AN ACCURATE ANALOG FERRITE PHASE SHIFTER

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Summary

An analog ferrite phase shifter has been developed for applications requiring an accurate relationship between phase shift and control current. A prototype unit is described that operates over a 1.3 GHz. range at X-band with VSWR under 1.2:1, loss under 1 dB., hysteresis at ±1 degree, and negligible frequency dispersion of phase shift.

I. Introduction

In contrast with digital, latching phase shifters, very little appears to have been done recently to advance the rather poor state-of-the-art of analog phase shifters. Since PIN diodes are suitable mainly for switching, it is clear that some form of ferrite device is the logical candidate for an analog phase shifter. Familiar types of analog ferrite phase shifters such as the suppressed-rotation (Reggia-Spencer) or circularly polarized dual-mode varieties suffer from moderate to excessive temperature drift and frequency dispersion, as well as complicated and material-dependent relationships between control current and phase shift. Furthermore, substantial hysteresis effects exist in these types of structures, so that large phase shift errors are experienced for nonmonotonic commands, as the phase shift vs. current characteristic depends on the previous magnetization history of the unit.

It is the purpose of this paper to describe an analog ferrite phase shifter approach that can provide unlimited dispersionless phase shift with uniformly low hysteresis. Furthermore, the phase shift angle is virtually independent of the shape or temperature variation of the magnetization curve of the ferrite material. As with most analog ferrite phase shifters, speed of response is essentially limited by drive considerations. Finally, the insertion loss and impedance match bandwidth compare favorably with other analog ferrite phase shifters.

II. Phase Shifter Configuration

The ferrite phase shifter configuration to be described is a magnetically variable version of the Fox-type phase shifter.[1] This phase shifter consists essentially of a transducer from rectangular to circular waveguide, followed by a linear-to-circular polarizer, a rotatable half-wave plate, a circular-to-linear polarizer, and a transducer from circular waveguide back to rectangular. The phase shift angle is proportional to twice the mechanical angle of rotation of the half-wave plate, and is independent of frequency. A commercial version of this phase shifter has been available for many years.* In this instrument the fixed polarizers and the rotatable half-wave plate are constructed by using dielectric slabs in the circular guide.

This configuration can be adapted to rapid phase variation by substituting a transversely magnetized ferrite rod for the rotatable half-wave plate. The principal axes of this "ferrite half-wave plate" are determined by the orientation of the applied transverse field. The transverse field pattern may have a dipole[2] or quadrupole[3] character. The dipole field interaction is reciprocal but much weaker than the nonreciprocal quadrupole field interaction with the TE_{11} mode. In order to rotate the field pattern electrically, the ferrite rod is fitted with a yoke or "stator" with a number of poles that are wound with two sets of coils that each generate quadrupole field patterns. These patterns are interlaced, and consequently a rotation can be simulated by partial excitation of each coil set in a sine-cosine relationship.

An obvious way to generate interlaced quadrupole-field patterns is to use an eight-pole yoke. A larger number of poles gives a more stable field distribution, i.e. one that rotates more smoothly as the coil currents are varied. Error analysis shows that an n-pole yoke will yield a "tracking deviation" $\Delta\theta$ of the phase shift angle from the nominal value θ, when the coil currents are applied in the ratio $\sin\theta$ and $\cos\theta$, that can be expressed as

$$\Delta\theta = \frac{4}{n} \tan^{-1} \left[\alpha \tan \frac{n\,\theta_0}{4} \right] - \theta_0$$

In this equation θ_0 is the input angle, defined by

$$\theta_0 = \tan^{-1} (I_1/I_2)$$

where I_1 and I_2 are the sine and cosine coil currents, n is the number of poles of the stator yoke, and α is a parameter that expresses the variation of half-wave plate differential phase shift with rotation angle, in terms of the phase shift vs. current slope. The significant conclusions are that the tracking deviation is inversely proportional to the number of poles, but increases when the ferrite is operated above the knee of the magnetization curve. Unfortunately, reduction of hysteresis demands operation above the knee, and hence a higher value of phase tracking deviation. As a result, a 16 pole arrangement was chosen, with fairly small $\Delta\theta$.

*Hewlett-Packard Model 885A Phase Shifter

III. Experimental Results

An X-band phase shifter of the type described above has been built and tested. Figure 1 shows a photograph of this unit. The essential design features and test results are as follows:

a. Quarter-wave plates - The quarter-wave plates are fabricated from ceramic dielectric materials, and use the broadband dielectric slab approach in a very compact geometry. Differential phase shift was 90 ± 2 degrees over the entire 1.3 GHz. design band.

b. Ferrite half-wave plate - The ferrite half-wave plate was made from a tube of garnet material with a ceramic filler. This configuration produced a small variation of differential phase shift with orientation of the driven bias field pattern. The frequency variation of differential phase shift was measured and found to be approximately 25 degrees over a 1.3 GHz. band, monotonically decreasing with frequency, as expected on the basis of elementary theory.

c. Insertion loss - Figure 2 shows a recorder trace of insertion loss vs. frequency.

d. Impedance match - The phase shifter uses ceramic dielectric transformers to standard WR-90 waveguide. Figure 3 shows a recorder trace of return loss vs. frequency.

e. Hysteresis - Figure 4 shows a recorder trace of the r-f phase shift error vs. the input command angle to the $\Delta\theta$-compensated driver. It is evident that a small hysteresis exists, but is limited to about ±1 degree.

f. Phase shift-frequency dependence - None observed.

g. Control speed - Slew rate was about 100 degrees per millisecond with existing coil and driver designs.

IV. Conclusions and Acknowledgement

The phase shifter described above exhibits performance characteristics far superior to other approaches for achieving an analog microwave phase shifter. Construction techniques for the test device shown were tedious and expensive; substantial improvements should be possible in volume production with special tooling.

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V. References

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3. A. G. Fox, S. E. Miller, M. T. Weiss, "Behavior and Applications of Ferrites in the Microwave Region", B.S.T.J., Jan. 1955, pp. 78-86.

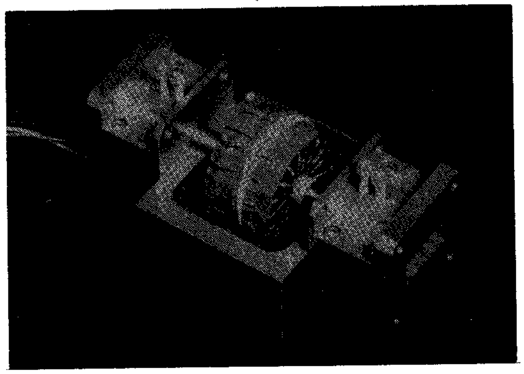

Figure 1 - Photograph of Phaser

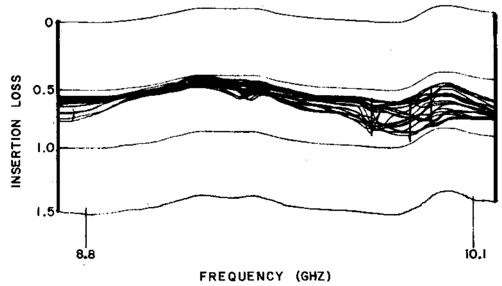

Figure 2 - Phaser Insertion Loss

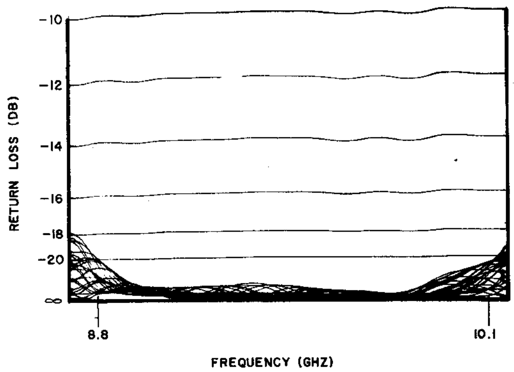

Figure 3 - Phaser Return Loss

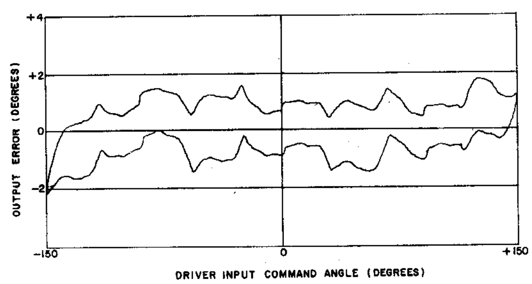

Figure 4 - Phaser Error Characteristic