IX-2. CIRCULARLY POLARIZED PHASE SHIFTER FOR USE IN PHASED ARRAY ANTENNAS

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An X-band ferrite phase shifter has been developed for operational use, the size and electrical performance of which are favorably suited for use in a phased array antenna that requires minimum center-to-center element spacings of 0.537 λ. The phase shifter has the same configuration as a Faraday rotator with a ferrite rod located at the center of a circular waveguide with an axially applied field. If a circularly polarized wave is passed through this geometry, a nonreciprocal phase versus current characteristic is obtained. The theory of operation of such a device is already well understood, so further elaboration is not necessary. Scharfman[1] and others have described this type of phase shifter in the literature.

Figure 1 is a cutaway view of a beam-steering element which is made up of a radiating element, phase shifter and electronic circuitry, all integrated into one package or cartridge. Each cartridge (Figure 2) in an array can be individually inserted or extracted much in the same way as an electron tube in a tube socket. All interconnections between elements are made by means of pins at the rear end of the cartridge. Circularly polarized energy enters and leaves the phase shifter at the front end.

A phase-current characteristic curve of the phase shifter is shown in Figure 3. To simplify control circuitry, the normal operating range of the phase shifter is between zero and 360 degrees which corresponds to a coil current of zero to 170 ma respectively.

This phase shifter is nonreciprocal since different values of phase are obtained for right and left hand circular polarization input. However, no control field reversals are necessary between transmit and receive for single bounce target returns. No antenna beam is formed for double bounce target returns.

Measurements using waveguide array simulator techniques[2] have shown that the integrated radiating element design has very broad bandwidth behavior for beam directions near broadside. The element spacing used in the array was 0.6 λ arranged in a square pattern. Figure 4 shows the element impedance vs frequency on a Smith chart for the near broadside waveguide simulator. A slight modification of radiating element geometry would move the cluster of experimental points to the center of the chart.

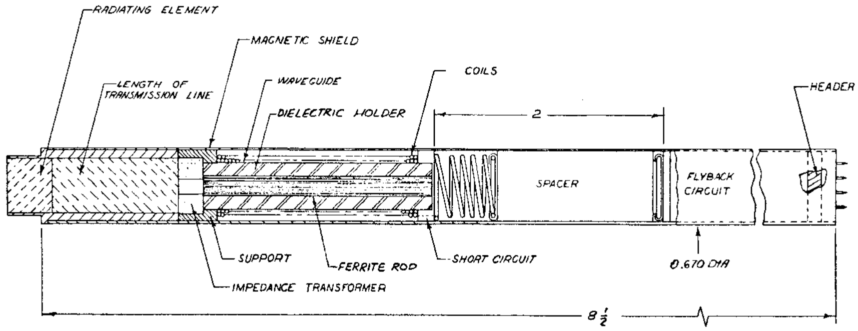

Figure 1 - Cutaway View of Beam Steering Element

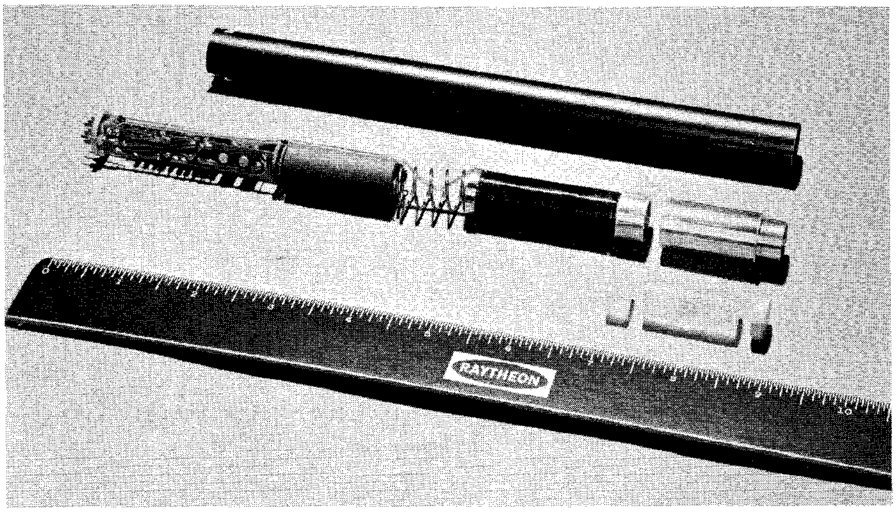

Figure 2 - Beam Steering Element

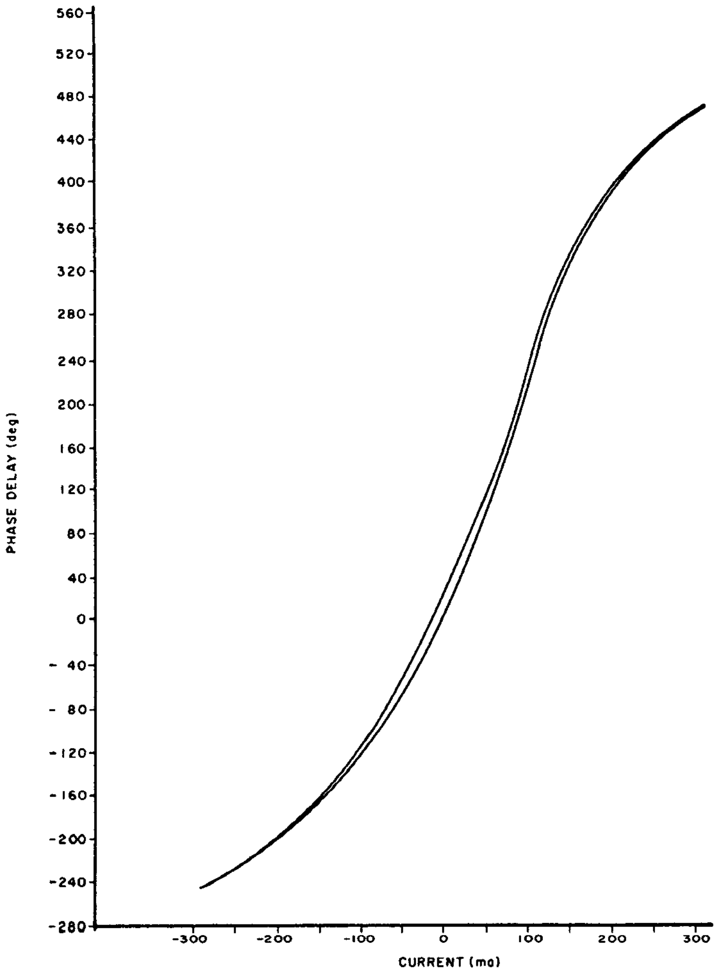

Figure 3 - Phase vs Current

Phase shifter specifications are summarized in Figure 5. In addition to other attractive features, this phase shifter can be produced for very low cost per element because of its simple construction.

Commercial brands of ferrite material cause maximum phase-current hysteresis loops of 36 degrees in the best cases. A new type of ferrite material has been developed by Raytheon that reduces this maximum width to less than 18 degrees with a corresponding insertion loss of 0. 5 db. In Figure 3 this width appears at zero coil current. This ferrite also will handle 2 kw of peak power in this particular phase shifter design before the onset of nonlinearity. The operation of the phase shifter as a one-pass device will allow 8 kw operation using the same Raytheon material.

Temperature gradients across the face of an array must be kept to a minimum. As a result, the phase shifter is rated to handle a maximum average power of 35 watts, which corresponds to phase change of 10 degrees due to RF heating. The shape of the phase-current characteristic varies insignificantly at temperatures between -30°C to +85°C. The absolute or insertion phase length change with temperature is 0. 7°/°C. This indicates that the ferrite rod temperature was 14°C above ambient with 35 watts input.

Isolation of the magnetic control fields between elements has been accomplished with appropriate shielding material so that the maximum phase error due to this control field interaction is less than 0. 1 degree.

A phased array antenna system, utilizing 1300 of the phase shifters described, has undergone extensive evaluation. The antenna performs over at least a 10 percent bandwidth with a measured rms beam-pointing accuracy of better than 1/40 beamwidth, and rms sidelobes greater than 35 db down. This performance is in reasonable agreement with the measured 7 degree rms phase error of 1300 ferrite phase shifters operating in the array. The insertion phase of each phase shifter was trimmed in order to obtain a maximum phase error of ± 7 degrees at zero coil current. Without trimming, maximum errors at zero current was ± 30 degrees.

This phase shifter concept has been extended up to K-band in one direction and down to S-band in the other.

REFERENCES

1) Scharfman, H., "Three New Ferrite Phase Shifters", IRE, p. 1456, October, 1956.

2) Hunnan, P. J. et al, "Simulation of Phased Array Antenna Impedance in Waveguide", IEEE, PGAP, November, 1963.

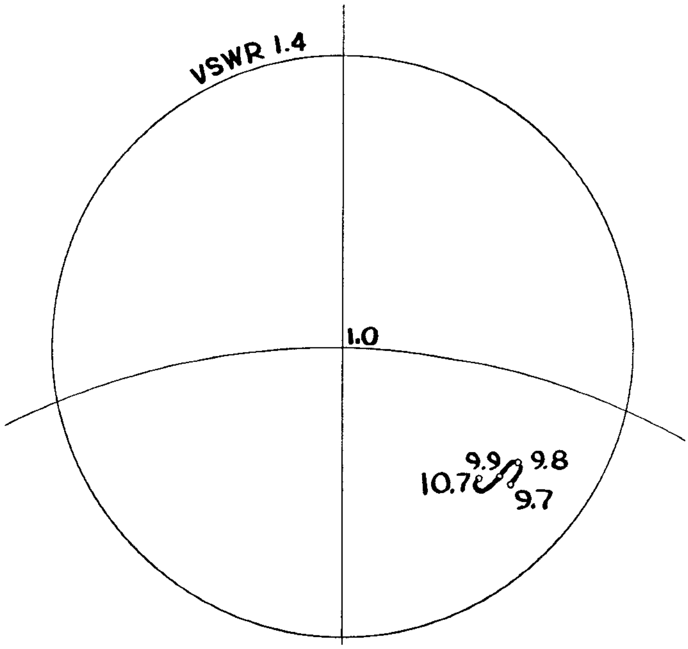

Figure 4. Smith Chart Impedance Plot of Near Broadside Simulator

Phase Range	360 deg
Frequency	X-band ±5%
Insertion Loss	< 0.5 db
Maximum Peak Power	2.0 kw
Maximum Average Power	35 w
Switching Speed	< 10 μsec
Switching Energy (maximum current range)	50 μjoules
Maximum dc Hold Power	0.12 w
Maximum Hysteresis Phase Error (typical)	±8 deg
Temperature Sensitivity	0.75 deg / °C
Reproducibility (rms phase error, 1400 units)	7 deg
Weight	4.0 oz

Figure 5 - Phase Shifter Specifications