A SIX-BIT GMIC PHASE SHIFTER FOR 6-18 GHz

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ABSTRACT

A low-loss broad-band six-bit phase shifter has been developed in a form suitable for airborne phased array radar applications. A glass-based microwave circuit integration technology (GMIC, Glass Microwave Integrated Circuit) is used, in which thin-film, process-oriented photolithographic technology is used to realize all of the passive components on a glass surface. Hybrid-coupled reflection circuitry covers the frequency range 6-18 GHz with losses averaging about 3 dB at 6 GHz to about 8 dB at 18 GHz over the 64 phase states covering a 360° range.

INTRODUCTION

Modern phased-array technology involves the use of individual "modules", one for each of the large number of antenna elements of the array. Typically, each module incorporates a number of functional blocks, including transmitting and receiving amplifiers and various control functions. One of the most important of these control functions is a digitally controlled bi-directional phase shifter which provides precision control of insertion phase covering 360° as a means to steer the antenna beam. We report here specifically on the development of a six-bit, low loss phase shifter for the 6-18 GHz band, using M/A-COM's GMIC manufacturing technology.

Initial consideration of the design objectives indicated that this bandwidth would be attainable with hybrid-coupled switching circuitry using diodes or transistors. Conventional hybrid integration technology on quartz or ceramic substrates appeared to present excessive variabilities in assembly with the multiplicity of wire bonds required and their poorly understood parasitic network effects. M/A-COM's GMIC technology provided means to realize a low loss phase shifter covering the 6-18 GHz band using a repeatable, low cost, wafer-level, batch process manufacturing approach.

PHASE SHIFTER DESIGN

The phase shifter circuit chosen for the six-bit phase shifter is the hybrid coupled circuit shown in Figure 1. Energy applied at the input to the hybrid is coupled to the two diode terminated ports with a 90° difference in phase. Signals reflected from these terminations are recombined at the output port of the coupler. The phase shift of the output signal is primarily determined by the characteristics of the reactive circuitry between the coupler and the PIN diodes as well as the diodes themselves. The advantage of the hybrid coupled circuit over other designs is that by properly designing the coupler and the impedance transformer circuits, phase shifts of any design value are possible and are achievable over wide bandwidths.[1],[2],[3] For this design the hybrid coupled circuit was chosen for all six phase shifter bits.

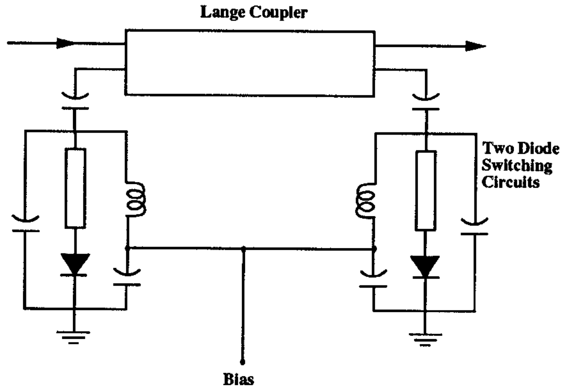

Figure 1: Basic schematic of the hybrid type reflection phase shifter. Components in the switching circuits are chosen to provide the desired phase shift as the diodes are changed from forward to reverse bias.

To meet the design goals of the six-bit phase shifter, each bit was designed to operate over the frequency band from 6-18 Ghz with the objective of flat phase shift, equal insertion loss for each state, and low VSWR. To approach these goals from a microstrip design, a Lange coupler together with the diode circuit shown in Figure 1 was employed. The diode circuit contains four circuit elements, two

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capacitors and two transmission line sections whose values are optimized for each phase shifter bit. The bias circuit containing a spiral inductor and a bypass capacitor is identical for each bit. Performance of the entire circuit, which includes the coupler, diode circuit and bias circuit, was simulated using EEsof Corp.'s Touchstone. For each phase shifter bit, the circuit elements were optimized for a given set of diode parameters.

CIRCUIT IMPLEMENTATION

The six-bit phase shifter was implemented using GMIC, M/A-COM's glass based microwave integrated circuit fabrication technology.[4] GMIC employs semiconductor derived processing technology that provides the microwave designer with repeatable, batch processed RF and DC circuitry using thin film resistors and capacitors, air-bridged spiral inductors and interconnects, and via holes for ground access and MMIC and discrete device insertion. One of the key advantages of using GMIC to make this phase shifter is the significant reduction in parts assembly when compared to its hybrid MIC equivalent. To build the hybrid equivalent would require at least sixty discrete parts (i.e. coils, chip capacitors, chip resistors, chip diodes) excluding the substrates for the Lange couplers, DC interconnection and wire bonds. The GMIC version with its passive elements integrated in-situ on the substrate needs only twelve chip diodes and their respective bond wire interconnects. Due to the high level of integration and batch processing, assembly time is dramatically reduced and circuit performance uniformity, unit-to-unit, is significantly improved.

The wafer layout for the first iteration consisted of individual bits as well as Lange coupler test structures. The production wafer contained twelve six-bit phase shifters on a three inch wafer. The layout for the six-bit phase shifter is shown in Figure 2.

PERFORMANCE

In figures 3, 4, and 5, we show data for the entire phase shifter in 7 different states. In one state, all diodes are forward biased. In the others, one section at a time is switched to reverse bias. Testing was performed at the wafer level using coplanar waveguide probes on a fully automated test station. The .967 x .325 inch six-bit phase shifter yielded the following typical performance over the 6-18 GHz bandwidth: VSWR better than 2.3:1, an average insertion loss of about 3 dB at 6 GHz increasing to about 8 dB at 18 GHz, and a 3.5° RMS phase error. The measured performance agrees well with the simulated performance although there is a slight

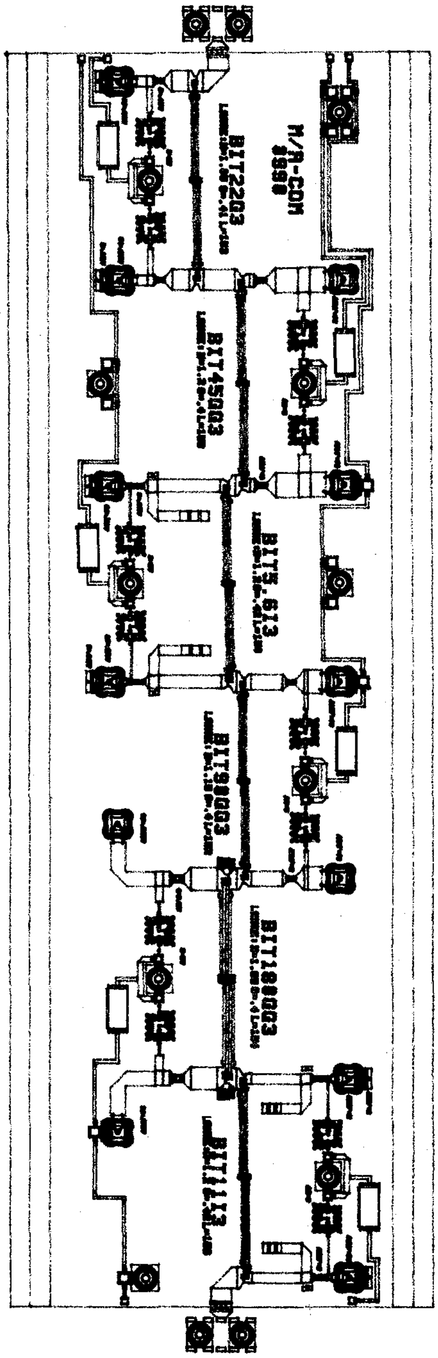

Figure 2: 6-18 GHz Six-Bit GMIC Phase Shifter
(.967" x .325" x .025")

increase in insertion loss at the high end of the frequency band.

CONCLUSION

This paper has presented the results of a low loss broadband six-bit phase shifter utilizing GMIC, M/A-COM's new generation batch-process-oriented manufacturing technology. The phase shifter design is a reflective type that utilizes a Lange coupler and switched diodes to achieve phase shift through 360°. It was fabricated using discrete PIN diodes and achieved state-of-the-art performance in a space conservative design.

ACKNOWLEDGMENTS

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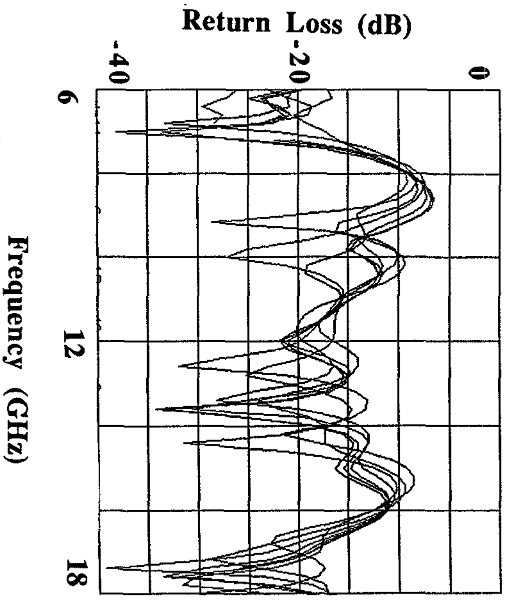

Figure 3a: Simulated Return Loss

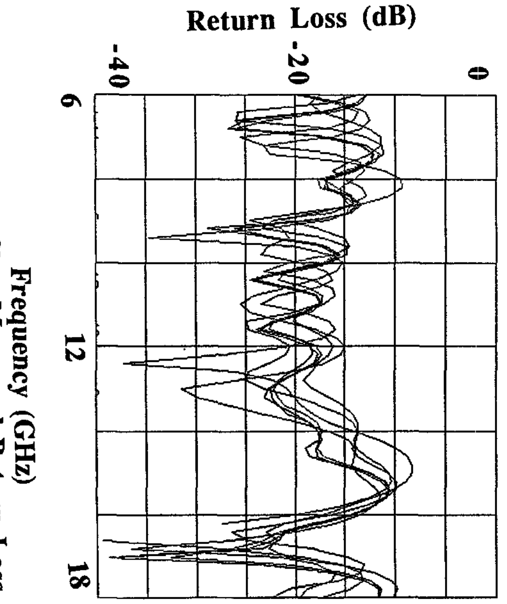

Figure 3b: Measured Return Loss

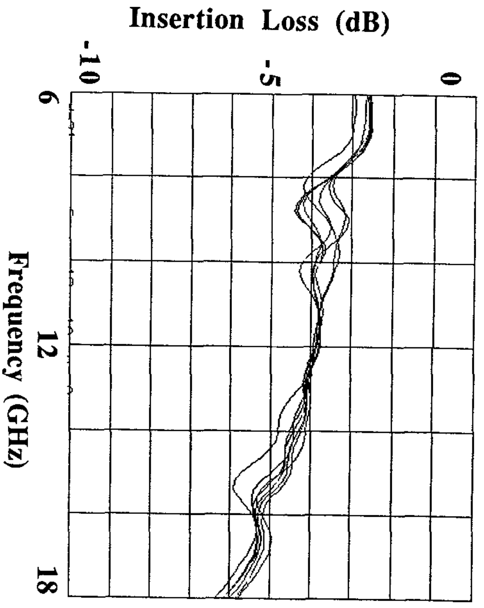

Figure 4a: Simulated Insertion Loss

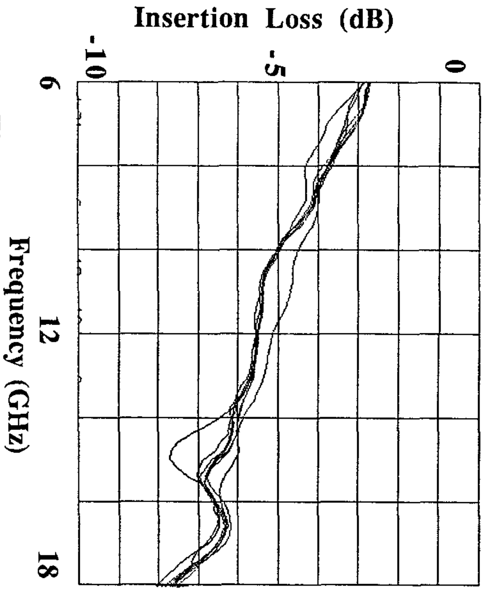

Figure 4b: Measured Insertion Loss

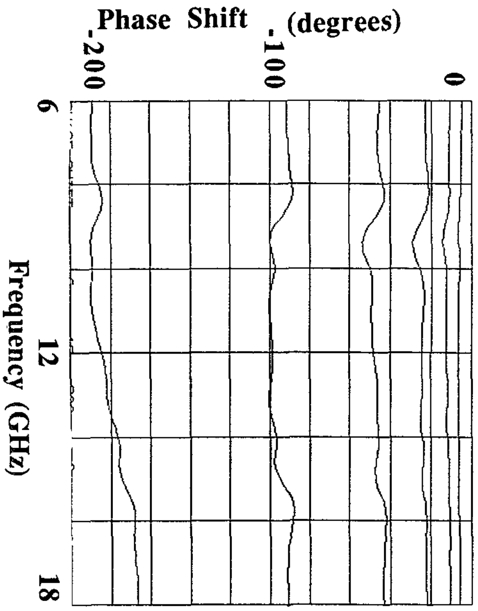

Figure 5a: Simulated Phase Shift

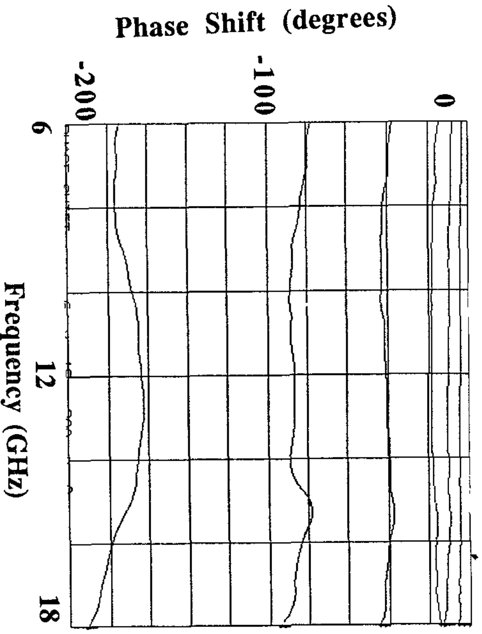

Figure 5b: Measured Phase Shift

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