A K_a-BAND MMIC ARRAY FEED TRANSMITTER FOR DEEP SPACE APPLICATIONS

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ABSTRACT

A K_a-band solid state transmitter capable of power greater than 5 W is being developed. The transmitter consists of an array of 21 elements each driven by a single stage MMIC power amplifier, three stage MMIC pre-amplifier and four bit phase MMIC phase shifter. The design of the array and measurements of the antenna pattern of the full array and an electronically beam steered sub-array are reported.

INTRODUCTION

Spacecraft transmitters have traditionally relied on traveling wave tube amplifiers (TWTAs) which tend to be expensive, difficult to implement and unreliable. To avoid these problems on future missions, JPL is presently developing a K_a-band solid state amplifier transmitter which utilizes MMIC devices. The approach is to array a number of devices and spatially combine the power from them to produce levels adequate for deep space communications (>5 W) [1,2,3,4]. The array illuminates a two reflector antenna system. Fine pointing of the beam will be by electronic beam steering of the array implemented with MMIC phase shifters. This array is presently under construction at JPL and we report here on the details of its design and test results.

MMIC PHASE SHIFTERS AND POWER AMPLIFIER

The array feed consists of 21 elements each driven by a set of four integrated circuit chips. There are:

- A 350 mW single pseudomorphic HEMT power amplifier MMIC with 0.25 μm gate length shown in Figure 1.
- A 100 mW three stage pseudomorphic HEMT pre-amplifier with 0.25 μm gate length
- A four bit GaAs FET MMIC phase shifter with 0.5 μm gate length shown in Figure 2.
- A custom designed silicon serial to parallel converter IC to drive the phase shifter.

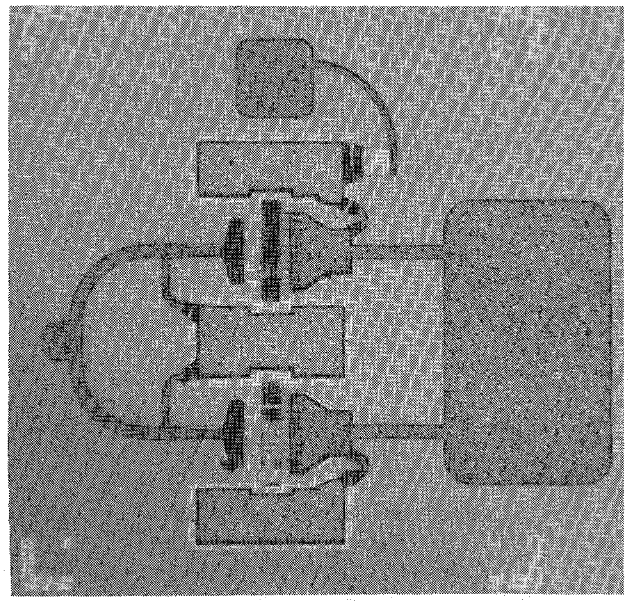

Figure 1 *- TI HEMT power amplifier chip.*

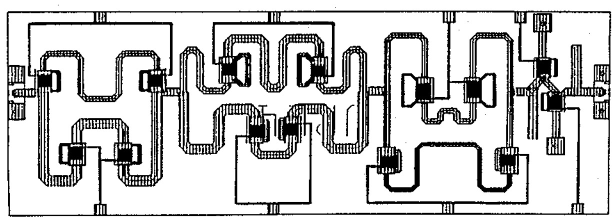

Figure 2 *- Honeywell four bit phase shifter.*

The MMIC power amplifier and pre-amplifier chips were developed by a group at Texas Instrument led by H.Q. Tserng and P. Sanier and have been described in

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detail in the literature [5,6]. The MMIC phase shifters were developed at Honeywell by a group led by V. Sokolov and J. Mondal and have also been described in the literature [7,8]. These devices were developed under contract with the NASA Lewis Research Center with production units funded by JPL. The VLSI chip was designed at JPL and fabricated by the DARPA MOSIS foundry. This chip receives a serial data stream, converts it to parallel data and stores it prior to transferring it to the phase shifters.

Thirty phase shifters were mounted on carriers and measured in each of 16 phase states. Figure 3 summarizes the results of these measurements showing the mean and standard deviation of nominal phase angle vs. measured phase angle. The mean phase deviation was 2.6 % with a standard deviation of 19%. The mean insertion loss was -10.5 dB with a standard deviation of 1 dB.

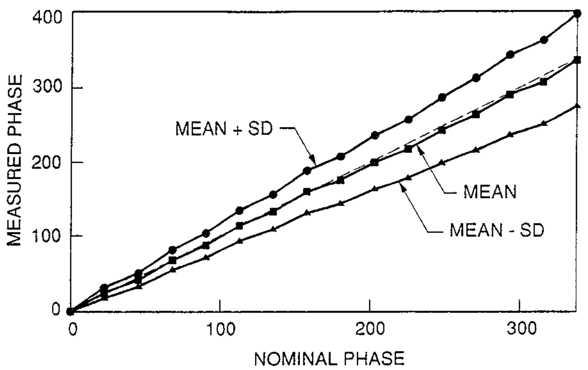

Figure 3 *- Phase shifter phase and attenuation performance.*

MMIC CARRIER CONSTRUCTION AND BEAM CONTROL SYSTEM

The integrated circuits were mounted on two types of carriers. The phase shifters and digital ICs were mounted on one type of carrier and the pre-amplifier and power amplifier chips were mounted together on another. A photograph of the phase shifter carrier is shown in Figure 4. On the left side of this carrier is a printed circuit board which connects timing signals and bias voltages for the silicon ICs to the serial data bus. These are carried in a trough which passes under the microstrip input lines. These lines are connected to the ICs which produce parallel data which, in turn, are distributed to the phase shifters. The carrier is fabricated of approximately 6 mm thick kovar with 0.25 mm alumina circuit board which has been laser cut.

The power amplifier carriers are constructed of molybdenum with each chip mounted in a copper sub-carrier soldered into the carrier. Bias voltages to the chips are distributed by lines in troughs similar to those in the

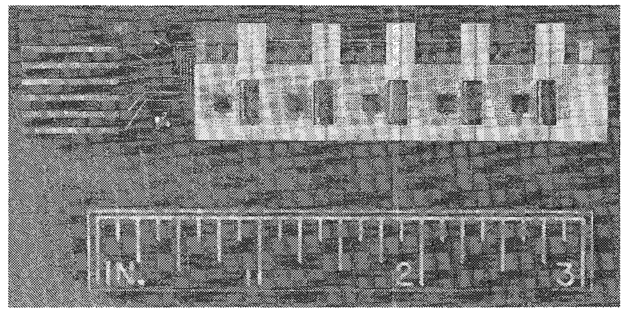

Figure 4 *- Photograph of phase shifter carrier.*

phase shifter carrier design. Both the phase shifter and power amplifier carriers are designed to interface with RF test connectors to permit testing of individual phase shifters and pairs of amplifier chips.

SUB-ARRAY AND ARRAY FEED DESIGN

The carriers are mounted together with a beam forming network and antenna radiating elements to form a linear sub-array as shown in Figure 5. Five of these sub-arrays are integrated with a vertical beam forming network to produce the full array as shown in the photograph in Figure 6. The beam forming networks consist of a series of branch line couplers on 0.13 mm Rogers duroid and terminated with 50 Ω chip resistors. The chip resistors are attached to quarter wave length open circuit radial stub. The transition between the vertical and horizonal beam forming networks is through commercial blind mate connectors. The radiating elements consist of Vivaldi slot line radiators which were designed by a group at the University of Massachusetts led by S. Yngvesson. This work has been described in detail in the literature [9].

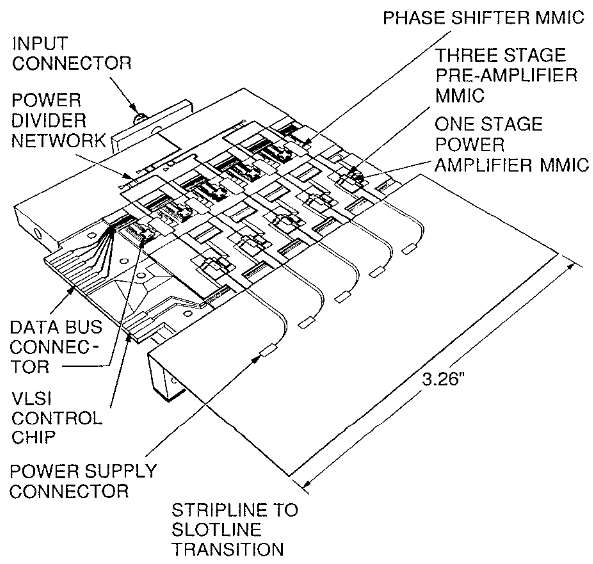

Figure 5 *- Linear sub-array construction.*

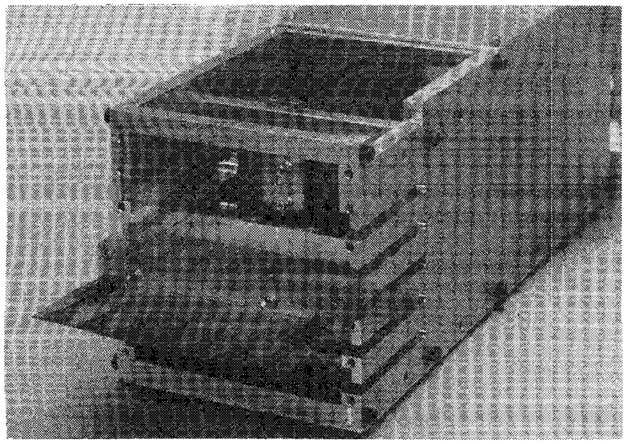

Figure 6 *- Fully integrated 21 element array.*

ANTENNA PATTERN MEASUREMENTS

Measurements of the antenna patterns were taken in two configurations. The first is with a single sub-array installed in the array assembly and the second is with the full array of elements installed as shown in Figure 6. Figure 7 shows a pattern for the sub-array with the beam steered to boresight and Figure 8 shows the beam scanned to 10° off boresight. Figure 9 shows the full array beam steered to boresight. Measurements of the full array at boresight has been discussed in greater detail in a previous paper [10].

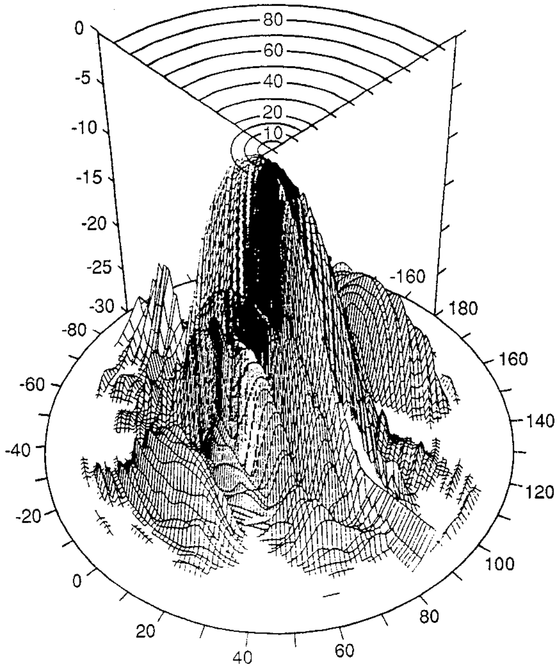

Figure 7 *- Antenna pattern for sub-array (boresight steering).*

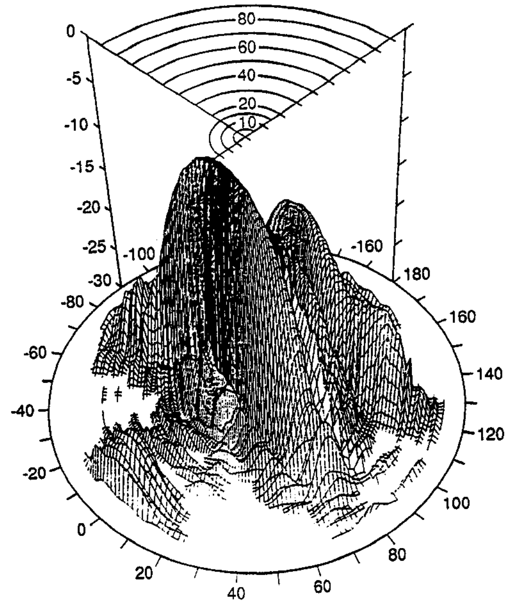

Figure 8 *- Antenna pattern for sub-array (10 deg. steering).*

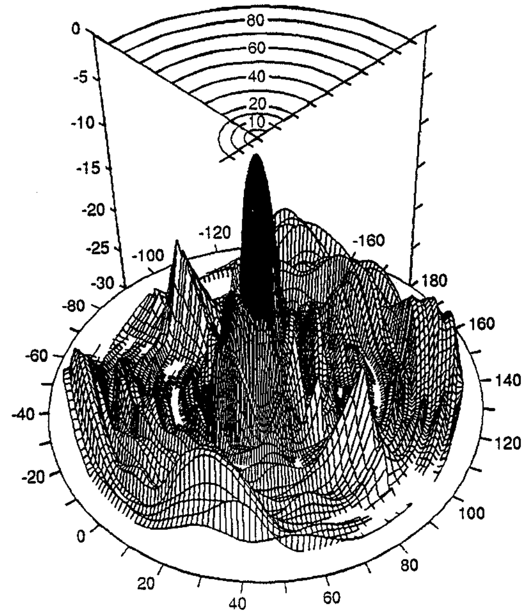

Figure 9 *- Full Array Antenna Pattern Steered to Boresight*

SUMMARY

A K_a-band solid state transmitter capable of power greater than 5 W is being developed. The transmitter consists of an array of 21 elements each driven by a single stage MMIC power amplifier, three stage MMIC pre-amplifier and four-bit MMIC phase shifter. Measurements of the antenna pattern of the full array and an electronically beam steered sub-array have been carried out.

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