

Application Note POL-1

Phased Array Polarization Switches

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1 Introduction

The introduction of polarization agility in a military radar system enables several operational capabilities that are not present in single-polarization radars. These include:

Target Enhancement: Long metal objects such as missiles typically have very different radar cross sections for a linear horizontal polarized radar pulse versus a linear vertical pulse. The ability to transmit and receive on both LV and LH and compare the results greatly increases the radar's ability to detect such targets in the presence of attempts at concealment.

ECCM: Numerous techniques are used to attempt to jam the fire control radars of combat aircraft and missiles. Many of these techniques are rendered much less effective (or difficult to implement at all) if the fire control radar has the ability to switch polarizations rapidly. Changing the radar's polarization randomly on a pulse-to-pulse basis makes the ECM designer's job much more challenging.

Target Identification: When the radar target is a complex scatterer, it will generally have a polarization conversion characteristic that is unique to that type of target. By transmitting on LV, LH, and one sense circular and receiving in each of these three polarizations for each transmitted polarization, it is possible to measure this polarization conversion for the target and use this information to help identify the type of target.

Rain Clutter Suppression: In order to suppress rain clutter, it is desirable to transmit on one sense circular polarization (say RHCP) and receive on that same sense circular polarization. With RHCP illumination, the backscatter from raindrops is strongly LHCP while returns from aircraft or other complex scattering objects have a large RHCP component.

Many modern radar systems, for airborne, space, and terrestrial applications, use active phased arrays for their radar antennas. In order to implement polarization agility on an active phased array, one must have a polarization switch that is sufficiently compact to be integrated at each radiating element in the array, and that has low insertion loss and rapid switching capability. This application note describes an EMS-patented¹ polarization switch that meets these requirements and also features:

- built-in T/R duplexing function, removing the need for an output circulator
- low power consumption – can be powered off between polarization switching events
- simple construction, compatible with low cost mass production processes

The EMS polarization switch can be applied from X-band through Ka-band. The sections below describe EMS' polarization switch, including details of the physical implementation and key performance parameters.

¹ U.S. Patent no. 5,304,999: **Polarization Agility in an RF Radiator Module for Use in a Phased Array**

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2 Polarization Switch Implementation

The top half of Figure 1 shows a typical implementation of a solid state transmit/receive module feeding a single-polarization radiating element. There are of course numerous variations on this theme, such as the use of independent amplitude and phase control components for the transmit and receive sides of the module instead of one ahead of the T/R switch. When it comes to feeding the radiating element, however, most implementations use a circulator duplexer feeding the element as shown in the figure.

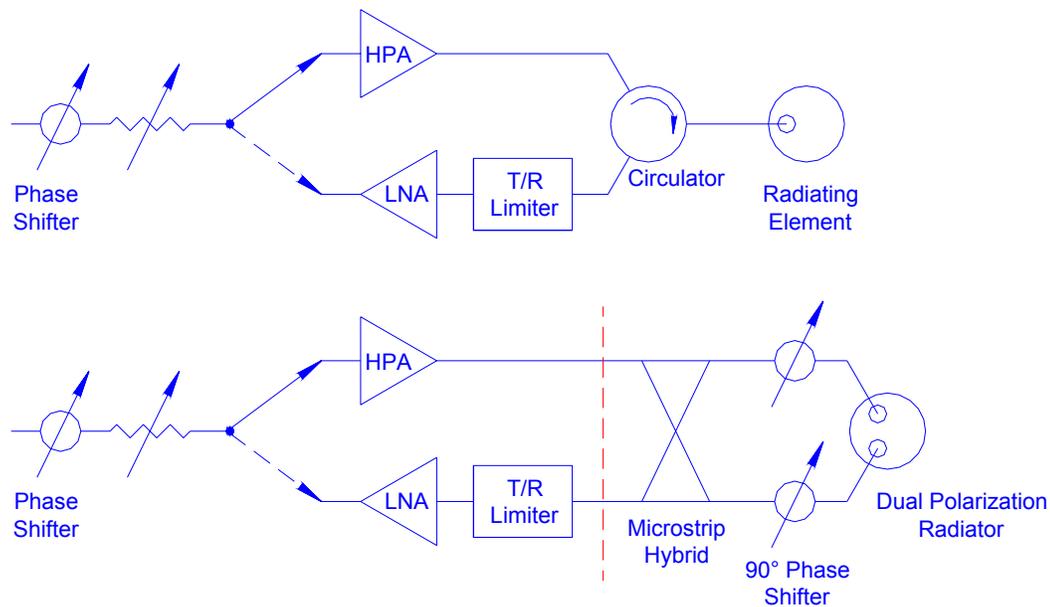


Figure 1. EMS' ferrite phase shifter based polarization switch.

The bottom half of Figure 1 shows how the EMS polarization switch replaces the T/R duplexing circulator and incorporates the polarization switching function. A key component in the operation of the polarization switch is the circular waveguide radiating element which consists of two crossed-linear polarized feeds followed by a reciprocal quarter-wave plate and a non-reciprocal quarter-wave plate. The details of the radiating element's construction are shown in Figure 2 and Figure 3.

For linear polarizations, the polarization switch's duplexing function results from the nonreciprocal nature of the 90° phase shifters used to feed the radiators. The 90° dual toroid phase shifters used in this application have the property that if one is set for 0° phase shift in the transmit direction, then a signal passing through the phase shifter in the *receive* direction will incur a 90° relative phase shift.

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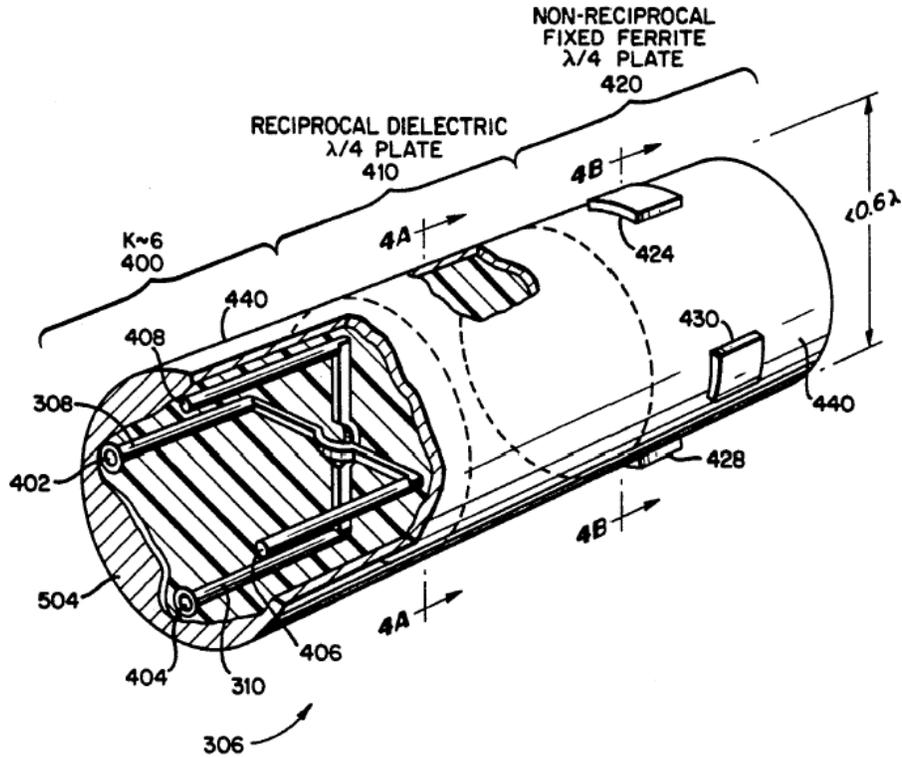


Figure 2. Circular waveguide radiating element incorporating a reciprocal quarter-wave plate, a non-reciprocal quarter wave plate, and two orthogonal linear polarization feed loops

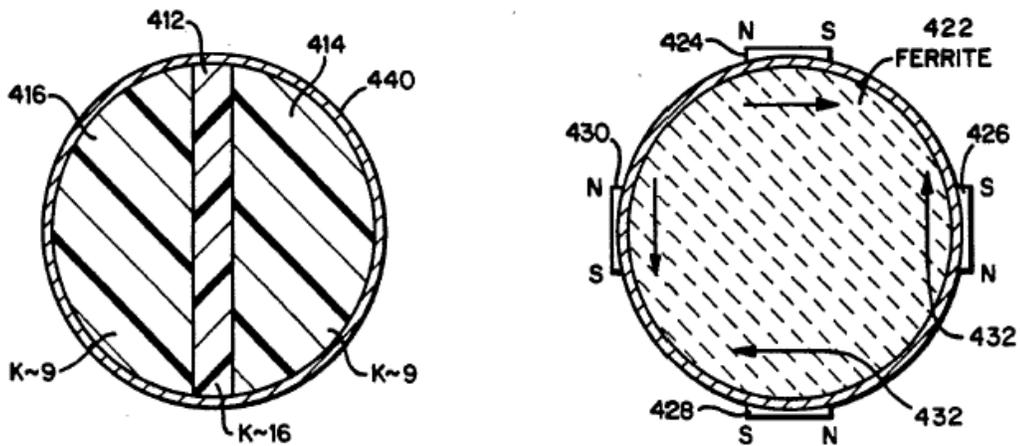


Figure 3. Layout of the reciprocal and non-reciprocal quarter wave plates

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Transmit and Receive Linear Vertical

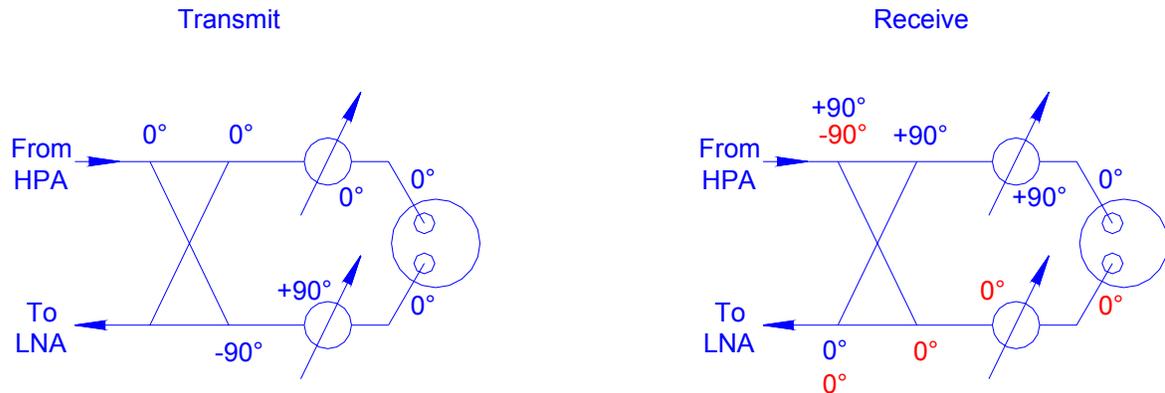


Figure 4. Phase shifter settings for linear horizontal radiation.

Figure 4 shows how the duplexing works for linear vertical polarization. As they are oriented in the polarization switch, both the reciprocal and non-reciprocal quarter wave plates just act as lengths of transmission line when they are excited with linear horizontal or linear vertical polarization. To radiate linear vertical polarization, the two probes in the radiating element are driven in phase (individually the two probes are 45° slant right and 45° slant left polarization). To achieve this in-phase excitation in the presence of the microstrip hybrid's 90° phase difference between its outputs, the lower phase shifter must be set to +90°. As shown at right in Figure 4, a setting of $\phi_1 = 0^\circ$, $\phi_2 = 90^\circ$ on transmit corresponds to $\phi_1 = 90^\circ$, $\phi_2 = 0^\circ$ on receive. So, tracing the signals back through the circuit on receive, we see that the two equal-amplitude, equal-phase components which emerge from the radiating element when receiving LV combine out of phase (cancel) at the HPA port of the hybrid, and add in phase at the LNA port.

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Transmit and Receive Right-Sense Circular

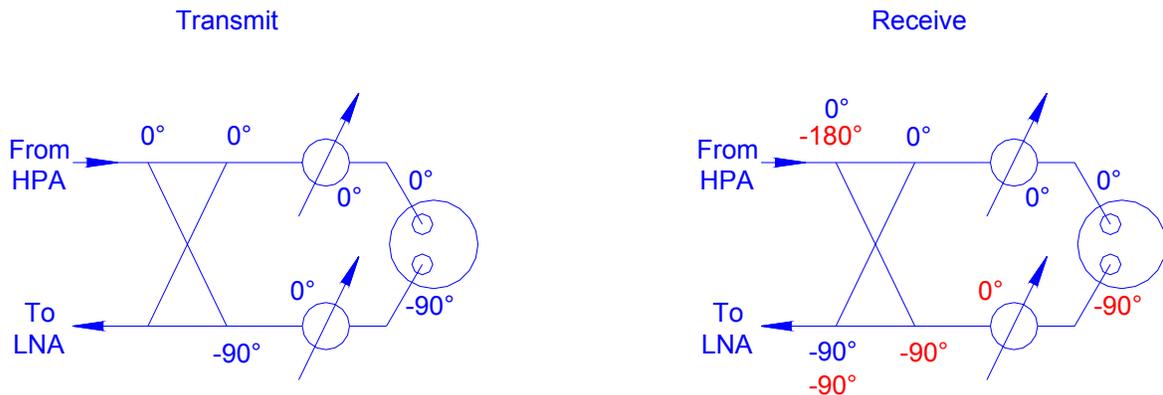


Figure 5. Phases within the polarization switch for transmitting and receiving RHCP.

Figure 5 shows the situation for RHCP. Here the duplexing is done by the combination of the reciprocal and non-reciprocal quarter wave plates. To radiate RHCP, both phase shifters are set to the same value, launching a circularly polarized wave into the radiating element by virtue of the hybrid's 90° offset. The fact that the phase shifters look like $(0^\circ, 0^\circ)$ on transmit and $(90^\circ, 90^\circ)$ on receive has no net non-reciprocal effect. Within the radiating element, the reciprocal quarter wave plate converts the circularly polarized signal launched from the coupling loops into a slant linear polarization. The non-reciprocal quarter wave plate then transforms it back into RHCP. On receive, the reciprocal and non-reciprocal quarter wave plates transform the incoming RHCP wave into the opposite sense circular from that which was radiated from the loops on transmit, giving the phase relationship shown on the right side of Figure 5.

Figure 6 shows a sketch of an X-band implementation of the polarization switch using EMS' dual toroid hybrid mode phase shifters. In this implementation a Lange microstrip coupler is used to feed the two phase shifters. As described above, with this switch configuration, phase shifter settings of $(0^\circ, 90^\circ)$ result in transmission and reception on linear vertical polarization, $(90^\circ, 0^\circ)$ gives linear horizontal polarization, and $(0^\circ, 0^\circ)$ or $(90^\circ, 90^\circ)$ gives transmission and reception on RHCP. Figure 7 shows a mock-up of the polarization switch with its associated driver electronics.

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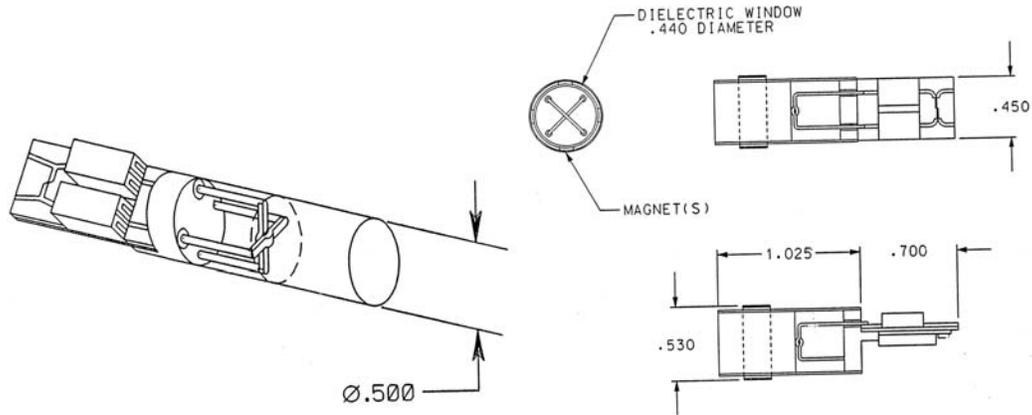


Figure 6. Typical dimensions of an X-band polarization switch fabricated with EMS' low-loss ferrite phase shifters.



Figure 7. Actual size mock-ups of the polarization switch where the circular waveguide walls have been replaced with clear plastic to reveal internal details.

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3 Performance Summary

Table 1 gives a summary of typical performance parameters for an X-band ferrite polarization switch. The insertion loss quoted here includes the Lange coupler and the two hybrid mode ferrite phase shifters. It should therefore be compared to the insertion loss of the microstrip circulator it replaces. Loss for an X-band microstrip circulator is typically 0.4 dB. Thus, the EMS polarization switch introduces polarization agility into each radiating element at a cost of only 0.2 dB of insertion loss.

Table 1. Typical performance parameters of the X-band polarization switch

Parameter	Value
Frequency	8 to 10 GHz
Insertion Loss	0.60 dB
Return Loss	20 dB
Switching Time	1 μ s
Switching Energy	15 μ J
Peak Power	200 W
Average Power	20 W
Size	0.5×0.2×0.5”
Mass	2 g

4 Conclusion

EMS’ patented polarization switch enables polarization agility at the element level for active phased array radar antennas. The cost in terms of circuit complexity and insertion loss is small compared to other approaches. The polarization switch enables transmission and reception on linear vertical, linear horizontal, and one sense circular polarization. The EMS polarization switch features low insertion loss, low power consumption and compact construction. The polarization switch is applicable from X-band through Ka-band.