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Ka-BAND MMIC BEAM STEERED PLANAR ARRAY FEED

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ABSTRACT

A 32 GHz, twenty-one element array feed incorporating 63 MMIC devices and providing electronic beam steering using 21 VLSI silicon control chips is under development at JPL. The design improves on our earlier experience using a novel "building block" approach to construct a six element linear transmit array. The final array feed design is to be used for NASA deep space communications applications.

INTRODUCTION

Advanced communications systems for NASA deep space missions in the 21st century will utilize Ka-band (32 GHz downlink, 34 GHz uplink) to achieve link enhancement on the order of 8 dB relative to existing X-band (8.4 GHz) systems. A critical element of the system is the spaceborne transmitter. At JPL, a 21 element planar transmit phased array at 32 GHz is being developed utilizing microwave monolithic integrated circuit (MMIC) devices in order to test concepts for future spacecraft transmitters. This work builds on our previous effort with a six element linear transmit array at Ka-band.[1][2] The goal of the planar array feed is to produce an electronically beam steered($\pm 10^{o}$) array with output power of 3-5 W to feed a 1 meter reflector system. The array feed is to be located at the Cassegrain point of the 1 meter main reflector, as illustrated in Figure 1. This paper reports on the new design concepts that are being implemented to produce the 21-element array feed with emphasis on innovative solutions to the challenges of integrating the 63 MMIC and 21 VLSI devices with the signal and control distribution systems while maintaining the ability to test and repair major portions of the array.

MMIC DEVICES

The GaAs MMIC devices that control the phase and amplitude at each antenna element of the array have been developed under programs funded by the NASA Lewis Research Center. The MMIC phase shifters were designed and fabricated by Honeywell.[3] The layout of a phase shifter is shown in Figure 2. The 4-bit phase shifter consists of three digital switched line bits and one analog loaded line bit. The design achieves insertion loss values of less than 10 dB at 32 GHz and provides phase shifts from 0 to 360 degrees in 22.5 degree increments.

The MMIC power amplifiers were designed and fabricated at Texas Instruments.[4] A photograph of the two amplifiers used is shown in Figure 3. These are pseudomorphic HEMT devices with 0.25 micron gate lengths. The output amplifier is a single stage with 800 micron gate width, 350 mW rf output power minimum, 4 dB gain, and 20% efficiency. This amplifier is driven by a three stage HEMT amplifier with gate widths of 50, 100, and 250 microns for the 1st, 2nd, and 3rd stages, respectively. The output power of the three stage amplifier is 100 mW minimum with 20 dB gain and 25% efficiency.

ANTENNA DESIGN

The antennas were designed by the University of Massachussets [5] in a Vivaldi slotline configuration as shown in Figure 4. These elements were fabricated on 0.25 mm Rogers duroid 5880 and consist of a linearly polarized array with a 1.22 wavelength spacing. The radiated pattern from a six element array is shown in Figure 5. The endfire radiation from the slotline antennas allows construction of a two-dimensional array with 21 active elements.

ARRAY DESIGN

The array is composed of five subarray layers. Each layer slides into an aluminum structure which provides alignment of the antenna elements and connection with the rf signal distribution, DC power, and electronic beam steering control systems. A drawing of the array is shown in Figure 6.

Each subarray layer is composed of several "building blocks": 1) an input power divider, 2) a carrier for the MMIC phase shifters, 3) a carrier for the MMIC amplifiers, and 4) an antenna carrier. A subarray layer is shown in Figure 7. This "building block" approach allows for testing of each individual MMIC device by inserting a complete carrier into a separate test fixture and verifying performance before integration with the subarray layer. Repair of individual devices in the array is also facilitated by the ability to easily remove a subarray layer and its individual components.

The RF signal distribution system provides equal amplitude and phase outputs via microstrip branch line couplers. The couplers are constructed on 0.12 mm Rogers duroid 5880 laminated on an aluminum carrier. Signal distribution to the five subarrays is made possible by a 5-way vertical power divider. The subarrays connect to the vertical power divider through Omni Spectra 2.4 mm blind mate connectors that allow for easy plug-in type rf connection.

The phase shifter carrier has five phase shifters and five VLSI silicon control chips each with a hard wired address for its individual phase shifter. The silicon chip was designed at JPL and is being fabricated through the MOS Implementation Service (MOSIS). The rf and data control lines are etched on a single 0.25 mm thick alumina substrate with TiW/Au thin film metallization. Cut-outs are provided in this substrate for attachment of the phase shifters to the Kovar carrier. A second alumina substrate, which is placed in a trough running under the rf line, provides the data bus control lines that bring connections to the edge of the carrier. This substrate is also 0.25 mm thick but uses multilayer thick film gold lines in order to provide crossover connections from each data line to the edge where interconnection is made between substrates. Finally, interconnections between substrates and between chips and substrate are provided by 0.25 micron diameter gold wire bonds. The amplifier carrier has five pairs of MMIC amplifiers. The first amplifier of a pair is a three stage amplifier and the second is a single stage power amplifier. The construction of the carrier is similar to the phase shifter carrier with one main laser cut 0.25mm thick alumina substrate and a second alumina substrate that brings the bias lines out to the edge of the carrier. The second substrate uses thick film gold to handle the currents required at each amplifier. The amplifiers are connected to a common drain line and separate gate line for the three and one stage amplifiers. Edge card connectors are used on both the phase shifter carrier and the amplifier carrier to plug in connections at the side of each layer once installed in the array.

The transition from the MMIC amplifiers to the antenna elements is accomplished through a microstrip to slotline transition on the upper side of the antenna substrate as shown in Figure 7, while the Vivaldi elements are on the underside of the antenna substrate. Each antenna carrier not only supports the 0.25 mm duroid substrate but also provides a continuous ground plane for the antenna element array. Cut-outs are provided in this ground plane for the microstrip line to pass from MMIC amplifier to antenna element. This arrangement is shown in Figure 6.

The array beam pattern will be steered using control system software that operates on a PC. The operator will enter a beam steering angle at the console, the software will translate this angle into phase settings for the 21 phase shifters, and a serial data stream will be sent to the silicon chips along the bus. Each silicon control chip receives the serial data stream and accepts only the data for its individual address. A final control pulse is transmitted along the bus which causes all chips to convert their data to the parallel control voltages required by the phase shifters simultaneously. In this manner, electronic beam steering is accomplished for the array.

CONCLUSION

A 32 GHz, twenty-one element array feed incorporating 63 MMIC devices and providing electronic beam steering using 21 VLSI silicon control chips is under development at JPL. An innovative "building block" approach to construction was described that provides ease of verification of device performance prior to integration in the array. In addition, the subarray layer concept with plug-in rf connectors allows for ease of removal of a layer for repair of one of the components. This planar array demonstrates state of the art design technology required for implementation of Ka-band transmit arrays in future NASA deep space missions.

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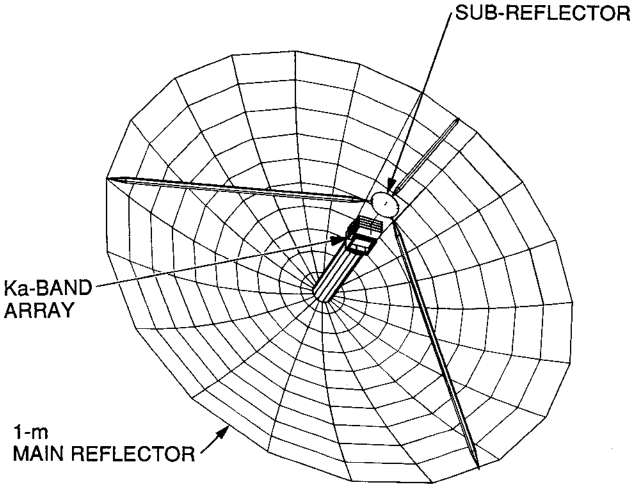

Figure 1. K_a-Band Array Feed with Cassegrain Antenna

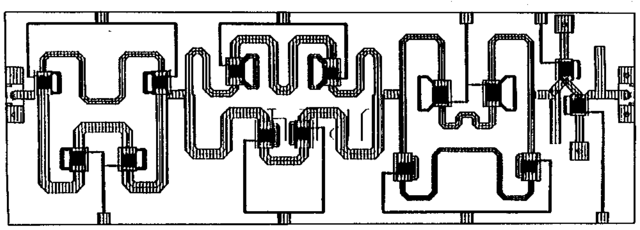

Figure 2. Honeywell MMIC Phase Shifter

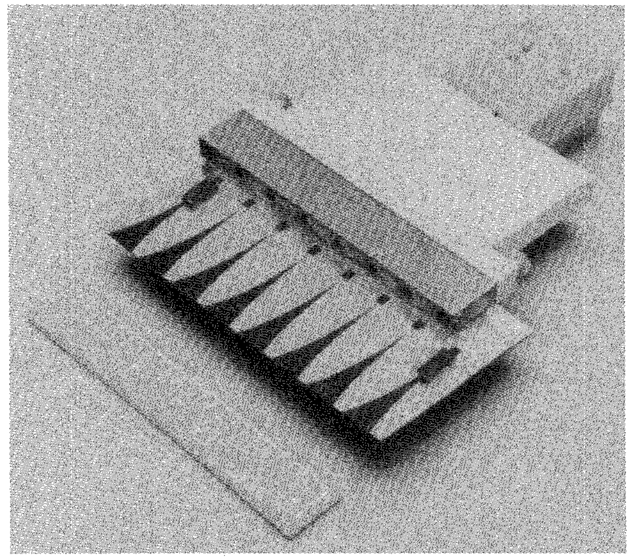

Figure 4. Six Element Vivaldi Linear Array

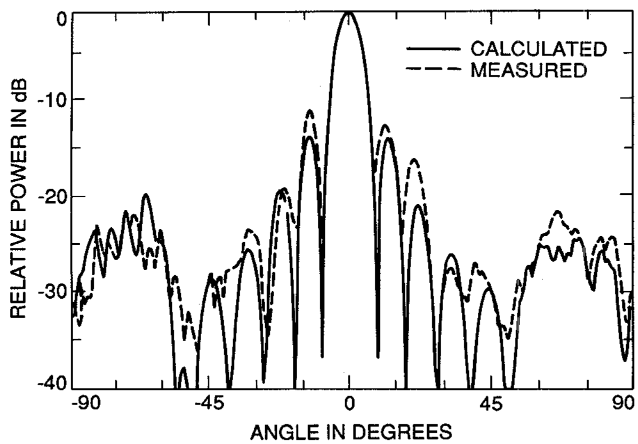

Figure 5. Radiated Pattern from 6-Element Array

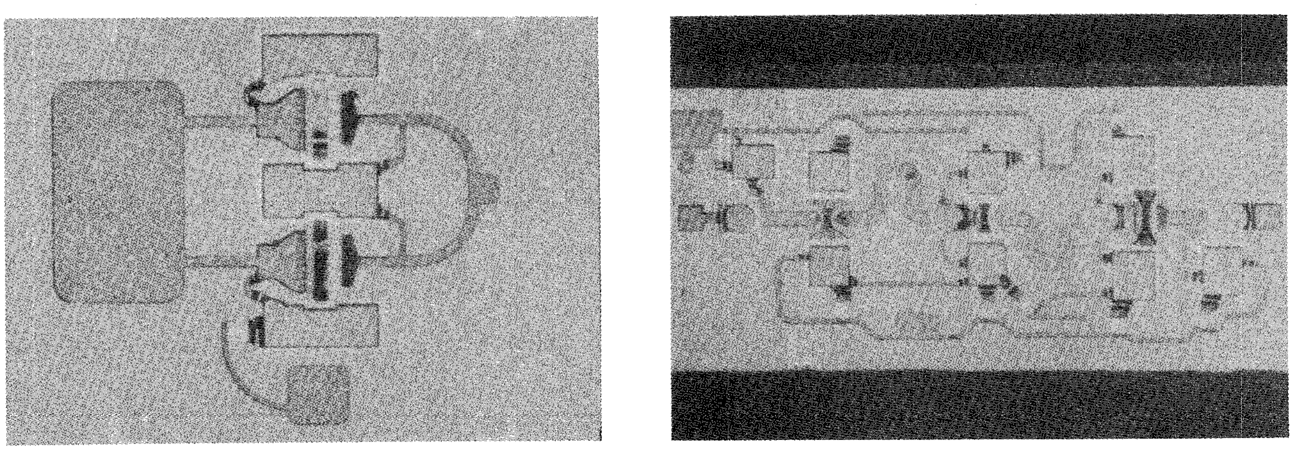

Figure 3. Texas Instrument HEMT Power Amplifiers

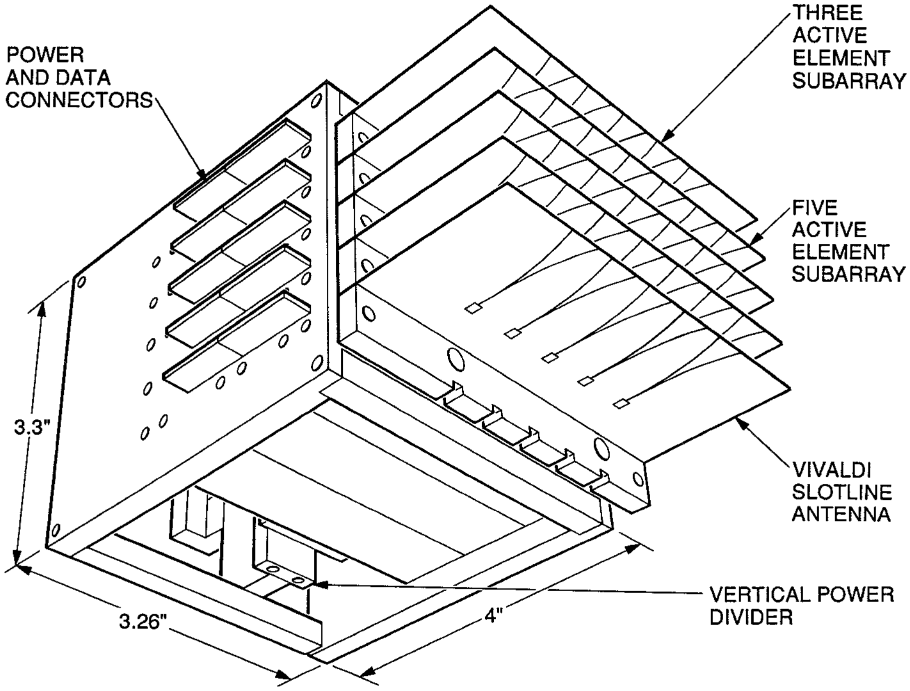

Figure 6. K_a-Band Array Feed

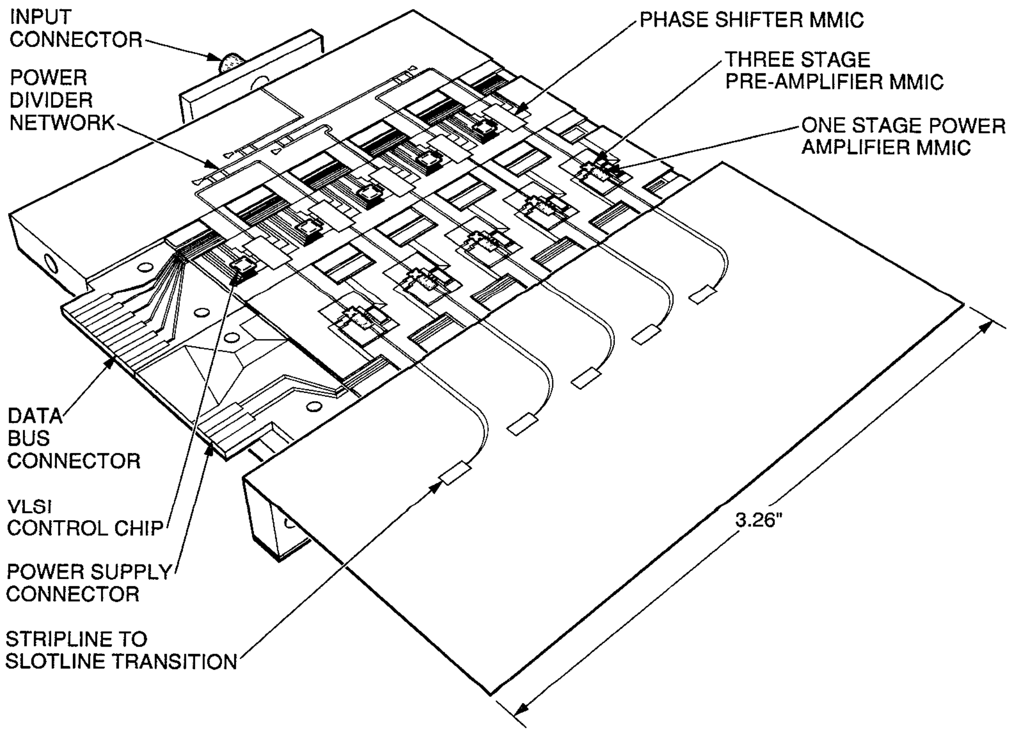

Figure 7. Five Element Subarray