A LOW COST LITHIUM FERRITE PHASE SHIFTER*

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Abstract

Low cost construction techniques for twin slab ferrite phase shifters are presented along with an experimental comparison of garnet and lithium ferrite materials. A 3-bit phase shifter with lithium ferrite material which is approximately half the price of garnet material had a measured loss of 0.4 dB and a peak power handling of 4.5 kW.

Introduction

Recent efforts at Hughes Aircraft Company, Ground Systems Group, to reduce the cost of S-Band element phase shifters have stressed the importance of obtaining good rf performance with nonprecision parts and with low cost magnetic materials.

Good rf performance, particularly insertion loss, is especially important in its impact on the transmitter cost. Specifically, a higher insertion loss would require greater transmitter power to maintain the same radar range, and the cost of increasing the transmitter output capability is about $10 per watt of average power. This is shown graphically in Figure 1 for a typical average element power of 10 watts. This curve shows for example that a 1 dB phase shifter has a transmitter cost impact of $58 per element, while a 0.5 dB phase shifter has an impact of only $26, a difference of $32 per element, or $320,000 in a 10,000 element array.

Phase Shifter Construction

In addition to being low cost, the phase shifter construction must exhibit the following requirements to obtain good rf performance:

- Minimum gap between toroid and waveguide broadwalls. An air or epoxy filled gap between the toroid and the waveguide broadwalls, serves as a launching mechanism for higher order modes which in turn cause insertion loss spikes at the resonant frequencies.
- Minimum pressure exerted on toroid. The pressure that the structure exerts on the toroid must be minimized, especially with garnet materials to avoid magnetostrictive effects.[1]
- Thermal design--the thermal design must be adequate to handle the average power requirement of the phase shifter.

One construction technique which satisfies all the above requirements is the foil wrapped approach shown in Figure 2. In this approach, the toroid is sandwiched between two low dielectric constant slabs and wrapped with a thin copper foil. Two methods have been used for bonding the foil to the ferrite. The first uses a thin adhesive which maintains good adhesion with less than a 1 mil bond thickness. In the second method, the ferrite is plated and then soldered to the foil. This technique forms a very good bond without sacrificing performance. The foil wrapped unit is then inserted into a loose tolerance housing which provides the mechanical strength, the flanges, and the cooling springs. The cooling springs can either be used as air fins or as a conducting path to a cold plate.

Performance

The phase shifter performance using a garnet (TTG-600)[2] toroid with the foil-wrapped construction is shown in Figures 3 through 6. The insertion loss with either the adhesive or solder bond is extremely low over a 20 percent bandwidth, while the peak and average power handling are reasonably high. The phase shift versus frequency response is flat and the insertion phase varies only slightly over the operating temperature range. This is very important in systems with high amplitude tapers across the array in order to minimize temperature induced systematic phase errors. It is also significant to note that the critical peak power level of a ferrite phase shifter which sees a 3:1 mismatch (the level it might expect to see in an array) is only about 20 percent lower than the same phase shifter followed by a matched load. One might expect that with a 3:1 mismatch the critical power level should have dropped by 50 percent as in diode phase shifters, however, because of the distributed nature and the non-reciprocal nature of ferrite phase shifters, the performance under a high mismatch was better than originally anticipated.

Lithium Ferrite Material

In a further effort to reduce phase shifter costs, lithium ferrite materials were investigated.[3] Due to the absence of rare earth doping, these materials are about half the cost of the garnets. One Ampex lithium ferrite material showed exceptional microwave performance in a 3-bit phase shifter (Figures 7 through 10) and excellent switching characteristics. The phase repeatability between two different batches was extremely accurate ($\pm 1.8\%$) and the magnetostrictive effects were also much less noticeable than with the garnets. The peak power handling is equivalent to that of the garnet shown in Figure 5. The only significant disadvantage to this lithium ferrite material is that its temperature sensitivity (Figure 8) is almost twice as high as garnets. With flux drive, however, this disadvantage means only a reduced operating temperature range.

Conclusions

For S-Band phased array applications of moderate element power ($\leq$ 5 kW peak), the foil-wrapped lithium ferrite phase shifter with flux drive is an

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excellent choice with superior performance at low cost.

References

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3. Temme, Dionne, Courtney, Argentina, Baba, "Lithium Ferrites for Microwave Devices," G-MTT Symposium Digest, May 1971, pp. 74-75.

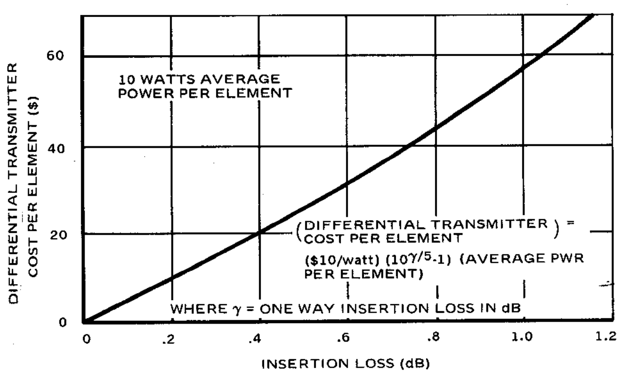

Figure 1. Effect of Phase Shifter Insertion Loss on Transmitter Cost

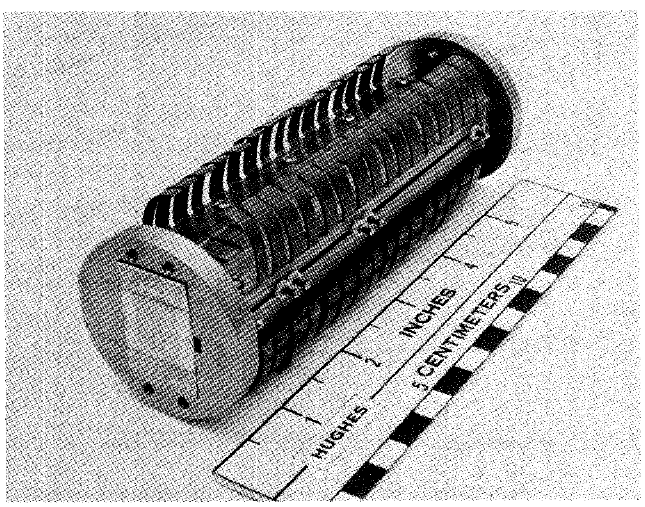

Figure 2. Foil Wrapped Phase Shifter

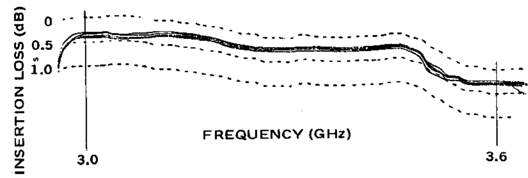

Figure 3. Insertion Loss Versus Frequency with Garnet Toroid

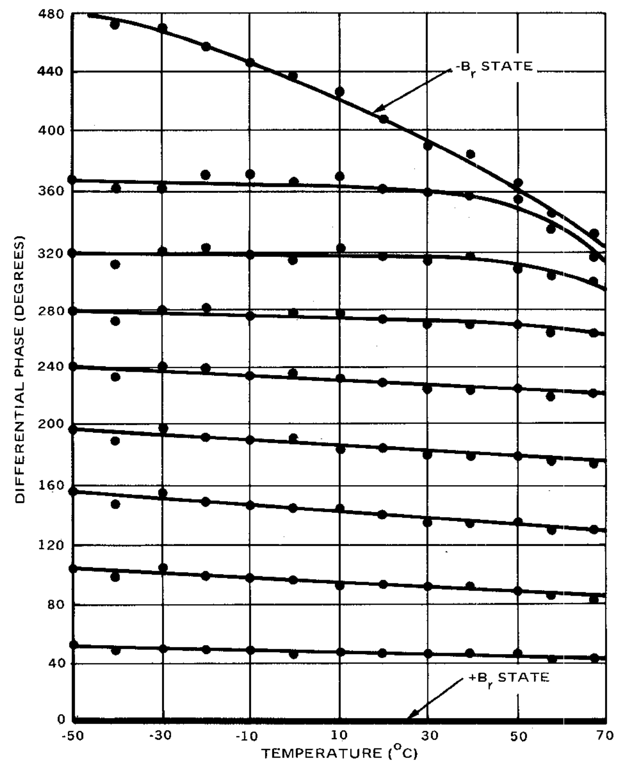

Figure 4. Differential Phase Versus Temperature with Flux Drive

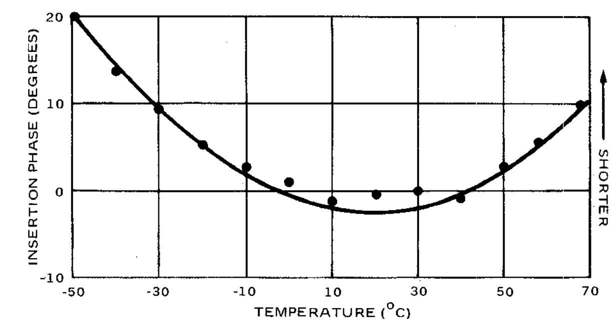

Figure 5. Insertion Phase Versus Temperature

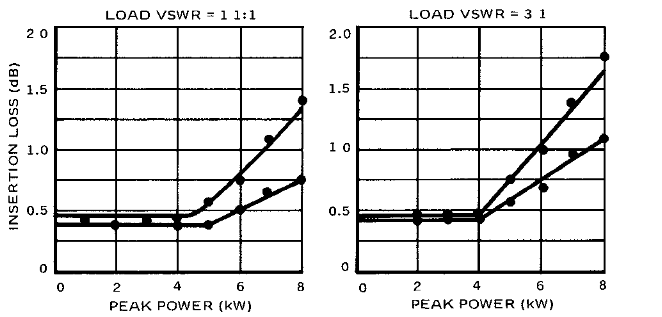

Figure 6. Garnet Phase Shifter Peak Power Performance for Matched and Unmatched Load Conditions

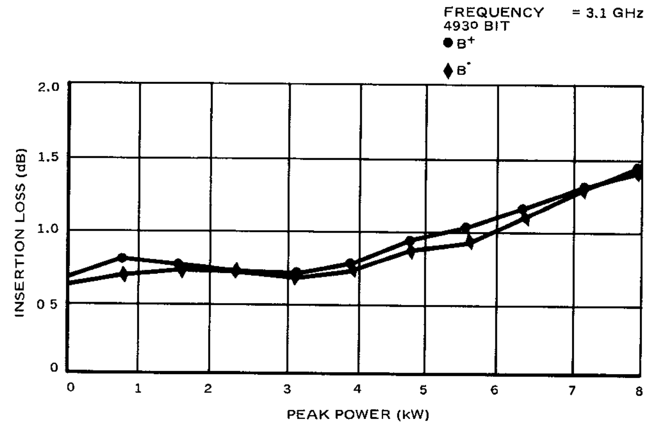

Figure 9. Lithium Ferrite Phase Shifter Peak Power Performance.

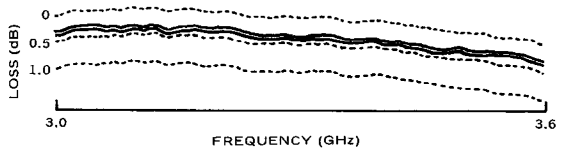

Figure 7. 3-Bit Lithium Ferrite Phase Shifter Insertion Loss

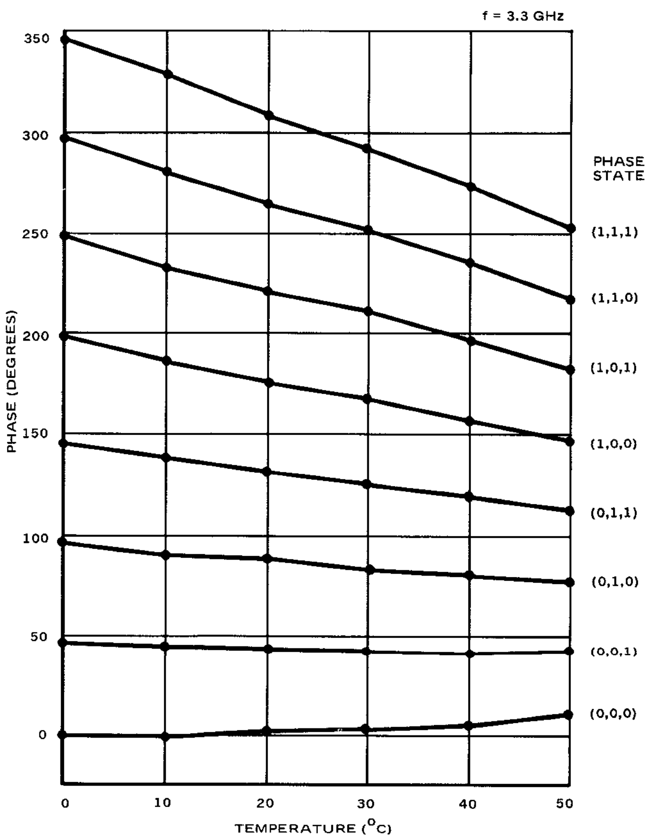

Figure 10. Lithium Ferrite Phase Shifter – Phase versus Temperature (Digital Drive)

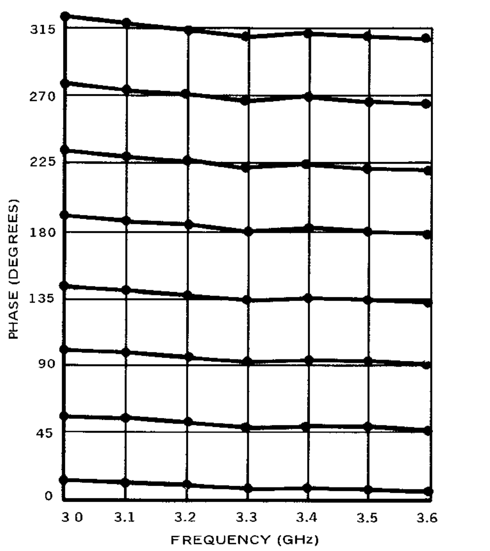

Figure 8. 3-Bit Lithium Ferrite Phaser- Phase vs Frequency