W-BAND ACTIVE TRANSMIT AND RECEIVE PHASED ARRAY ANTENNAS

B.J. Edward, D. R. Helms, R.S. Webb, S. Weinreb*

Martin Marietta LaboratoriesSyracuse

*Martin Marietta LaboratoriesBaltimore

ABSTRACT

The design and fabrication details for 94 GHz active receive and transmit array-modules are presented. An innovative approach for fabricating the modules employing a multi-layer DC substrate onto which all other componentry are mounted is described. Receive and transmit arrays have been assembled and are shown to have excellent performance. To the best of our knowledge, these represent the first active arrays demonstrated at W-band.

I. INTRODUCTION

Eight-element line array-modules constitute the building blocks for W-Band active receive and transmit arrays. Multiple array-modules are combined to realize larger one- or two-dimensional systems. The modules incorporate amplifiers and phase shifters at each radiating element to achieve high receive sensitivity or high transmit power generation efficiency, along with electronic positioning of the antenna beam. An innovative approach is employed for fabricating the modules consisting of a multi-layer DC/control substrate onto which is mounted RF substrates, active and passive circuit chips including MMICs, package wall, top lid, and radiating elements. Exclusive of the radiating elements, the modules are only 0.652 inches in width, 1.114 inches deep, and 0.072 inches thick. The overall module size is compatible with contiguous placement of units to form two-dimensional arrays. The module weight is only 0.15 ounces.

II. ARRAY-MODULE DESIGN

The block diagram for the transmit array-module is presented in Figure 1. The basic architecture for both receive and transmit modules is identical, with the exception of the receive module having low-noise amplifiers where the transmit unit has power amplifiers. All amplifiers in the transmit array-module are of a common design—a three-stage GaAs MMIC with PHEMT devices [1]. The phase shifter MMIC is an analog design having varactor diodes [2]. D/A converters within the module translate digital control input words to the analog voltages required for setting the phase. An analog control voltage is also generated and applied to the gate biasing of the amplifiers to achieve channel gain control. The transmit output power is nominally 10 mW per radiating element.

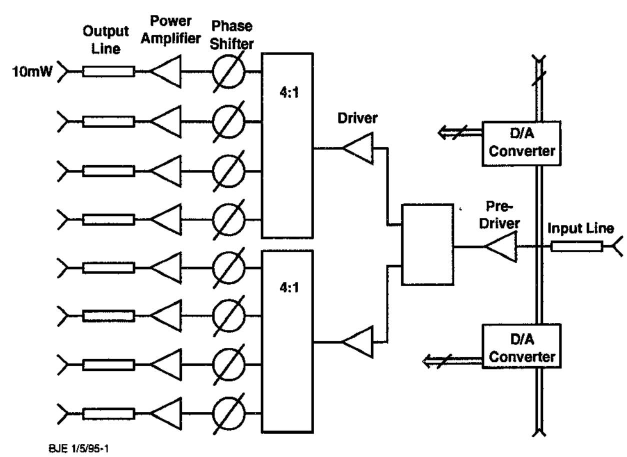

Figure 1. Transmit Array-Module Architecture. The receive module architecture is identical with the exception of having low-noise amplifiers in place of the transmit unit's power amplifiers.

CH3577-4/95/0000-1095$01.00 © 1995 IEEE

The receive array-module substitutes low noise amplifiers for the transmit's power amps. All amplifiers are of a common four-stage PHEMT design [3]. The other componentry is identical to that of the transmit unit. The receive gain is nominally 48 dB per channel with a gain control range in excess of 30 dB and a noise figure on the order of 5.5 dB.

An exploded view of the array module is provided in Figure 2. A multi-layer DC and control signal substrate/base, and RF substrates provide for all the interconnects within the module. Active and passive circuit chips, a package wall, top lid, and radiating elements are the remainder of the components. The DC substrate consists of a 0.020 inch thick molybdenum base onto which is deposited multiple layers of copper conductors and polyimide insulation. Conductor traces distribute the DC power and control signals throughout the module, running within the layers of polyimide and coming to connection pads on the top surface next to the circuit chips. Since multiple layers of these traces are formed that can cross each other and even run under other module components, very dense interconnects are realized. The top surface of the DC substrate is almost entirely gold-plated copper, with openings only at the connection pad locations and small fiducials to facilitate positioning of module components. This extensive conductive surface shields the DC traces from RF signals, greatly diminishing stray coupling via these paths. All of the other module components are mounted directly onto this surface.

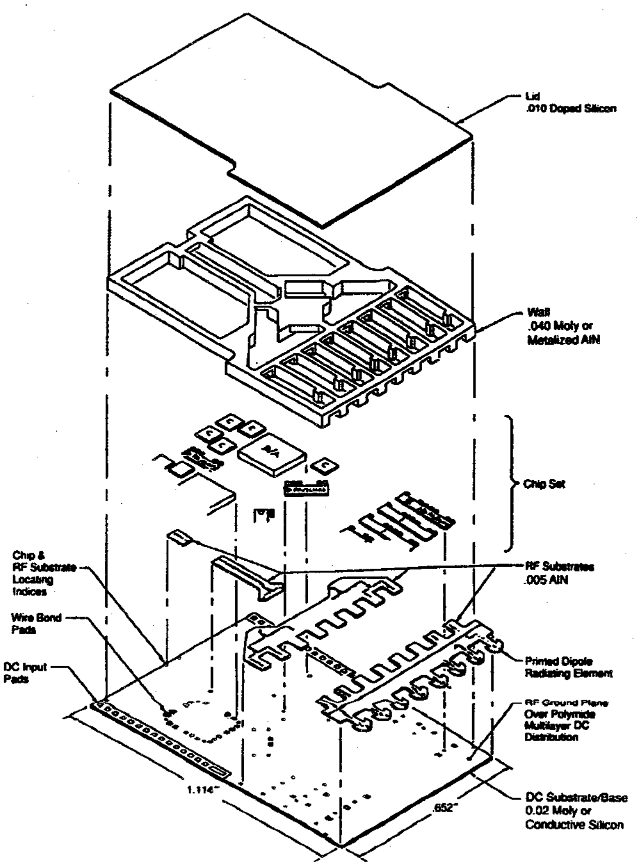

Figure 2. Exploded View of the Array-Module. A multi-layer DC distribution substrate serves as the base to which all other module components are mounted.

The RF substrates are low-loss ceramic, 0.005 inch thick, patterned with microstrip interconnects and cut to the required shapes by laser. These substrates are attached with either conductive epoxy or solder directly to the DC substrate. Chip components (MMICs, capacitors, etc.) are also mounted onto the DC substrate. When a high thermally conductive path is required directly under a component, such as under the power amplifiers, the DC substrate is designed to have exclusively metal layers at that component location.

The package wall also mounts to the DC substrate. The walls used in assembling the W-band modules are electro-discharge machined from 0.040 inch thick molybdenum. The conductive walls in conjunction with the continuous top metal of the DC substrate forms shielded enclosures for the circuitry, improving stability by electrically isolating various portions of the module assembly. A top lid mounts to the wall, completing the enclosure. The lid is fabricated from 0.010 inch thick silicon, optimally doped to attenuate waveguide modes within the enclosures. The outer surface of the silicon lid is metalized for shielding.

Printed dipole radiating elements also mount to the DC substrate, overhanging the front edge of the module [4].

These elements connect directly to the amplifiers through a short length of microstrip line. They are spaced at 0.082 inches to support electronic beam scan to 30 degrees from array broadside without the formation of grating lobes.

III. DEMONSTRATION ARRAYS

Receive and transmit eight-element array-modules have been assembled. The modules were fully tested for individual channel characteristics using a network analyzer in conjunction with RF probes, which was followed by radiation pattern and beam steering performance measured in an anechoic chamber.

An assembled receive module is shown in Figure 3. Measured gain and phase characteristics through one of the eight channels is reported in Figure 4. At 94 GHz the maximum gain is 47.8 dB, essentially equal to the anticipated level of 48 dB. A gain control range of 38 dB is exhibited. A full range of phase control is achieved over an extremely wide bandwidth.

Radiating elements were attached to the receive and transmit modules to form eight-element E-plane line arrays. The modules were mounted within test fixtures which include a corner reflector to establish the beamwidth in the H-plane. Measured broadside radiation patterns for the transmit array are presented in Figure 5. Patterns are well formed in both principal planes. In the E-plane the half-power beamwidth is 9.8 degrees and the peak sidelobe level is -14 dB, both very

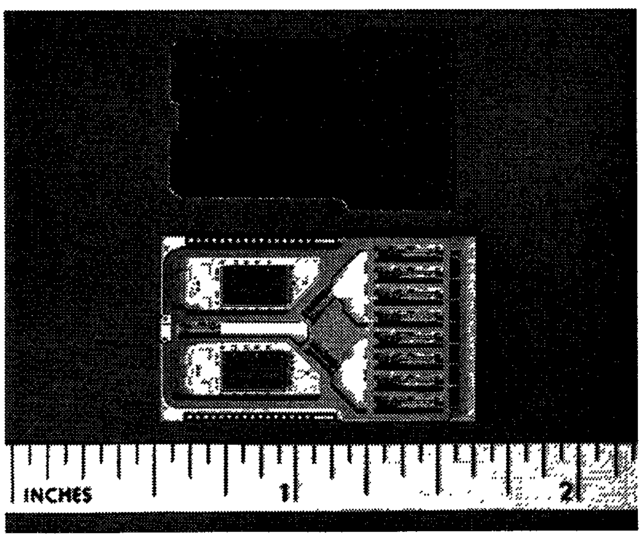

Figure 3. Assembled Receive Module. After RF probe testing of individual channels on the network analyzer, radiating elements are attached (right side of module in photo) and radiation pattern measurements performed.

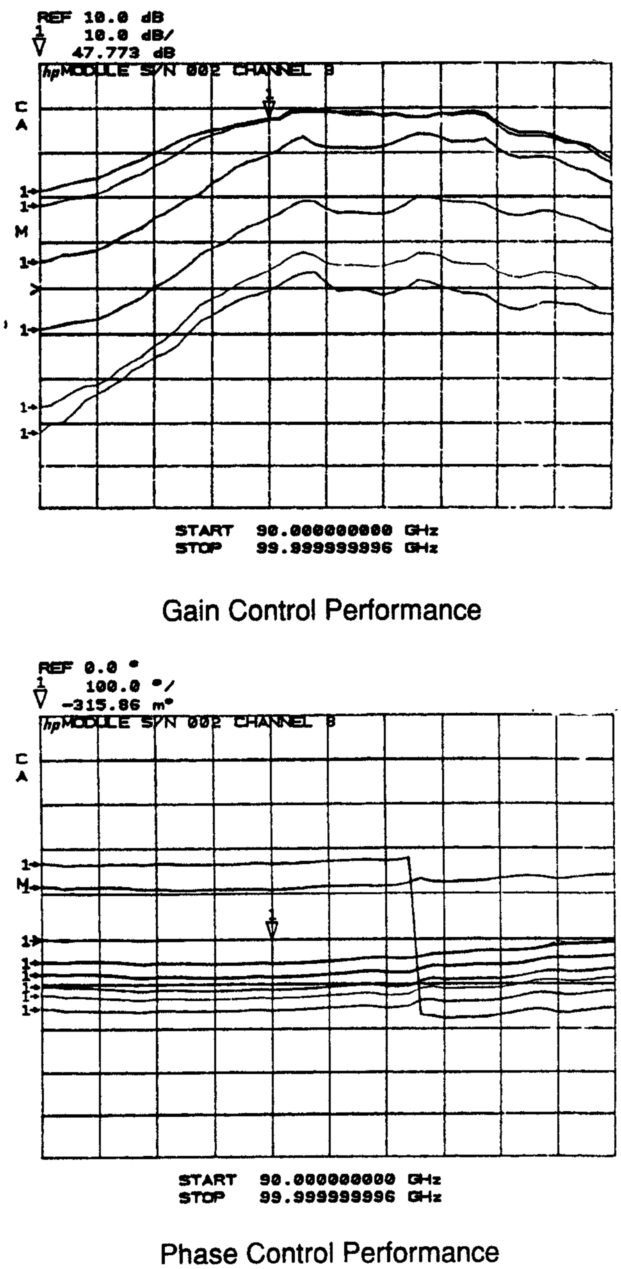

Figure 4. Gain and Phase Characterizatics of a Channel of the Receive Module. Peak gain is equal to the anticipated level, and a full range of gain and phase control is achieved.

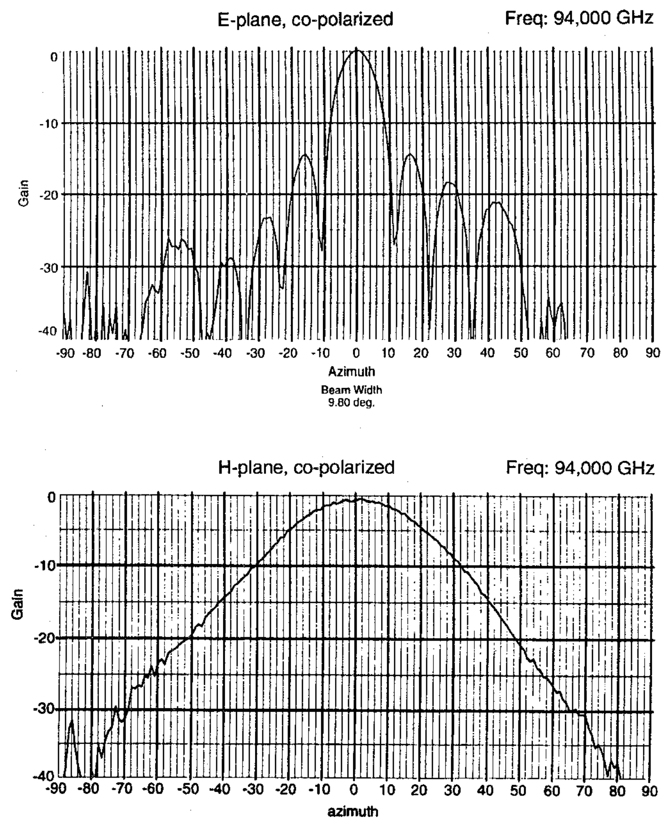

Figure 5. Eight-Element Array Broadside Radiation Patterns. Patterns are well formed in both principal planes with beamwidths and sidelobe levels close to predicted values.

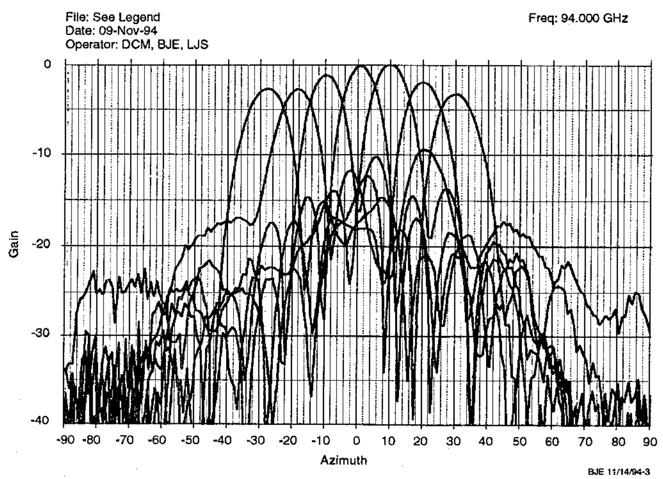

Figure 6. Transmit Array Scanned Beam Patterns for broadside, ±10,±20, and ±30 degrees. Receive scanned beams are essentially identical.

close to the anticipated values. In the H-plane the beamwidth measures 33 degrees. E-plane radiation patterns for the beam commanded to broadside, ±10,±20, and ±30 degrees are given in Figure 6. All scanned beams are very well formed.

IV. CONCLUSION

W-band active receive and transmit array-modules have been successfully designed and demonstrated. These modules comprise eight elements in a line array configuration and can be readily combined to realize larger one- and two-dimensional systems.

V. REFERENCES

[1] Duncan, S. W., et al, "Compact high gain W-band and V-band pseudomorphic HEMT MMIC power amplifiers," *1994 IEEE MTT-S Digest,* May 1994.

[2] Weinreb,S., et al, "Monolithic varactor 360 phase shifters for 75-100 GHz," *International Semi-Device Conference, ISDRS Digest of Papers,* Charlottesville, VA, Dec. 1-3, 1993.

[3] Tu, D-W, et al, "High gain monolithic P-HEMT W-band four stage low noise amplifier," *IEEE 1994 Microwave and Millimeter-Wave Monolithic Circuits Symposium.*

[4] Edward, B. J. and Rees, D. E., "A Broadband Printed Dipole with Integrated Balun," *Microwave Journal,* vol. 30, pp. 339-44, May 1987.