A 1-Watt X–Ku Band HBT MMIC Amplifier with 50% Peak Power-Added Efficiency

Fazal Ali, *Senior Member, IEEE*, Mike Salib, and Aditya Gupta, *Senior Member, IEEE*

Abstract— **A broad-band, high-efficiency MMIC power amplifier has been developed using AlGaAs–GaAs heterojunction bipolar transistors (HBT's). At 7-V collector bias, the fully matched monolithic amplifier produced 31 dBm CW peak output power with 9.2-dB peak gain and 50% peak power-added efficiency in the 8–15-GHz band. Several amplifiers from five different wafers have been successfully tested.**

I. Introduction

AlGaAs–GaAs heterojunction bipolar transistors (HBT's) have made significant progress as microwave power devices for high-efficiency, high-power applications [1]. Previously reported broad-band HBT MMIC power amplifiers have covered 7–10 GHz [2], 6.5–9 GHz [3], and 7–11 GHz [4], respectively. The first amplifier achieved 5.3 W (CW) with 4.6-dB gain and 22% power-added efficiency (PAE) using a single-stage common emitter design. The second amplifier used a single-stage cascode configuration to achieve >42% PAE, 31 dBm (1.26 W) and 14-dB small signal gain over 6.5–8.5 GHz . Performance degraded significantly beyond 8.5 GHz. The third set of amplifier results consisted of three common base (CB) HBT amplifiers designed for 1-W, 2-W, and 4-W output power levels. All these CB amplifiers exhibited significant PAE roll-off from 40%–30% peak at 7 GHz to 18%–15% at 11 GHz.

Last year, we reported a hybrid HBT amplifier covering 8–14 GHz with 1-W (CW) output power and 45% peak PAE [5]. The objective of the effort reported here was to demonstrate a fully monolithic (including on-chip matching and bias networks) version of the hybrid amplifier. As before, high PAE over the band was of prime concern.

II. HBT Circuit Design

HBT structures, for this work, were grown on 3-in GaAs substrates by MOCVD and were fabricated using Westinghouse's self-aligned base HBT process [6]. Heavy carbon doping was used in the base layer of the device to obtain low base parasitic resistance and a high-current drive capability.

Four HBT devices connected in the common emitter configuration were used as active devices in this single-stage, 1-W, power MMIC. Each HBT has four 2 μm × 20 μm emitter fingers, a dc-current gain (β) of 9–12 at operating currents (20–50 kA/cm^2), and BV_{cbo} = 20 V. Typical f_t and $f_{\max}$ at a collector potential of 7 V are 25 GHz and 55 GHz, respectively.

Manuscript received April 19, 1993.
The authors are with Westinghouse Electric Corporation Advanced Technology Laboratories, MS 3K11, P.O. Box 1521, Baltimore, MD 21203.
IEEE Log Number 9210804.

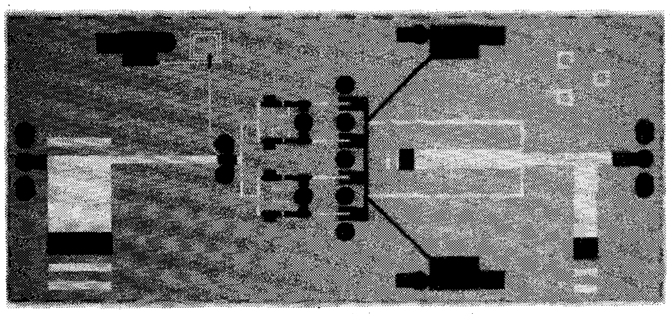

Fig. 1. Photograph of the broad-band HBT power MMIC fabricated.

The small signal S-parameters of this 160-μm^2 unit cell, capable of producing 25 dBm (P-1 dB), were recorded using on-wafer measurements up to 26 GHz and were used in the simulation of the one-stage amplifier. The output matching circuit design was based on optimum load impedance data across the band that was measured on an automated load-pull test set. The output matching network, a three-section filter, was synthesized using bandpass filter theory. The input matching network was designed around the small-signal input impedance. Fig. 1 shows the photograph of the HBT MMIC power amplifier (chip size: 57 × 137 mils). No attempt was made to minimize the chip size on this first design iteration. MIM capacitors with 1600 Å Si_3N_4 as the dielectric were used for RF bypassing, coupling and tuning elements. Some of the smaller capacitances in the input–output matching networks were realized using microstrip open stubs. The substrate was thinned to 4 mils and via-hole processing was used to assure low inductance ground.

III. Circuit Performance

Five HBT wafers were fabricated to evaluate the MMIC design. Wafer probing was used to determine the small-signal performance of the MMIC. After small-signal evaluation, the MMIC's were mounted on a molybdenum carrier for power output and efficiency measurements. The measured small signal gain of a typical HBT MMIC assembled in a carrier is shown in Fig. 2. The measured small signal gain was 6.5–9.4 dB over 8–15 GHz. Fig. 3 shows the output power and power-added efficiency over 8–15 GHz. At 10.5 GHz, a power output of 31 dBm (CW) was achieved with 9.2-dB gain and 50% PAE while operating in a class AB mode. Over the 9.5 to 13.5 GHz band the PAE is >40% and the power output is ~ 31 dBm. From 8 to 10 GHz, the efficiency and power output are lower

1051–8207/93$03.00

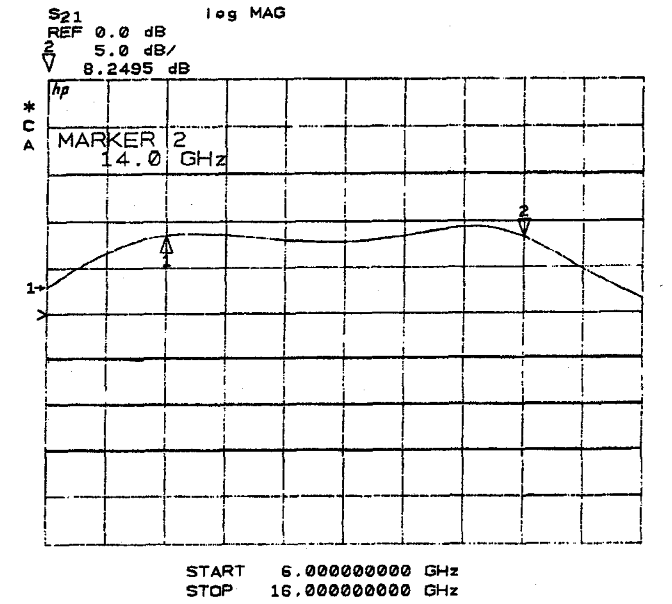

Fig. 2. Measured small signal gain of a typical HBT MMIC assembled in a carrier.

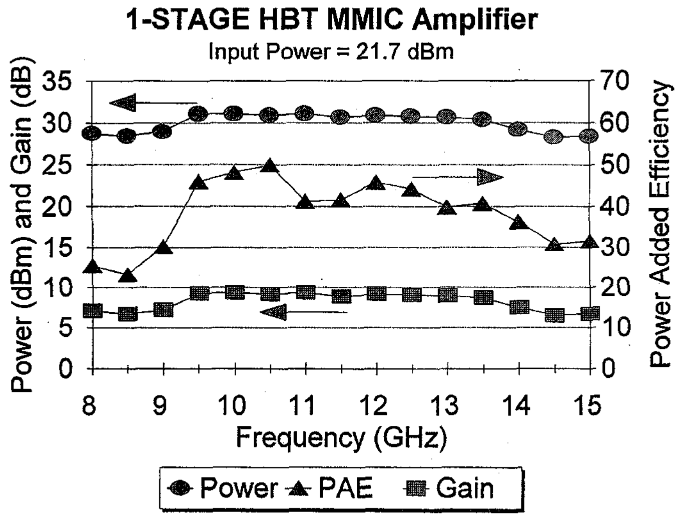

Fig. 3. Output power, power-added efficiency and power gain of the 8–15 GHz HBT MMIC.

than expected. The reason, nonoptimum load impedance, will be corrected in the next design iteration.

IV. Conclusion

A peak output power >1 W (CW) was achieved over the 8–15 GHz band with >35% PAE. The peak PAE was 50% at 10.5 GHz without any external tuning. These results prove that GaAs HBT's can be used in monolithic circuits for wideband, high-efficiency, high-power microwave amplifiers.

Acknowledgment

The authors acknowledge the support of B. Hewitt, M. Murphy, P. Smith, D. Dawson, R. Frietag and the processing staff at ATL. T. Cunningham and B. Fennell were immensely helpful in testing the MMIC's.

References

[1] F. Ali and A. Gupta, Eds., *HEMTs and HBTs: Devices, Fabrication, and Circuits.* Norwood, MA: Artech House, 1991, ch.5.
[2] B. Bayraktaroglu, M. Khatibzadeh, and R. D. Hudgens, "5-W monolithic HBT amplifier for broad-band X-band applications," *IEEE Microwave Millimeter-Wave Monolithic Circuits Symp. Dig.*, May 1990, pp. 43–46.
[3] R. Ramachandran *et al.*, "A high-efficiency HBT MMIC power amplifier," *IEEE GaAs IC Symp. Dig.*, Oct. 1990, pp. 357–360.
[4] N. L. Wang, W. J. Ho and J. A. Higgins, "4 W, 7–12 GHz, compact CB HBT MMIC power amplifier," *IEEE GaAs IC Symp. Dig.*, Oct. 1992, pp. 301–304.
[5] M. Salib, F. Ali, A. Gupta, and D. Dawson, "A 1-W, 8–14-GHz HBT amplifier with >45% peak power-added efficiency," *IEEE Microwave Guided Wave Lett.*, vol. 2, no. 11, pp. 447–448, Nov. 1992.
[6] A. Gupta, "Microwave power applications of gallium arsenide heterojunction bipolar transistors," *Proc. IEEE Princeton Section Sarnoff Symp.*, Mar. 26, 1993.