IV-6. A HIGH-POWER PHASE SHIFTER FOR PHASED ARRAY SYSTEMS

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In many large phase-phase array systems it is desirable to provide RF phase shifting at the input to rows, columns, or sub-arrays of element phase shifters in order to drastically reduce the complexity of the phase control system. The phase shifting may be provided by a high power phase shifter which must necessarily handle all the power that the row, column or sub-array radiates. To provide this high power phase shifting capability, a 115 kw peak, 600 watt average power C-band phase shifter has been developed. The unit is a Reggia-Spencer (Reference 1) type of phase shifter capable of 360 degrees of continuous reciprocal phase shift. It is 2.4 by 2.1 by 8.2 inches, and weighs less than 1.5 pounds. This paper covers the design and development of the unit.

Ferrimagnetic Material. To obtain the peak and average power requirements, a ferrimagnetic material had to be developed. The material desired was a temperature compensated garnet with either rare earth doping or small grain size or both. The temperature compensated garnet would be helpful in handling the high average power and would reduce the temperature control problem. The rare earth doping and/or small grain size would be required to increase the level where the onset of ferrimagnetic limiting began.

The first criterion, a temperature compensated garnet, was fairly easy to obtain as these materials are commercially available. The second criterion, however, required special development. Both rare earth doping and small grain size were inspected, with the latter being selected for the eventual model. The selection was based on peak power handling and insertion loss. This final material was a temperature compensated garnet whose average grain size was reduced to less than 2 microns. The improvement of the peak power handling as the crystal grain size was reduced is shown in Figure 1. As may be seen from the figure, the normal 10 to 12 micron material limited at about 8 kw while the 5 micron material showed limiting at about 30 kw. When the grain size was reduced to less than 2 microns, absolutely no limiting was detected up to 115 kw.

Design of the RF Structure. The design of the RF structure involved selecting the cross-sectional dimensions of the garnet bar and maximizing the amount of phase shift from this particular bar. The cross-sectional dimensions were obtained from two considerations: (1) the bar should be large enough to support a TE_{11} mode (Reference 2), and (2) the bar should not be large enough to support higher order modes (Reference 3). Taking these considerations into account a bar size of 0.394 by 0.510 inch was selected.

Maximizing the amount of phase shift can be controlled by three techniques: (1) shaping the input and output transitions of the garnet material, (2) allowing a dielectric gap to exist between the garnet bar and the broadwalls of the waveguide and (3) side loading the garnet bar with a dielectric.

The shape of the input-output transition sections appeared to be the most critical factor in obtaining good phase shift. Various types of transitions were tested and by far the best phase shift was obtained with pyramid shaped tapers. This seems to agree with Rizzi and Gatlin's conjecture that a TE_{11} mode propagates in the region of the garnet medium.

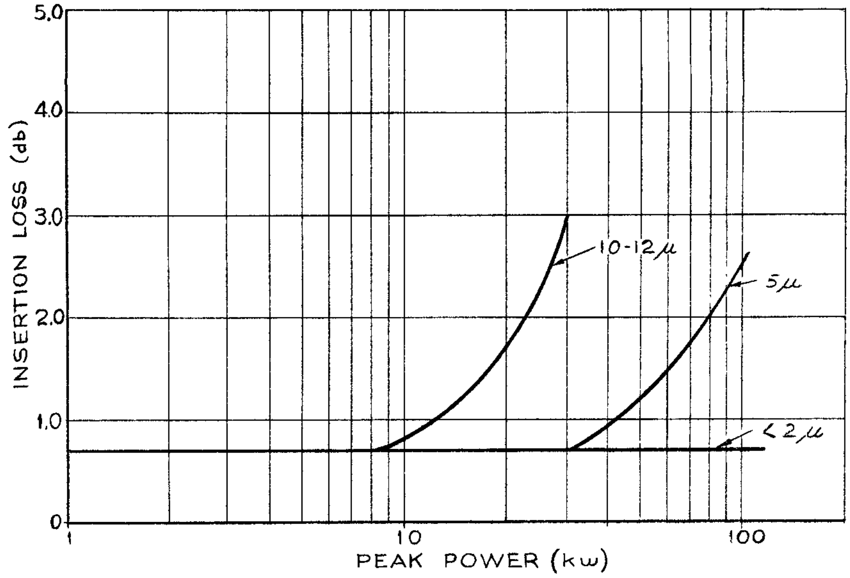

Figure 1. Improvement of Peak Power Handling versus Crystal Grain Size

Additional phase shift can be obtained by allowing a dielectric gap between the garnet bar and the waveguide broadwalls (Reference 4). The height of the gap was obtained experimentally by observing where severe multiple reflections began to occur. It is believed that at this point a higher order mode is propagating in the garnet region that is not matched to the waveguide by the transformers that match the TE_{11} mode. The results of this test are shown in Figure 2. From the figure it can be seen that an increase of 60 percent was accomplished using this technique.

The final method of improving phase shift was by side loading the garnet bar. This method did not significantly improve the phase shift, but as will be seen it was necessary for implementing the cooling technique.

Using these techniques a maximum phase shift of 450 degrees for an effective bar length of four inches was obtained. The bandwidth of the unit was 8 percent centered around 5.5 gc and the insertion loss was 0.9 db.

Cooling Technique. To remove the heat caused by dissipated RF energy, a number of cooling techniques were evaluated. Most of the techniques involved the use of a cold plate with the garnet bar being in direct contact with the waveguide broadwalls. These methods were unsatisfactory from a thermal standpoint and could not include the technique of phase shift improvement shown in Figure 2.

One cooling technique that was particularly outstanding and could include the phase shift improvement involved the use of direct dielectric liquid cooling. In this method, shown in Figure 3, the garnet bar is completely encapsulated in a teflon jacket and a low loss dielectric liquid is allowed to flow along the surface of the garnet material. By controlling the temperature and flow of the liquid, the dissipated heat can be removed. The success of this method is due to two factors: (1) two-dimensional cooling can be utilized, and (2) the cooling liquid is in direct contact with the garnet bar.

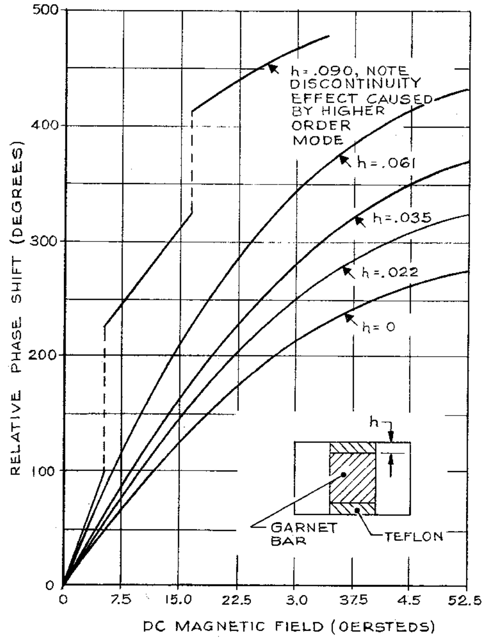

Figure 2. Improvement of Phase Shift versus Teflon Gap Height "h" between Garnet Bar and Waveguide Broadwalls

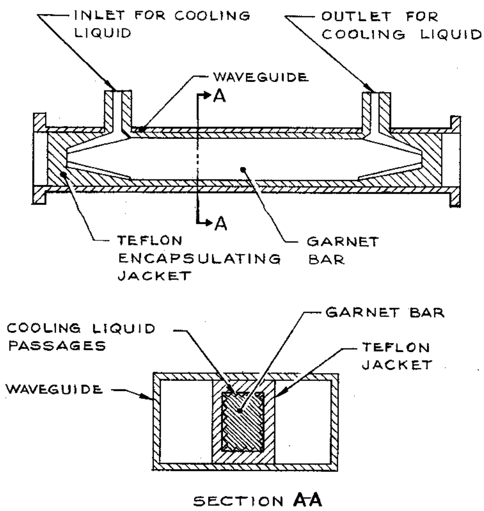

Figure 3. Direct Dielectric Liquid Cooling Technique

Using this cooling technique, phase shift versus dc magnetic field measurements were made at various power levels from 0 to 600 watts. Figure 4 shows the results of this test and indicates that the worst temperature sensitivity occurred at the zero dc magnetic field level. At this point the unit had a maximum phase error of 0.012 degrees per watt.

A photograph of the final unit is shown in Figure 5.

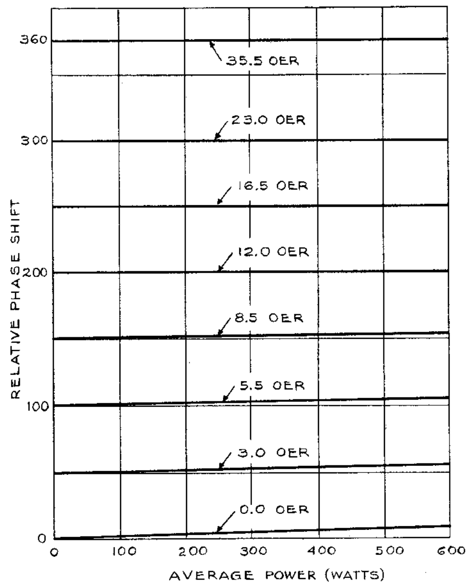

Figure 4. Phase Shift for Constant Magnetic Field Levels under Average Power Variation

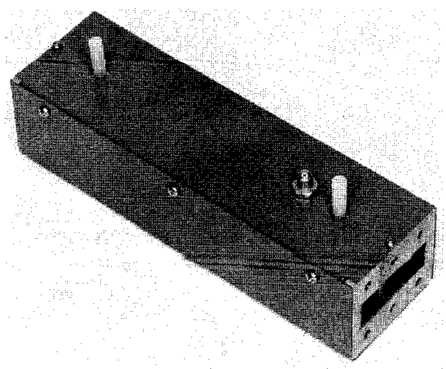

Figure 5. High Power Phase Shifter

ACKNOWLEDGEMENT

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