K_a-BAND MMIC BEAM STEERED TRANSMITTER ARRAY

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ABSTRACT

A 32 GHz six element linear transmitter array utilizing state-of-the-art MMIC phase shifters and power amplifiers has been developed and tested as part of the development of a spacecraft array feed for NASA deep space communications applications. Measurements of the performance of a number of MMIC phase shifter and power amplifier was carried out and electronic beam steering was demonstrated.

INTRODUCTION

Communication systems for NASA deep space missions presently operate at X-band. Advanced deep space missions in the mid-1990's will utilize K_a-band systems (32 GHz downlink, 34 GHz uplink) to achieve communications enhancement on the order of 8 dB. The spaceborne transmitter is a critical element in these systems and at JPL a 32 GHz solid state transmitter is under development utilizing MMIC devices. As a step in this development a six element linear array has been designed and tested. The array utilized state-of-art MMIC switched line phase shifter and power amplifiers devices developed under programs funded by the NASA Lewis Research Center. Although *receiver* MMIC array development at K_a-band has been reported [1], this paper reports the results of *transmitter* development.

MMIC DEVICES

The MMIC phase shifters were designed and fabricated by Honeywell [2,3]. A photograph of a phase shifter is shown in Figure 1. These devices contain 14 MESFETs in three digital switched line and one analog loaded line phase shifter. The switched line phase shifters provide nominal phase changes of 45, 90 and 180 degrees. The loaded line phase shifter produces a nominal continuous phase variation from 0 to 45 degrees.

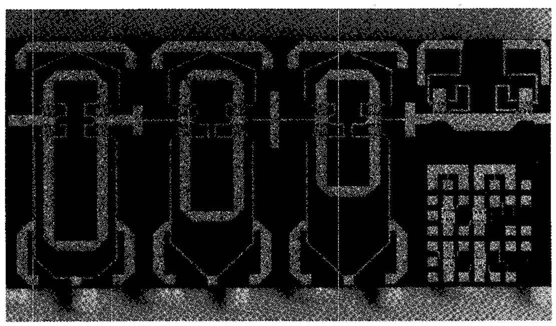

Fig. 1. Honeywell phase shifter.

The MMIC power amplifiers were designed and fabricated by Texas Instruments [4]. A photograph of an amplifier is shown in Figure 2. The devices used in the array were two stage amplifiers utilizing GaAs MESFETs with 0.25 μm gate lengths and gate widths of 0.1 mm and 0.3 mm for the two stages with a design goal of 20 dBm output power.

ARRAY DESIGN

The array was composed of an RF signal distribution subsystem, a set of two MMIC car-

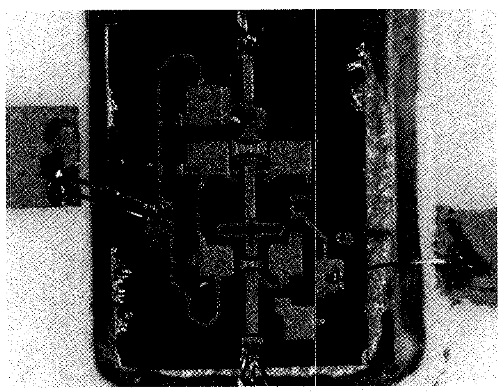

Fig. 2. Texas Instruments MMIC power amplifier.

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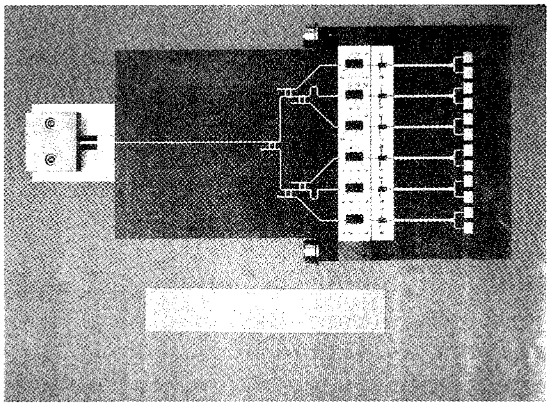

Fig. 3. Six element array.

The array was composed of an RF signal distribution subsystem, a set of two MMIC carriers and a patch antenna subsystem. A photograph of the array system is shown in Figure 3 with a bipodal Van Heuven [5] waveguide to micostrip transition at the input drive port.

The RF signal distribution system consisted of a set of branch line couplers to produce equal amplitude and phase outputs. The signal distribution system was constructed on 0.12 mm thick Rogers duroid 5880 and was designed using the Touchstone simulation and MiCAD layout systems. Each coupler was terminated by a 50 ohm TaN thin film resistor connected to an approximately quarter-wave length radial line open circuit stub.

The MMIC carriers were designed to permit measurement of each MMIC device and to interface with the array. Individual devices were measured by attaching waveguide to microstrip transitions to the carrier as shown in Figure 4. The carrier strips consisted of laser cut, 0.25 mm thick alumina substrates with etched TiW/gold circuit metalization that were soldered to gold plated kovar ground planes. The dc and control lines were brought through the carrier and substrate via miniature coaxial feedthroughs mating with DIP socket connectors. The MMICs were attached to the carriers with silver epoxy and wire bonded to 25 μm diameter gold wire.

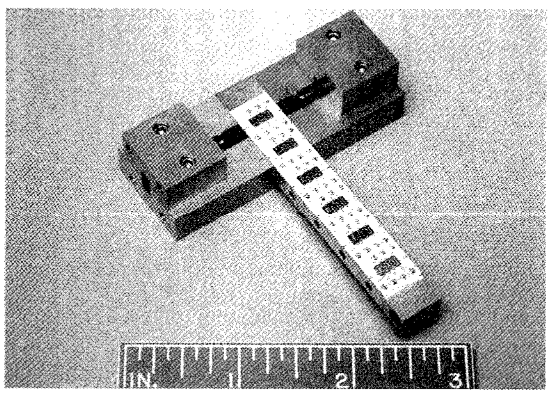

Fig. 4. MMIC carrier.

The antenna section was designed on 0.25 mm Rogers duroid 5880 and consisted of six pairs of linearly polarized patch antennas with 1.01 λ spacing. These elements radiated in a direction normal to the plane of the dielectric when all elements were driven in phase.

TEST RESULTS

The MMIC devices were measured on an extended HP8510 at 32 GHz in the carriers. Phase shift measurements were referred to the nominal zero phase state of each device and attenuation was referred to back-to-back waveguide to microstrip transitions. Figure 5 is a plot of nominal phase versus measured phase for six phase shifters. The devices used in the array were from two wafers each made with slightly different mask sets. The mean and standard deviation of the phase shift was 7.0 ± 1.6% over the range 0 to 300 degrees. Attenuation as a function of nominal phase angle is shown in Figure 6. The mean attenuation at zero phase shift is 10.4 dB for the first group and 8.0 dB for the second, the attenuation changed at a rate of approximately 0.8 dB/100

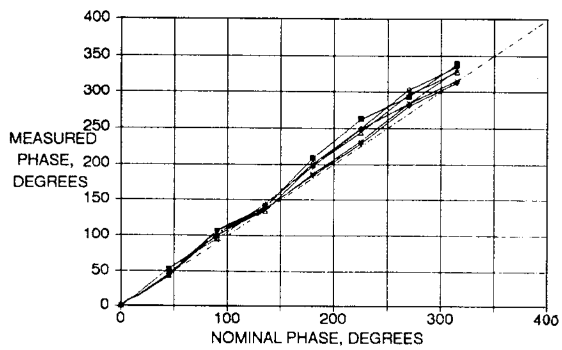

Fig. 5. Phase shifter phase

degrees and 2.8 dB/100 degrees for the two groups. Despite this variation in attenuation reasonable array beam steering was obtained.

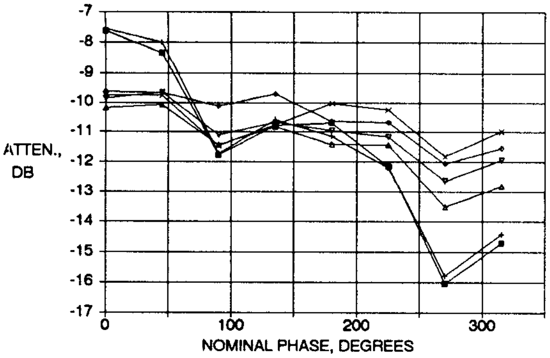

Fig. 6. Phase shifter attenuation measurement.

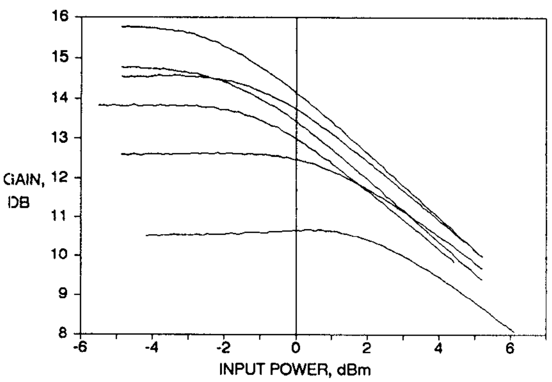

Fig. 7. Power amplifier gain.

The gain versus input power of the TI power amplifier MMIC amplifiers is shown in Figure 7. The six devices had been fabricated from the same wafer and had a low power gain mean and standard deviation of 13.7 ± 1.7 dB. The mean and standard deviation of output power at 1 dB gain compression was 13.6 ± 0.3 dBm. Several devices were externally tuned and were found to be capable of producing as much as 21.5 dBm with power added efficiency of 14.5% at 1 dB gain compression.

The array was placed in a fixed position in an antenna range with a 10 cm reflector to receive the transmitted signal. The measurement system and a phase shifter bias switching system were controlled by a PC. A program was written to set the phases based on keyboard entries of beam steering angles. The pattern measured as the beam was electronically steered from -8 to +8 degrees is shown in Figure 8, the measured steered beamwidth was 7.5 degrees.

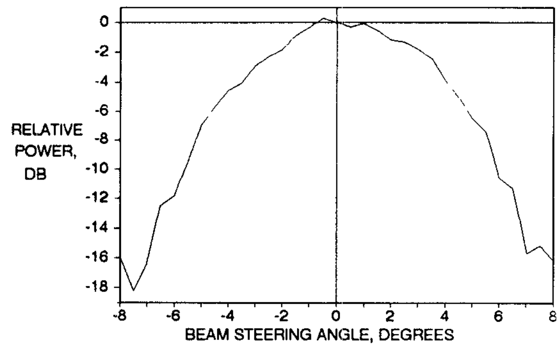

Fig. 8. Steered antenna pattern.

CONCLUSIONS

A 32 GHz six element linear transmitter array utilizing state-of-the-art MMIC phase shifters and power amplifiers has been developed and tested as a precursor to the design of a two dimensional array. The switched line phase shifters were accurate to within 7% on average and the power amplifier 1 dB compressed output power varied over 0.3 db. The array had a beamwidth of 7.5 degrees and demonstrated acceptable beam steering over ± 8 degrees.

ACKNOWLEDGEMENTS

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