DIELECTRIC WAVEGUIDE PHASE SHIFTER

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Summary

Using ferrite waveguide toroids and dielectric ribs ($\varepsilon_r = 50$), we have demonstrated that a dielectric waveguide (no metal walls) phase shifter ($\Delta\phi = 600°$) can propagate with reasonable insertion loss ($\approx$ 3 dB) and modest cross coupling ($\approx$ 15 dB). With brass inserts, the cross coupling can be further reduced (> 20 dB) with some sacrifice of insertion loss and phase shift.

The use of dielectric waveguide phase shifters should allow simpler, lower-cost phased arrays in the conventional frequency range (3 to 20 GHz). At millimeter wave frequencies there is the possibility of making a column of phase shifters from slabs of ferrite and dielectric using flat-grinding and cutting techniques.

The nonreciprocal twin-toroid ferrite phase shifter (Fig. 1a) used in many phased-array radar antennas typically employs a high-ε_r dielectric material (ε_r = 38 or ε_r = 50) to concentrate the microwave energy and thereby reduce the cross section and length of the phase shifter. Since the high-ε_r center rib is the primary channel for the microwave energy, the rf fields outside the dielectric decay rapidly. The ferrite region which contributes most significantly to the phase shift is that adjacent to the high-ε_r dielectric. The remaining legs of the waveguide toroid provide a closed flux path and contribute little to the phase shift, electric length, or insertion loss of the phase shifter. If the metal waveguide walls are removed, then the dielectric should still act as the primary channel for the microwave energy.

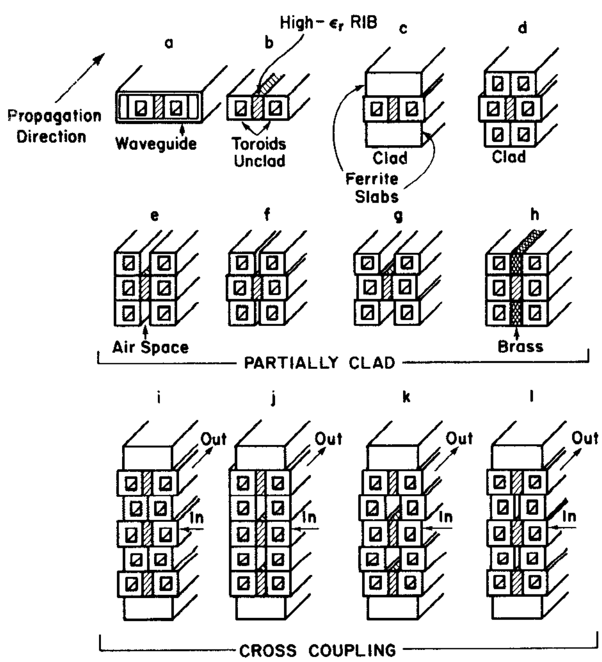

Fig. 1 Configurations tested.

To demonstrate that such a structure without metal walls can be a reasonable phase shifter, measurements of insertion loss, reflection, and phase shift were made from 4 to 8 GHz on the configurations shown in Fig. 1. These configurations were formed from a series of waveguide toroids which were 220 mils wide, 250 mils high, approximately 5 inches long and which had walls that were 55 mils thick. Our matching transformers consisted of three steps plus a dielectric plug which coupled the full-sized waveguide (1.872 in. × 0.872 in.) to a heavily dielectrically loaded waveguide (0.75 in. × 0.25 in.) of the type illustrated in Fig. 1a. The initial measurements on the structure illustrated in Fig. 1b, which had a 60-mil rib with ε_r = 50, indicated that it was necessary to clad the top and bottom of the rib with ferrite (as in the structures of Fig. 1c and Fig. 1d) in order to obtain propagation over the 5 to 6 GHz region that was the range of operation of the waveguide phase shifter (Fig. 1a). Without the cladding there was a large reflection coefficient and a tendency to radiate from the exposed portion of the rib. The leakage of energy from one toroid-rib propagator to the adjacent one (cross coupling) was measured using the configuration of Fig. 1i. The incoming signal came through the matching transformer into the middle toroid-rib combination labeled In (Fig. 1i) while the outgoing signal was measured through a matching transformer connected at the opposite end to an adjacent toroid-rib combination labeled Out (Fig. 1i). The ends of the Input and Output sections away from the matching transformers were coated with lossy material to prevent reflections. The results of these measurements at 5.5 GHz with the 60-mil rib are summarized in the following table.

	Dielectric Waveguide Phaser (Fig. 1d)	Conventional Waveguide Phaser (Fig. 1a)
Length	5 in.	5 in.
Insertion Loss	3 dB	2 dB
Return (Reflection) Loss	9 dB (VSWR=2.1)	14 dB (VSWR=1.5)
Phase Shift	420°	680°
Cross Coupling (Fig. 1i)	10 dB	None

To obtain better containment of the wave and thereby reduce cross coupling, thicker dielectric ribs (80, 100, 120, 140 and 160 mils) were tried. The phase shift results for the clad geometry (Fig. 1d) are given in Fig. 2 as a function of rib thickness. The phase shift decreases to approximately 250° for the thicker ribs. The insertion loss and reflections were somewhat higher since the matching transformers were designed primarily for a 60-mil rib. Taking into account the increase of insertion loss (now 4 to 5 dB) and reflection (now 6 to 8 dB), the cross-coupled energy was estimated to be 13 to 15 dB down from the main wave.

The phase shift for thicker ribs was improved by removing the ferrite cladding. The unclad geometry (Fig. 1b) gave the phase shift results shown in Fig. 3. In the vicinity of a 100 to 120 mil rib thickness, the phase shift is large ($\approx$ 600°) and almost independent of frequency. For thicker ribs the phase shift falls off, indicating that 100 to 120 mils is optimum. With

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thinner ribs the energy is not confined, and with thicker ribs the rf fields at the ferrite-rib interface are decreased resulting in less phase shift.

The partially clad configurations (Fig. 1e, 1f and 1g) using a 100-mil rib were also investigated. Openings above the 100-mil rib of 50, 100, and 150 mils were tried and gave phase shift of about 600°, indicating that although the air space above the dielectric rib is necessary to produce high phase shift its size is not critical. An insertion loss of 4 dB was due in part to the high return loss (reflection) of 4 dB. The cross coupling (Fig. 1g, 1k and 1l) was about 15 dB.

A slight variation (Fig. 1h) was also measured. It consisted of a 100-mil brass insert mounted above and below the dielectric rib. We obtained somewhat less phase shift (500°), a higher insertion loss (6 dB), and a comparable return loss (reflection) of 4 dB. The cross coupling was below 20 dB.

The present approach to assembling centimeter-wave ferrite phase shifters consists of plating individual toroid-dielectric assemblies and then inserting them in a waveguide or some other appropriate fixture. A dielectric waveguide approach would eliminate the plating step and thereby offer a cost reduction. At millimeter wave frequencies, dimensional tolerances become very small, parts become fragile, and waveguide attenuation becomes high. At 94 GHz, the thicknesses of ferrite toroid walls and dielectric ribs are on the order of 5 mils. Assembly of individual phasers will be expensive due to the requirement for intricate machining and the high probability of part breakage. At millimeter wave frequencies, we can envisage making a column of dielectric waveguide phase shifters by working with dielectric strips bonded between sheets of grooved ferrites. By using sheets, ferrite and dielectric grinding costs and breakage should be reduced.

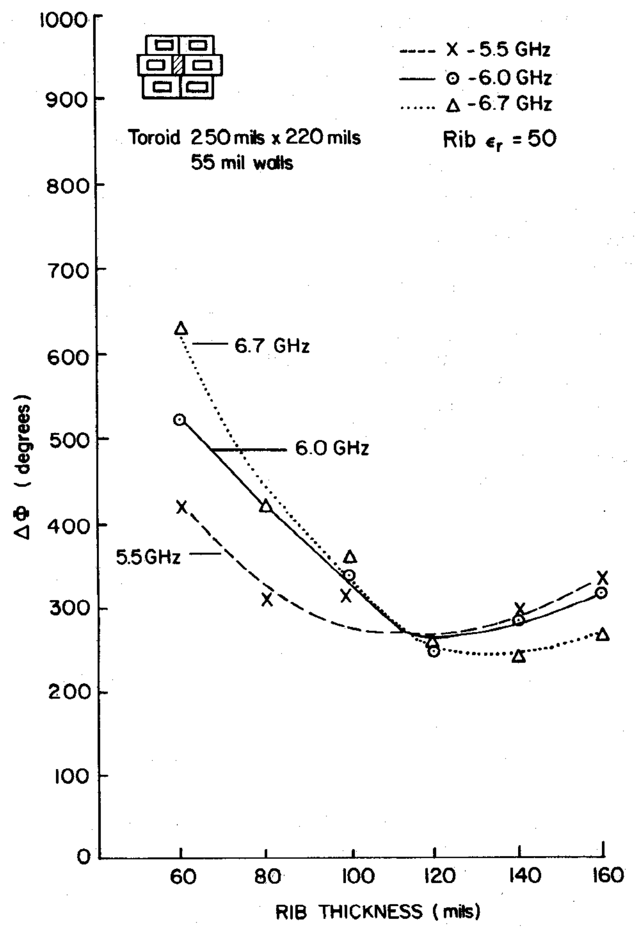

Fig. 2 Phase shift vs. rib thickness for clad configuration.

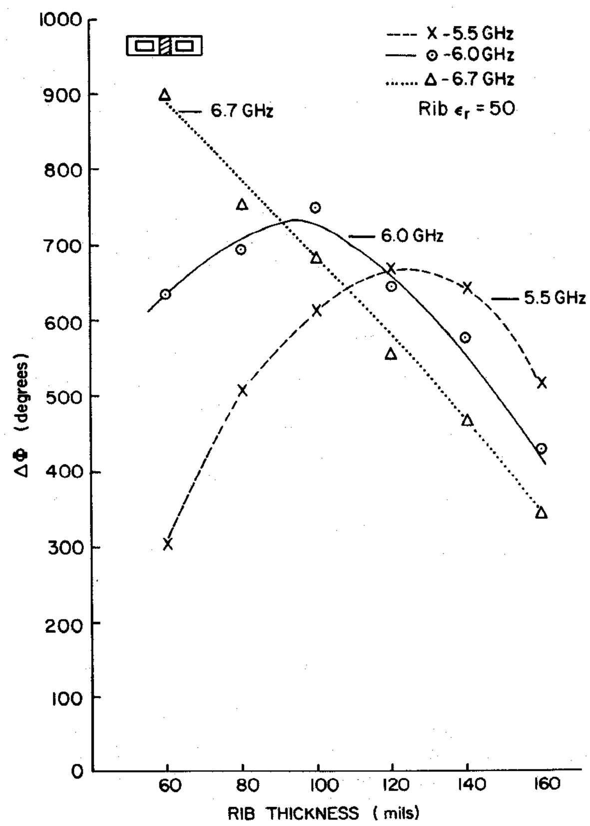

Fig. 3 Phase shift vs. rib thickness for unclad configuration.