MMIC PHASE SHIFTERS AND AMPLIFIERS FOR MILLIMETER-WAVELENGTH ACTIVE ARRAYS

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ABSTRACT

The development of MMIC phase shifters and amplifiers at 20 and 44 GHz for application in space based active antenna arrays is described. RF probing to characterize the active elements at these frequencies is shown to provide a good basis for the MMIC design.

INTRODUCTION

Future space applications will require active space-based antenna arrays to provide scanning spot beams and/or anti-jam capability at millimeter-wavelengths. Such applications will require large numbers of highly repeatable receiver or transmitter modules. These modules must be small enough to meet the requirements imposed by the physics of the array, and inexpensive enough to make the system cost effective. Therefore, MMIC technology appears to be the key to making such systems practical. For that reason Ford Aerospace has an ongoing program to develop monolithic amplifiers and phase shifters for active arrays at frequencies such as 20, 30, 44 and 60 GHz.

A key circuit element is a digital phase shifter. Initial efforts were devoted to 20 GHz switched line, four-bit phase shifters. After the successful completion of this task, these results were used as the basis for developing the 44 GHz digital phase shifters reported in this paper. These are believed to be the first of this type to be reported. Similarly, three-stage 20 GHz MMIC amplifiers were developed and these results used as the basis for the design of 44 GHz MMIC amplifiers. The development of all of these circuits was facilitated substantially by the use of a Cascade Microtech millimeter-wavelength probe for the characterization of the active elements as well as for the evaluation of the complete phase shifters and amplifiers.

PHASE SHIFTERS

A switched-line phase shifter, using FETs as the active elements in the single-pole double-throw switches, was the chosen approach. This approach is compatible with the associated MMIC circuitry such as FET amplifiers, consumes no power, and makes simpler demands on the control circuitry than an analog approach (an important

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consideration since control circuitry can account for most of the power and mass of an active array module). The basic circuit used for each phase bit at both 20 and 44 GHz is shown in Figure 1 (1,2). An inductor resonates the capacitance of the FET in the "off" state. An implanted resistor in each gate lead serves as a choke. Vias are provided to permit microwave probe measurements. FET-inductor combinations were also fabricated in a configuration to permit probe measurements and accurate s-parameter characterization of these basic switching elements to serve as the basis for the design of the phase shifters. An example of these results is shown in Figure 2. The transmission through the switching element is shown in both the "on" and "off" states. The isolation in the "off" state shows the inductor resonating the FET capacitance at 44 GHz. Similar measurements at 20 GHz had served as the basis for the design of a four-bit phase shifter whose performance is shown in Figure 3. Using the 44 GHz switched FET measurements, phase shifter bits were designed and initial

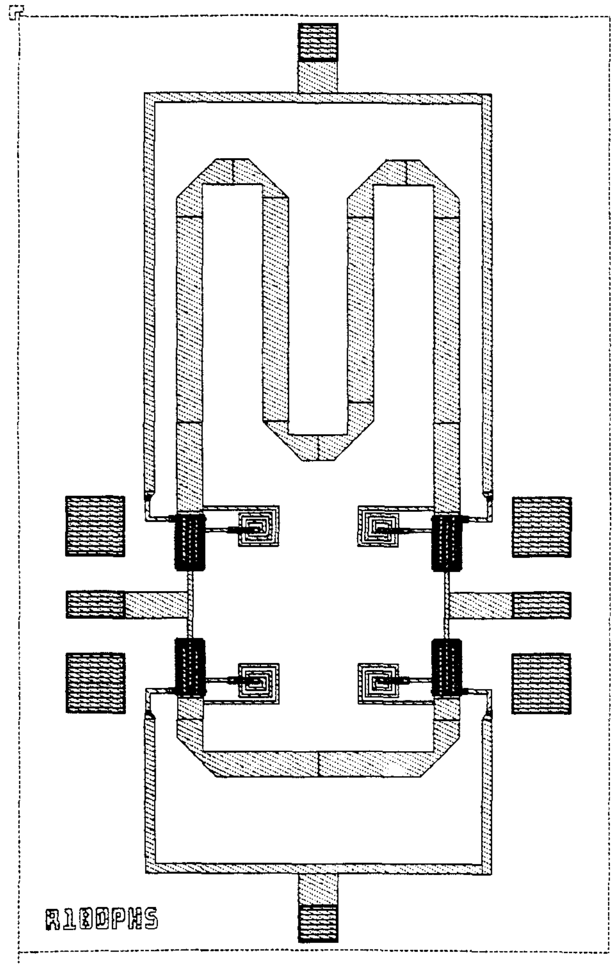

Figure 1. Layout of typical phase shifter element.

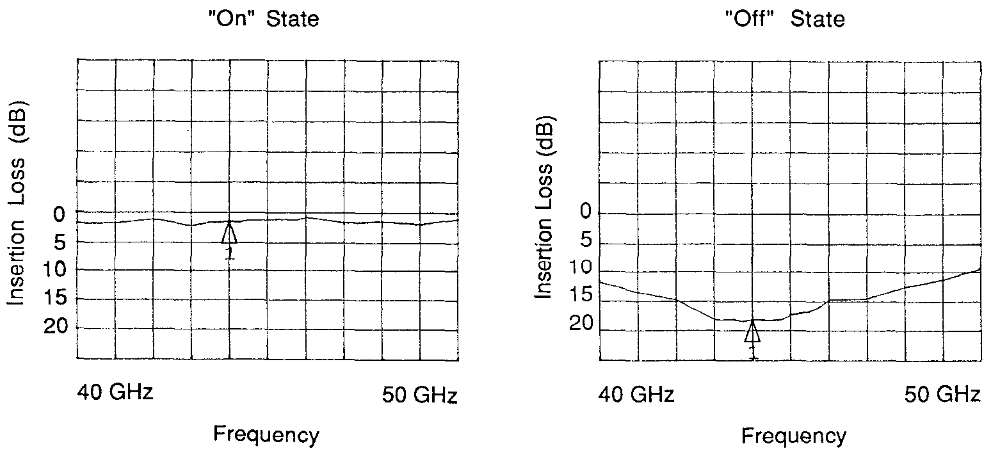

Figure 2. Measured performance of a switching element for a 44 GHz phase shifter.

results have been obtained. The performance of the 180 degree phase bit at 44 GHz is shown in Figure 4. Figure 5 is a photograph of a portion of a wafer showing several 44 GHz phase bits. A complete four-bit 44 GHz phase shifter is now in fabrication and the results will be presented. The FETs used in the 20 GHz phase shifter have 1 micron gates, whereas the 44 GHz phase shifters utilize 0.5 micron gates.

AMPLIFIERS

The development of MMIC amplifiers for active array elements is also well along. The performance of a three-stage 20 GHz amplifier is shown in Figure 6. This

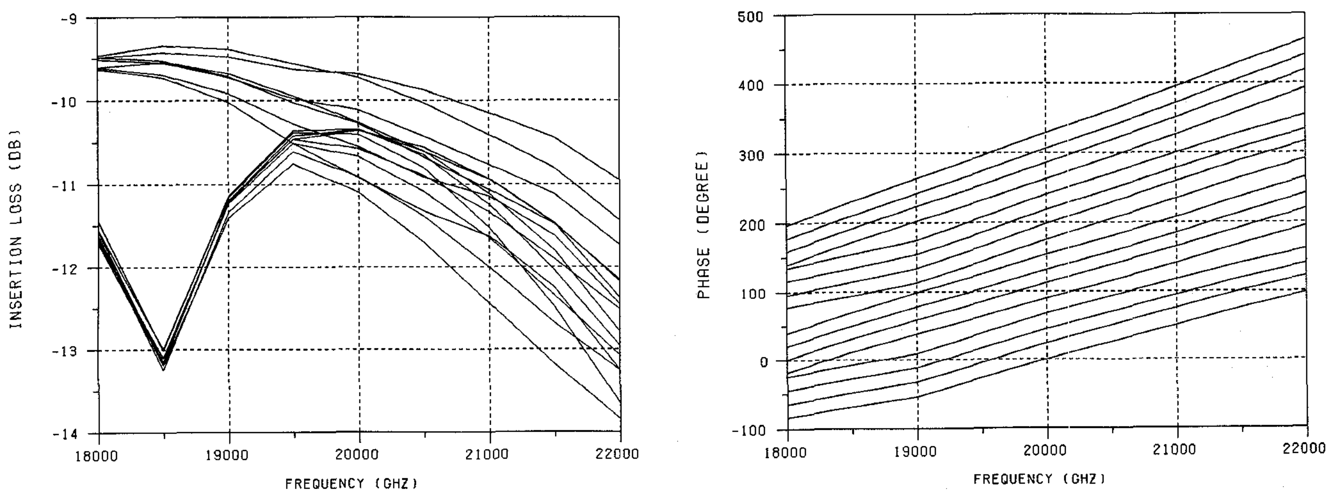

Figure 3. Measured performance of all 16 states of a four-bit 20 GHz MMIC phase shifter.

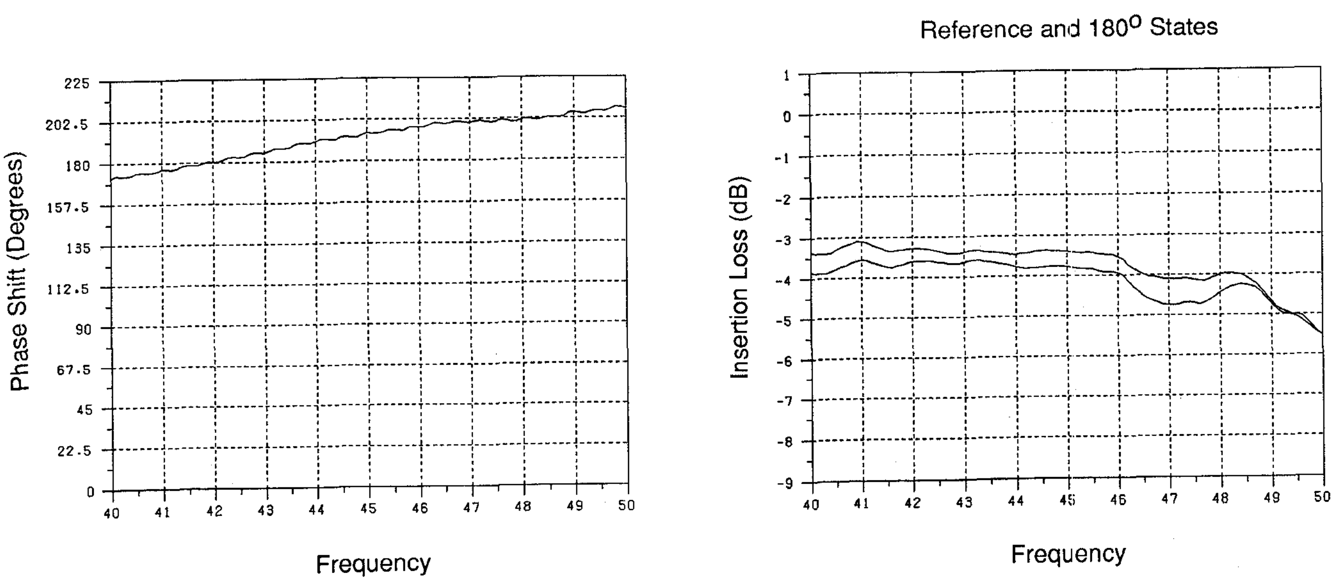

Figure 4. Measured performance of a 180 degree 44 GHz phase shifter.

performance is in excellent agreement with Touchstone predictions based on microwave probe characterization of FETs of the type used in the amplifier. The amplifier consists of two stages using FETs with 150 micron gate widths and a final stage using a 300 micron FET. All the gate lengths are 0.5 micron. Now, the use of the millimeter-wavelength probe to characterize quarter-micron FETs has enabled the design of 44 GHz MMIC amplifiers which are now being processed.

FABRICATION

The GaAs MESFETs active channel and N+ region are formed by selective silicon 28 ion implantation directly into a 3-inch diameter, (100), semi-insulating GaAs substrate. The implants are activated using capless furnace annealing with arsine overpressure.

The source and drain regions are defined by photolithography, followed by AuGe/Ni/Au ohmic metal evaporation. Ohmic contact is formed by hot-plate alloying. The half-micron length gate is deposited using Ti/Pt/Au after a gate-recess etching. MIM capacitors are formed by 2000 Angstroms of PECVD Si_3N_4.

The typical transconductance of the 0.5 x 150 micron device is 150 mS/mm. The typical pinch-off voltage is around -2.3 Volt at 1 ma/mm Ids. The ft of the device is around 18 to 22 GHz, and fmax is around 70 GHz. The noise figure of this type of device is 1.5 to 1.6 dB with 9 dB associated gain at 12 GHz with bias conditions of 15% of Idss.

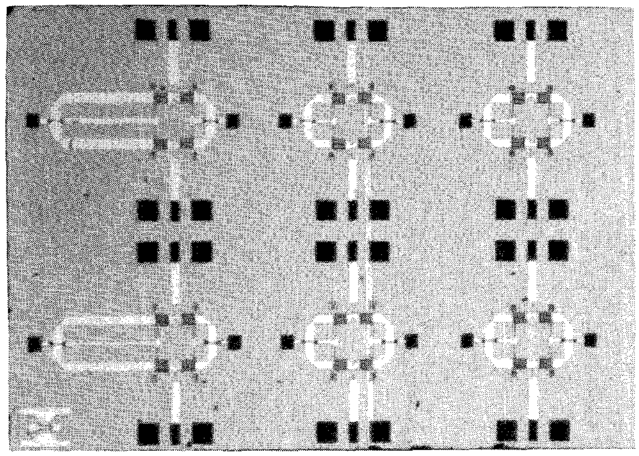

Figure 5. Photograph of a portion of the 3 inch GaAs wafer showing several 44 GHz phase shifters.

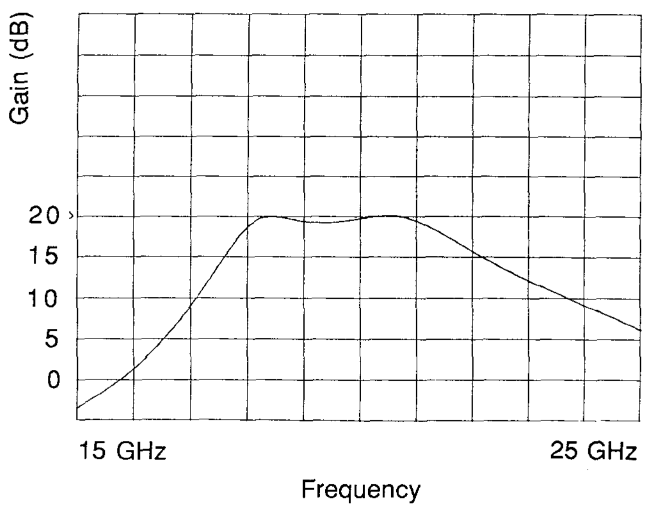

Figure 6. Performance of a 3-stage 20 GHz amplifier.

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