation Monopulse Null Position Accuracy	1.0 Degree
Beam Steering Quantization Azimuth	.03 Degree
Beam Steering Quantization Elevation	.5 Degrees
Beam Pointing Accuracy Azimuth	±.1 Degrees
Beam Pointing Accuracy Elevation	±1.2 Degrees
Beam Switching Time	30 Microseconds
Operating Temperature	-32 to 71 Degrees C
Nonoperating Temperature	-54 to 71 Degrees C
Operating Altitude	0 to 15,000 Feet
Nonoperating Altitude	0 to 40,000 Feet
Average RF Power	100 Watts
Weight	35 lbs.
Size	5-3/4”h x 11-1/4”w x 13-1/8”d

AZIMUTH PATTERNS (H-PLANE)



ELEVATION PATTERNS (E-PLANE)



MICROWAVE APPLICATIONS GROUP

3030 Industrial Parkway • Santa Maria, California 93455 • (805) 928-5711
www.magsmx.com • sales@magsmx.com