IX-4. A MINIATURIZED C-BAND DIGITAL LATCHING PHASE SHIFTER

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Recent developments in rectangular waveguide latching phase shifters have been directed primarily toward achieving good electrical performance with reduced size as a secondary objective (Reference 1). Miniaturization efforts have concentrated chiefly on strip line and coaxial structures (References 2 and 3). While these designs have achieved moderately good low power electrical performance and some reduction in physical size, they have exhibited inherent frequency dependence not associated with rectangular waveguide phase shifters.

This paper describes a digital latching phase shifter which combines the desired electrical performance of rectangular waveguide construction with the compactness of strip transmission line. The electronic drivers required to latch the toroids into the $+4\pi M_r$ and $-4\pi M_r$ remanent states are positioned adjacent to the microwave structure to form a complete phase shifter package having a cross section of 0.8 inch by 0.8 inch designed specifically for half-wavelength stacking in an antenna array.

The design described in this paper has the general configuration shown in Figure 1. The garnet toroids which occupy the center portion of the device dielectrically load the rectangular waveguide, permitting C-band propagation in a guide width normally cut off at 10.7 GHz (Reference 4). The strip transmission line on each end of the waveguide widens into a horizontal septum. Dielectrics are loaded antisymmetrically above and below the septum with materials having different dielectric constants. The resulting asymmetric propagation constant converts the strip line TEM mode to a modified TE mode which propagates in the toroid-loaded waveguide. Since microwave energy which interacts with the garnet material has the form of a TE_{10} mode, phase shifter characteristics comparable with rectangular waveguide construction are realized.

The phase shift of a test model using a 2.8 inch toroid under several loading conditions is shown in Figure 2. A garnet material (Sperry G251-15% gadolinium and 5% aluminum doped YIG) having a $4\pi M_s$ of 1150 gauss was used initially. Flat phase shift with frequency of 70 degrees per inch is achieved by selecting a c/a ratio of 0.41. Figure 3 shows the temperature and peak power characteristics of several garnet materials with varying gadolinium content. The addition of gadolinium obviously increases the temperature stability of the device, but because of its higher linewidth, it results in a higher insertion loss.

The five-bit phase shifter incorporates the concepts gained from measurements on the one-bit model. The five-bit model shown in Figure 4 uses Sperry G419 which is an aluminum garnet with a $4\pi M_s$ of 1200 gauss and a $4\pi M_r$ of 840 gauss. The toroid geometry is modified somewhat to facilitate dielectric loading of the slot. The bits are separated with 0.030 inch slabs of Transtech D-16 material to eliminate bit interaction. The electronic drivers used to latch the toroids consists of five

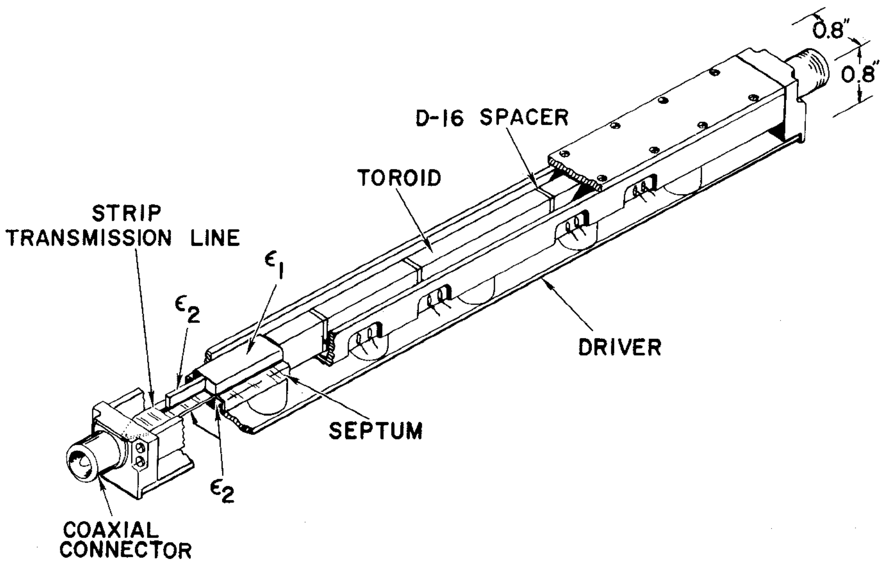

Figure 1. Strip Line Transmission - Rectangular Waveguide Phase Shifter Configuration

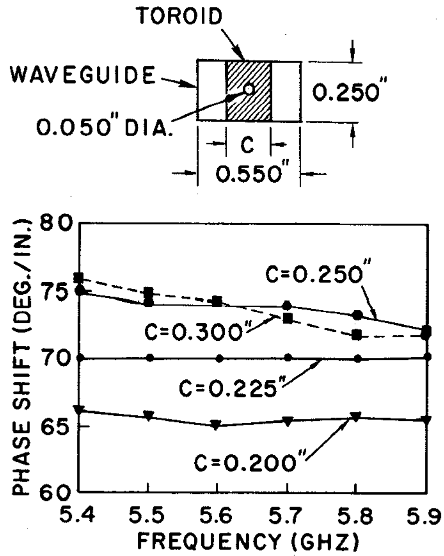

Figure 2. Phase Shift of One-Bit Model Under Several Loading Conditions

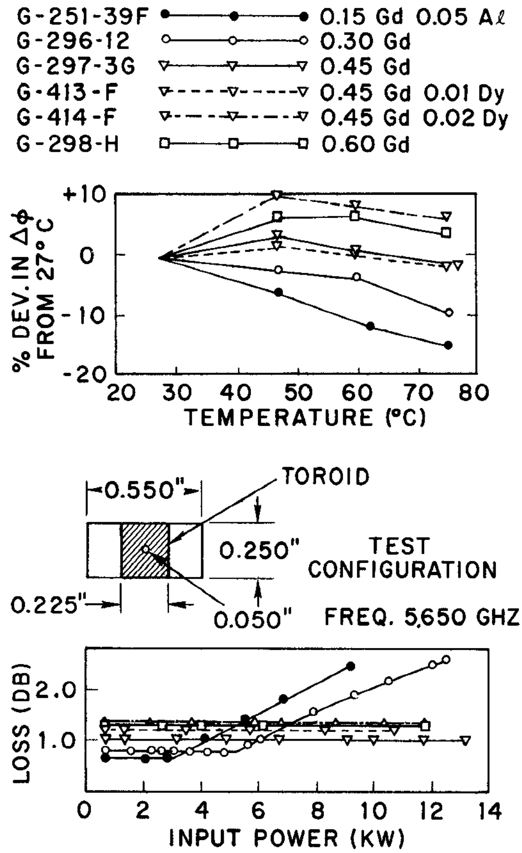

Figure 3. Temperature Variation in Phase Shift and
Peak Power Data of Several Garnet Materials in the One-Bit Model

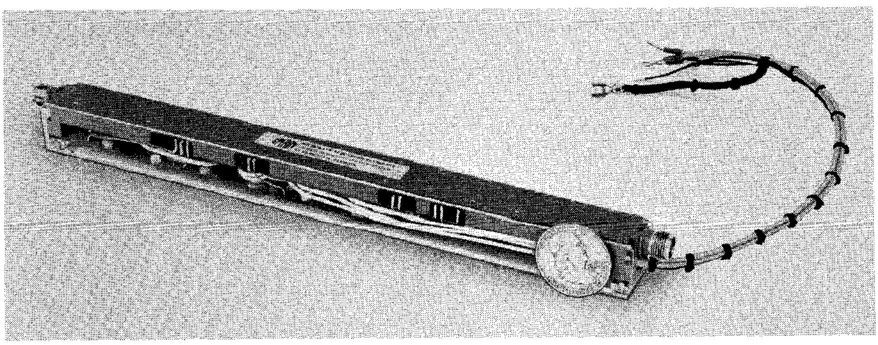

Figure 4. Five-Bit Model with Attached Electronic Driver Circuit

modular circuits. Each module has a transistor driver circuit for each of the remanent states. A diode gate permits switching of each bit between states with a single wire trigger.

The VSWR and insertion loss of the five-bit unit are shown in Figure 5. Phase deviation with frequency of each of the five bits is less than 2% across a 10% bandwidth. The peak power limiting threshold is one kilowatt for Sperry G419 material and increases for higher gadolinium doping. For instance, 45% gadolinium material (Sperry G297) in the five-bit model does not limit up to 35 kw peak power. The phase shift of the five bits as a function of temperature is shown in Figure 6. The variation in phase shift with temperature may be excessive for some applications, but may be reduced with moderate gadolinium doping of the garnet. However, additional gadolinium material will necessitate a compromise between achieving minimum loss and maximum temperature stability.

This configuration could obviously be converted to waveguide input and output if it should be more compatible with system layout. The general approach appears to offer new antenna design and/or layout possibilities to the phased array systems engineer.

ACKNOWLEDGMENT

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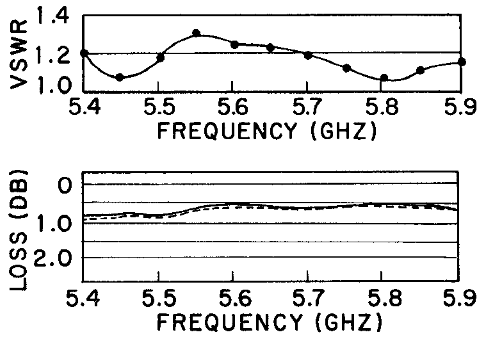

Figure 5. VSWR and Insertion Loss of the Five-Bit Model

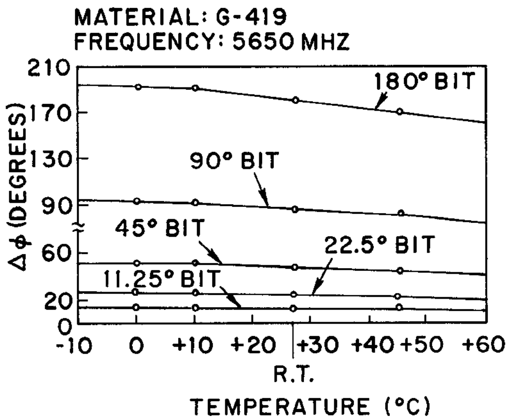

Figure 6. Temperature Variation in Phase Shift of each Bit of the Five-Bit Model