PRODUCTION RESULTS OF X-BAND GaAs MMIC 5-BIT PHASE SHIFTERS

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ABSTRACT

The measured results of the production of high performance, highly reproducible GaAs monolithic 5-bit phase shifters for phased array system applications are presented. Very good DC (> 90%) and RF (75%-80%) yields have been achieved on an X-Band phase shifter from the test results of thousand of these ICs. The performance correlation of these phase shifters have been verified between wafer level results and assembled module level data. To our knowledge, this is the first monolithic single chip small size (96 mils x 48 mils) five-bit phase shifter in the X-band to achieve over 70% total production yield.

INTRODUCTION

Recent emphasis in the design and development of GaAs MMICs has started to shift toward circuit performance with high reproducibility and manufacturability [1-6]. The MMIC insertion into operating systems such as Phased-Array Radars is dependent on the production of high-yield, reproducible, high-performance and low-cost GaAs MMICs. This paper presents the production results of a 7-12 GHz, fully monolithic 5-bit phase shifter (chip size: 96 mils x 48 mils), which is an important component of a Phased Array T/R Module. This effort demonstrates the feasibility of manufacturing these cost effective, reproducible monolithic phase shifter ICs for system insertion.

PHASE SHIFTER CHIP

The X-band five-bit monolithic Phase Shifter chip utilizes a vector modulator design approach. Figure 1 shows a photograph of the monolithic 5-bit phase shifter chip. The chip measures 96 mils x 48 mils. The circuit utilizes a push-pull and lumped element design approach for augmenting yield and minimizing chip size.

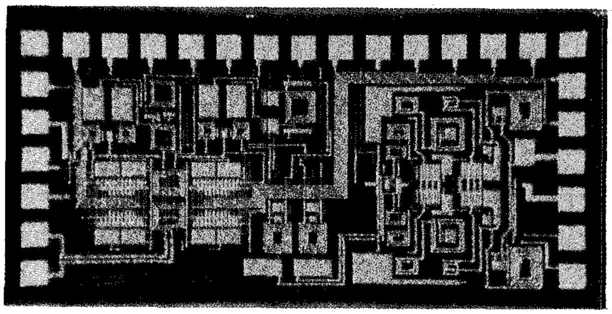

Figure 1. Photograph of the five-bit monolithic phase shifter

MMIC FABRICATION PROCESS

This monolithic Phase Shifter was fabricated using 0.5 micron ion-implanted GaAs MESFET process with an Ft (Gm/2iiCgs) of 18 GHz. Both analog and digital functions can be integrated in this process [7,8]. After processing the wafers were thinned to 7 mils and back metallized. This process did not use any via holes. The fabrication process was monitored based on Process Control Monitors (PCMs) distributed over the wafer area. The PCM usually contains a variety of test structures (FETs, resistors, capacitors, diodes, inductors) which enables to check the process design parameters independently of the RF circuits

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RESULTS

Wafer level measurements were carried out on a semi-automated wafer probe station equipped with RF wafer probes and a DC probe card. The RF probe has multi-contact probe heads especially designed for this application. The three way arrangement of two RF probes and a dc probe card on the wafer probe station is shown in Figure 2. Ten three inch wafers (seven mils thick) from two different lots were evaluated after 100% visual inspection.

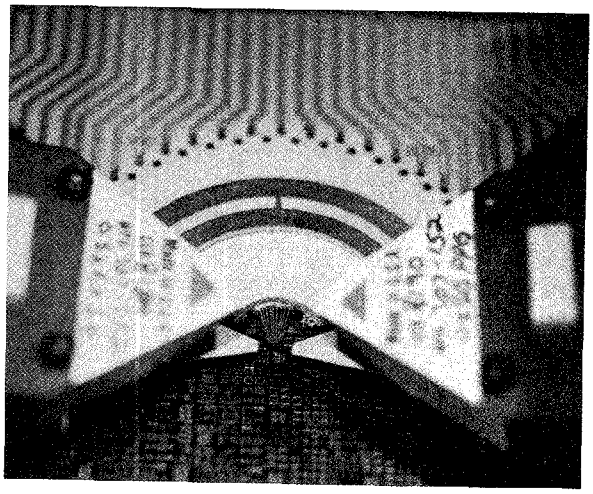

Figure 2. Wafer probe station with two RF probes and a DC probe card

The measured five-bit phase shift performance over all 32 phase states across the 7-12 GHz band is shown in Figure 3. Over this wide band, an RMS phase error of 4 degrees and a maximum phase error of 10 degrees are achieved. Figure 4 depicts the insertion loss variation over all 32 phase states in the 7-12 GHz band with an RMS loss deviation of 1 dB. Figure 5 shows the polar plot of S21 (referenced to the zero state) at 0^{o}, 45^{o}, 90^{o}, 135^{o}, 180^{o}, 225^{o}, 270^{o} over 8-10 GHz frequency band. The input and output VSWR of this X-Band phase shifter is better than 2:1. The switching time from any given phase state to the next state (11.25 degrees away) is less than 4ns.

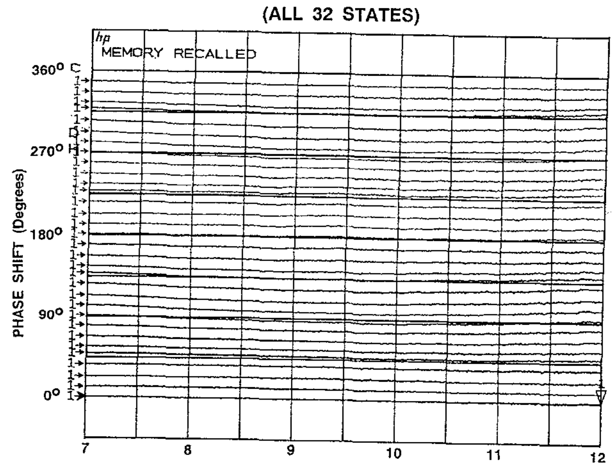

Figure 3. Phase shift performance of monolithic phase shifter

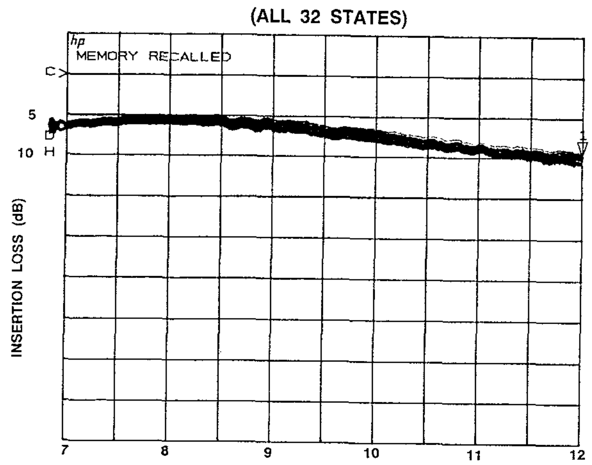

Figure 4. Insertion loss of monolithic phase shifter

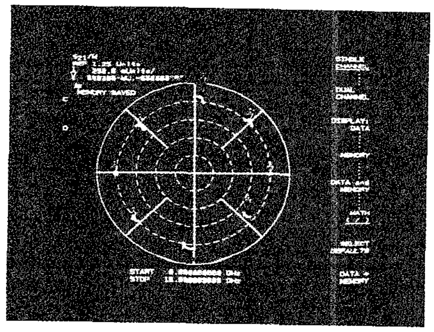

Figure 5. Polar plot of S21 at 0o, 45o, 90o, 135o, 180o, 225o, 270o over 8 - 10 GHz

The RMS phase error distribution (across the frequency band) over the wafer and from wafer to wafer is plotted in Figure 6. It shows that these wafers have a yield of 72% when the criterion is 6 degrees RMS phase error. Figure 7 is a histogram of the mean insertion loss distribution of these phase shifters for the 9-11 dB range. It shows that 70% of the devices fall within a 9.75 - 10.75 dB insertion loss window.

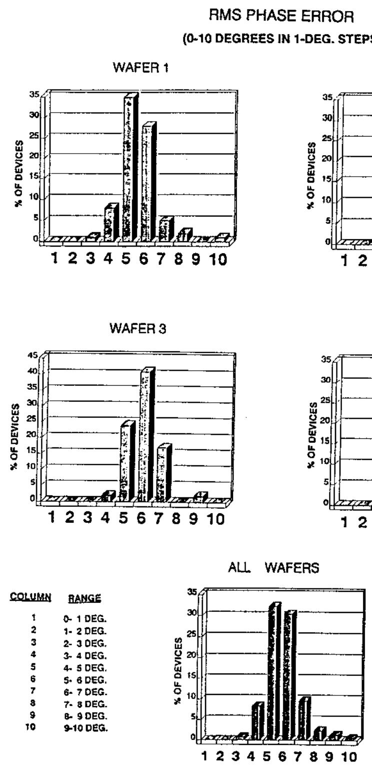

Figure 6. Histogram of the RMS phase error distribution across the wafer and from wafer to wafer

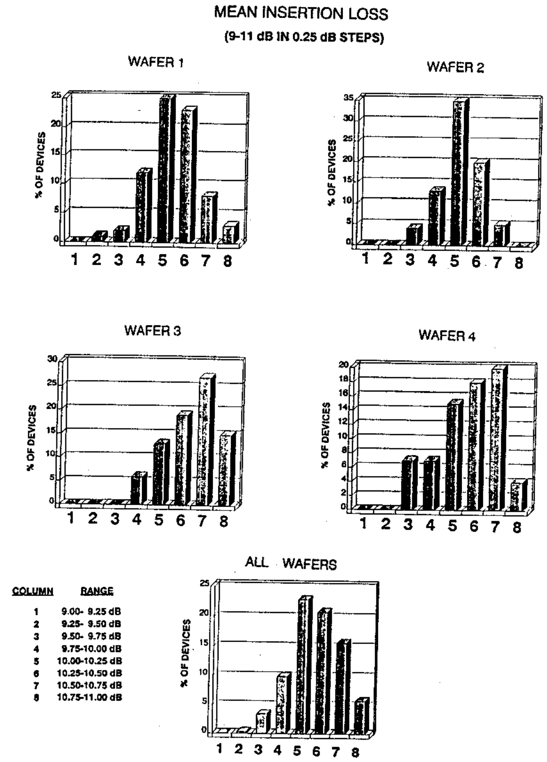

Figure 7. Histogram of the insertion loss distribution across the wafer and from wafer to wafer

Also shown in the same figure, is an overall insertion loss spread across the wafers. The devices that failed DC and RF criteria (approximately 15% of the total phase shifters per wafer) are shown as shaded areas in the wafer map of Figure 8.

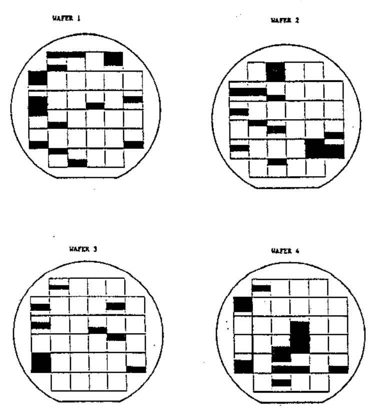

Figure 8. A sample wafer map indicating failed devices

The temperature performance of the phase error of this 5-bit phase shifter assembled in a package at 10 GHz is shown in Figure 9. Over the temperature range (-54°C to +94°C) the phase deviation is only two degrees.

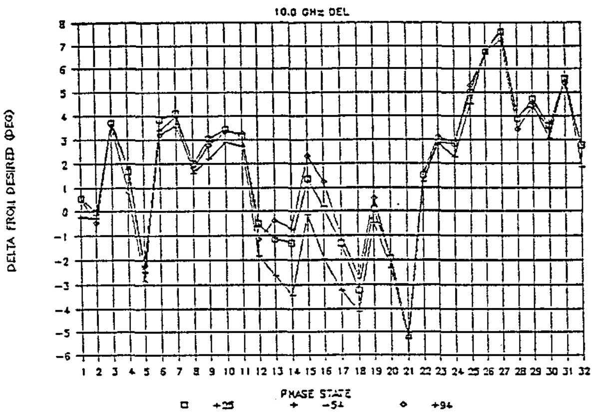

Figure 9. Temperature performance (-54oC to +94oC) of a packaged phase shifter

Figure 10 depicts a packaged phase-shift receive module. This module contains the five-bit phase shifter, buffer amplifiers and MIC substrate and balun. The measured RMS phase error of this packaged module (Figure 11) was in good agreement (within one degree) with the wafer level results

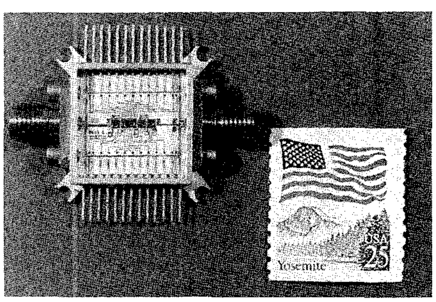

Figure 10. Packaged phase shift module with buffer amplifiers

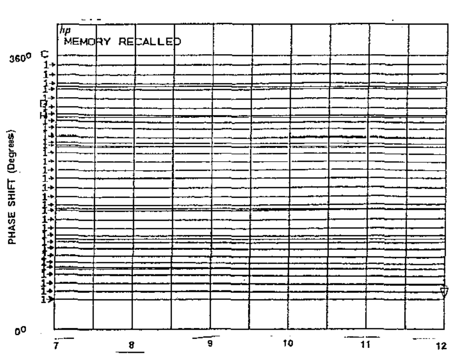

Figure 11. Phase shift performance of the packaged module

CONCLUSION

GaAs monolithic X-band five-bit phase shifters have demonstrated a total production yield greater than 70% and nearly identical circuit performance across a wafer and from wafer to wafer. This high-yield, highly reproducible phase shifter will make the manufacturing of next-generation phased array monolithic T/R modules a viable low-cost part.

ACKNOWLEDGEMENT

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