W-BAND 0.3W PHEMT MMIC POWER AMPLIFIER MODULE

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ABSTRACT

A compact (1.8 by 3.0 by 3.8cm) WR-10 waveguide amplifier module providing 310-mW power output, 20-dB gain, and 5 GHz of 1-dB bandwidth at a center frequency of 96 GHz is described. The module is comprised of 22 identical pHEMT chips, 4-way microstrip power combiners and dividers, and a 4-way waveguide power combiner.

INTRODUCTION

A need exists for compact, W-band power amplifiers (PAs) with power in the 0.2- to 2-W range for use in small radars and communication systems. This power can be produced by combining a number of MMIC power amplifier chips. The efficiency of large millimeter-wave transistors (say >400-μm gate periphery at W-band) and the efficiency of various types of power combiners limit both the power and overall efficiency at millimeter wave frequencies. This paper describes a 0.31-W amplifier that utilizes power combining of 16 MMICs with a combination of microstrip and waveguide combiners to form a convenient in-line WR-10 waveguide module.

CONSTRUCTION

A block diagram and a photograph of the module are shown in Figures 1 and 2. The MMIC power amplifier used throughout the module has been described in a previous paper[1]. In summary these MMICs provided >40 mW of power output from a 0.9- by 3.1- by 0.1-mm GaAs chip utilizing four 0.1- by 100-um pHEMT transistors with two transistors combined in the output stage. The PAs were first tested on wafer for small signal phase match and power output with +7 dBm of input power. The power output, efficiency, and gain of one of the best of these PAs are shown in Figure 3. The phases of most of the tested PAs were within a ±20-degree window; the resulting 5 degree rms phase error results in negligible power loss.

Four three-stage MMIC power amplifiers were first combined on a carrier, which also contained a fifth identical MMIC used as a driver amplifier. The carrier included a 4-way microstrip GaAs power combiner and an identical chip used as a power divider. The four-way divider was comprised of three Lange couplers with four 300-μm fingers of 6-μm width and 6-μm spacing. These Lange couplers were somewhat overcoupled, which resulted in a loss from input port to each of the four-way outputs of 7.7, 9.3, 6.3, and 7.7 dB. To some extent this imbalance was compensated for by using the same chip rotated 180 degrees for both the power combiner and power divider; a channel that had more loss in the output combiner gets more drive power from the input power divider.

The quad chip carriers were tested with wafer probes before integration into the module, and the power output versus power input for all four carriers is shown in Figure 4. The average output of 110 mW is consistent with an average chip power output of 41 mW and four-way microstrip power combiner loss of 1.7 dB.

A compact four-way waveguide power combiner utilizing three rat-race ring hybrid junctions was constructed in a split-block, which forms the mounting base for the chip carriers. The ring hybrids were cut into each half of the split block and utilized 0.8 height waveguide

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and H-plane right-angle bends to bring the inputs to an upper surface where the quad chip carriers were located. E-plane probe transitions from waveguide to grounded coplanar-waveguide (CPW) were fabricated on small GaAs probe chips to allow three bond-wire connections (center conductor and two grounds) to CPW bond pads on the quad chip carriers. A backshort covered these transitions as can be seen in Figure 2. The termination of the fourth port of the ring hybrid was realized by means of 200-ohm per-square tapered vane of metalized Mylar inserted within the split block along the center line of the waveguide. The insertion loss of a prototype ring hybrid was measured to be 0.25 dB and the expected loss of the four-way waveguide combiner was 1.05 dB, allowing 0.15 dB for waveguide loss and 0.35 dB loss for the waveguide probe to CPW transition. However, the measurements of 440 mW for the sum of the quad power outputs and 260 mW for the module waveguide output, both at 94 GHz, indicates a loss of 2.3 dB. It is believed that the additional 1.25 dB of loss arose from the gap in the backside ground plane in the CPW quad to CPW waveguide probe transition. Further evidence for this effect was the observation of small changes in output power when small metallic object were brought close to the transition region. The gap in the backside ground plane is being corrected on an improved module.

The module included a four-way microstrip input power divider realized by cascaded Wilkinson power dividers on 100-um-thick GaAs and two additional MMIC power amplifier chips at input to increase the module gain. Line lengths were carefully controlled to allow the input microstrip power divider to track the phase of the output waveguide combiner. An overall protective cover (not shown in the photograph) completed the module.

PERFORMANCE

The power output vs frequency for the module with +3 dBm of input power is shown in Figure 5, and the power output as a function of input power at a frequency of 96.4 GHz is shown in Figure 6. The power output at 1 dB gain compression is approximately +20 dBm. The module operates from a single +4.3 V supply and consumes 3.5 A for a total of 15 W of DC power.

REFERENCE

[1] S. W. Duncan, et al, "Compact High Gain W-Band and V-Band Pseudomorphic HEMT MMIC Power Amplifiers," Digest of Papers, IEEE 1994 Microwave and Millimeter-Wave Monolithic Circuits Symposium, San Diego, May 22-25, 1994, pp. 32-36.

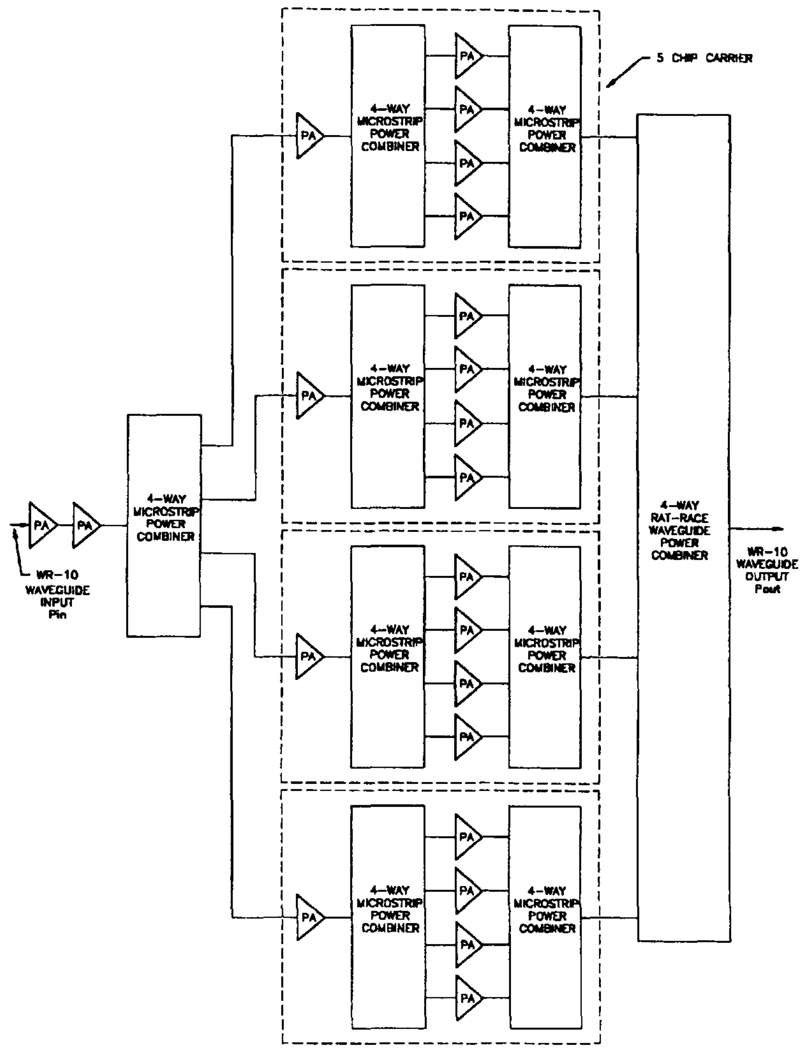

Figure 1. Transmitter block diagram.

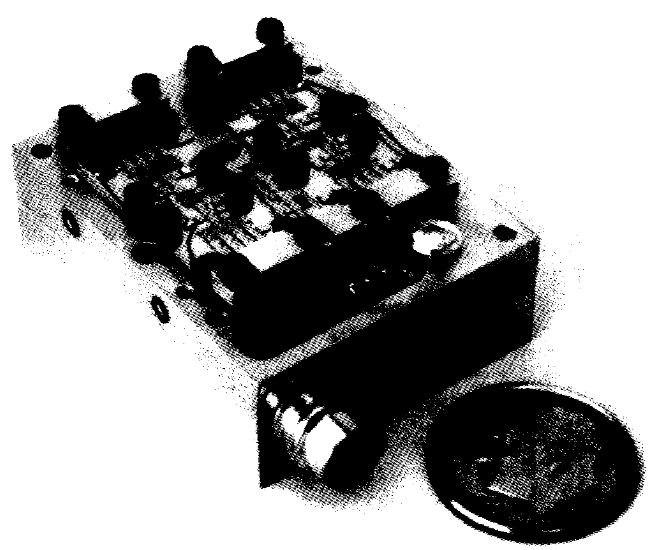

Figure 2. Photograph of power amplifier module.

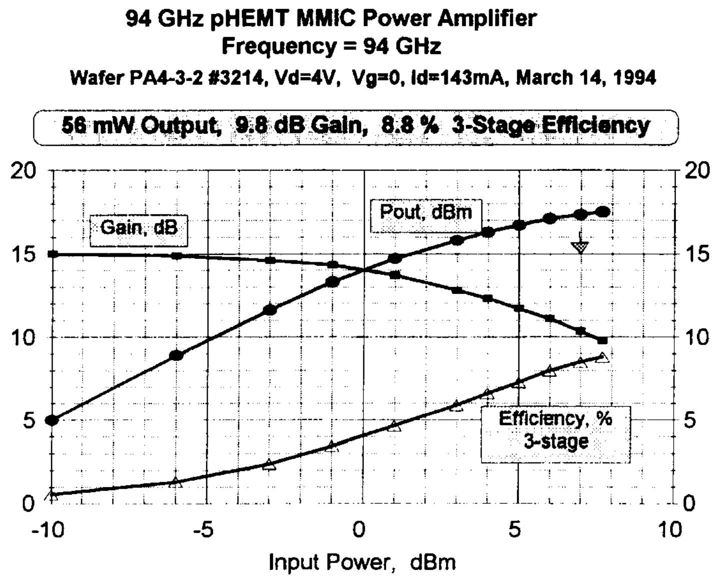

Figure 3. Characteristics of a single power-amplifier MMIC chip.

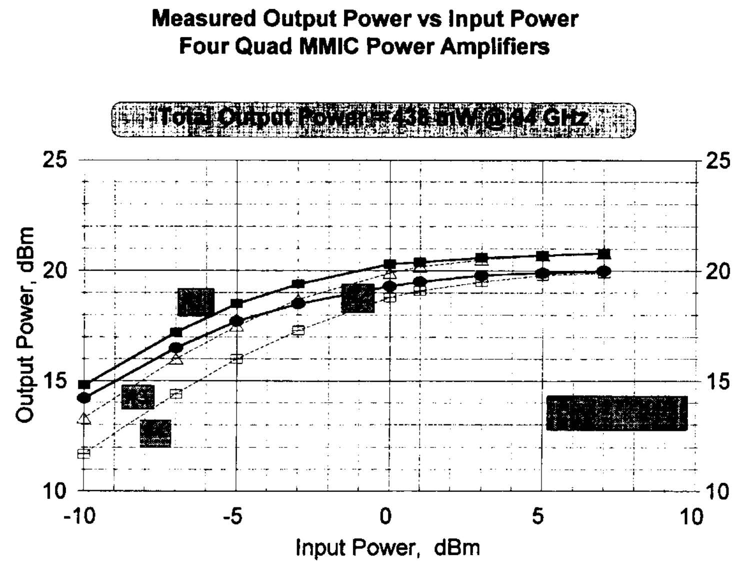

Figure 4. Power ouptut vs power input for all 4 MMIC carriers.

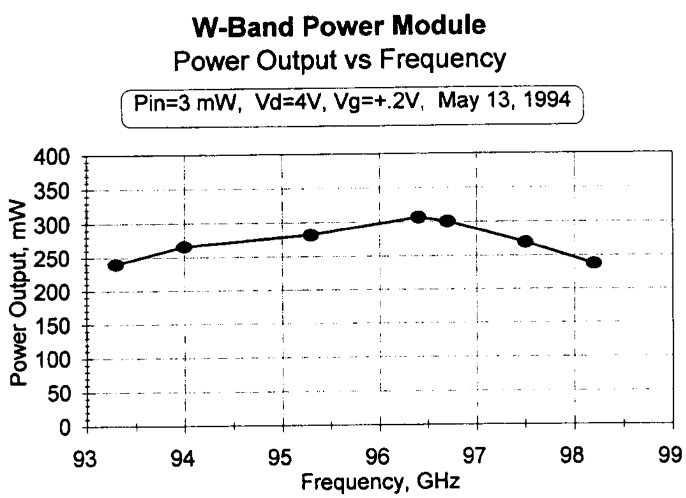

Figure 5. Power output vs frequency for the complete module.

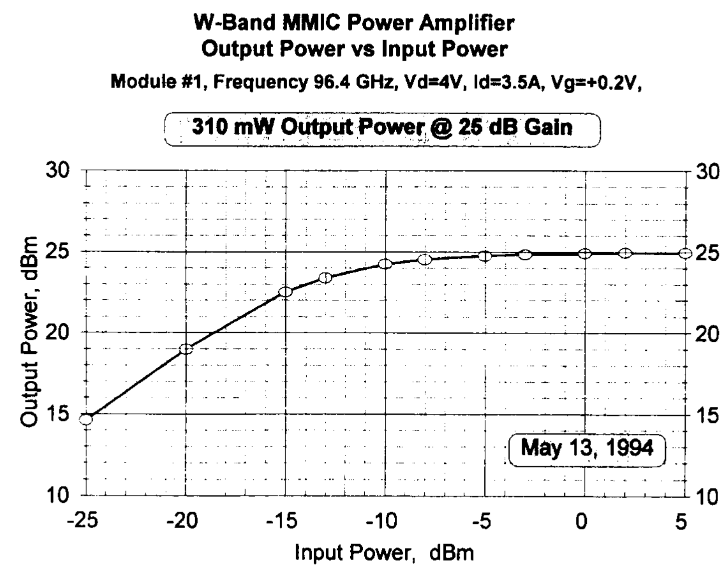

Figure 6. Power output vs power input for the complete module.