A 1-Watt, 8–14-GHz HBT Amplifier with >45% Peak Power-Added Efficiency

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

***Abstract*—Four 0.25-W gallium arsenide heterojunction bipolar transistors (HBT's) were combined in a single-stage hybrid microstrip amplifier. An output power of >1 W was achieved over the 8.5–13.5-GHz band with >35% power-added efficiency (PAE). The peak PAE was 45.4% at 12.5 GHz. This result was repeated on a second unit that was subsequently tuned for improved performance at the upper end of the band. The PAE at 14 GHz increased to >43% with 1-W output while, at 8 GHz, it remained at ~30%.**

I. Introduction

GALLIUM ARSENIDE heterojunction bipolar transistors (GaAs HBT's) are well suited for applications requiring high efficiency at high-output power levels [1]. Previously reported broad-band HBT power amplifiers covered 7–10 GHz [2] and 6.5–9 GHz [3], 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. Significant performance degradation was observed beyond 8.5 GHz.

The objective of this effort was to show the feasibility of a 1-W amplifier with >35% PAE over a 6-GHz frequency band extending from 8 to 14 GHz. Of the objectives listed, the PAE goal is the most aggressive and it provided the biggest challenge in the realization of this amplifier. Several hybrid amplifiers were fabricated toward this end; this letter summarizes the results achieved.

II. HBT Hybrid Amplifier

Four in-house developed GaAs HBT's were used as active devices in a hybrid microstrip amplifier. The devices, connected in the common emitter configuration, are arranged in pairs as shown in Fig. 1. The substrate thickness is 4 mils. Each HBT has four 1.5 μm $\times$ 20μm emitter fingers, a dc-current gain (β) of 9–12 at operating currents (20–50 kA/cm^2), and BVcbo = 20 V. Typical f_T and $f_{\max}$ at a collector potential (VCE) of 7 V are 30 GHz and 55 GHz, respectively. The power performance of this unit cell measured at 10 GHz using tuners is: 285-mW output power, 12-dB associated gain, and 60–62% PAE. The devices are biased at $V_{CE} = 7$ V.

Manuscript received July 24, 1992.
The authors are with the Westinghouse Electric Corporation, Advanced Technology Division, P.O. Box 1521, MS 3K11, Baltimore, MD 21203.
IEEE Log Number 9204122.

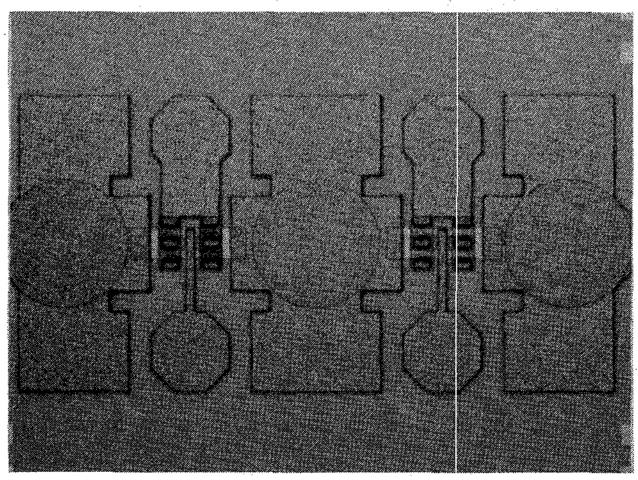

Fig. 1. Photograph of two common emitter GaAs HBT's sharing a via hole in the center. Two such pairs are used in the hybrid amplifier.

The hybrid amplifier, Fig. 2, employs low-loss multisection impedance transforming networks and high-Q chip capacitors to provide RF matching. Chip resistors are used for stability. All the distributed networks are fabricated on alumina substrates. The substrate thickness of the various quarter-wave transformer segments is chosen to minimize step height discontinuities and RF losses. Thus, the input and output transmission lines are on 25-mil substrates while the transformer at the output of the device is on a 5-mil substrate and that before the resistors is on a 10-mil substrate. The gold plated carrier is made of CM15, a material with a good thermal coefficient-of-expansion match to GaAs. The four HBT's and the nearest quarter-wave transformers are on a ledge, as shown. There is no step height discontinuity at the interface to the input and the output substrates. The circuit diagram is shown in Fig. 3.

III. Circuit Performance

The power, gain and efficiency of the amplifier over the 8–14-GHz band are plotted in Fig. 4. These data have *only* been corrected for 0.15 dB connector insertion loss at both ports. The output power is $\geq$ 1 W over 8–13.5 GHz and the PAE is $\geq$ 35% over 8.5–13.5 GHz. The mid-band power gain is ~7 dB while the small-signal gain is 8.5 dB. The peak PAE is 45.4% at 12.5 GHz. Performance comparable to that shown in Fig. 4 was obtained on two other amplifiers. One of these was retuned for better performance at the upper end of the band that resulted in 1 W at 14 GHz with >43% PAE. The

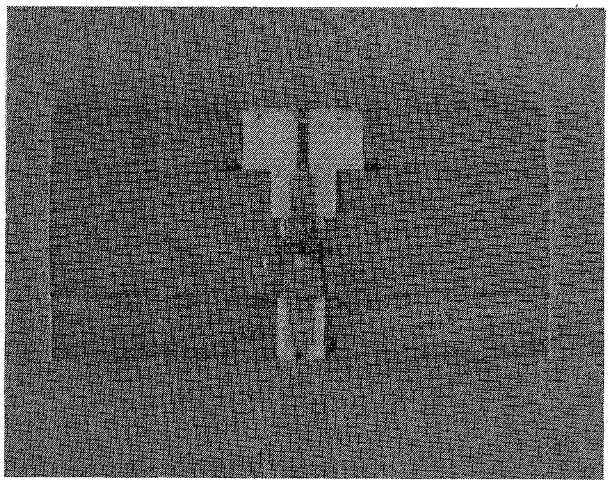

Fig. 2. Photograph of the hybrid amplifier.

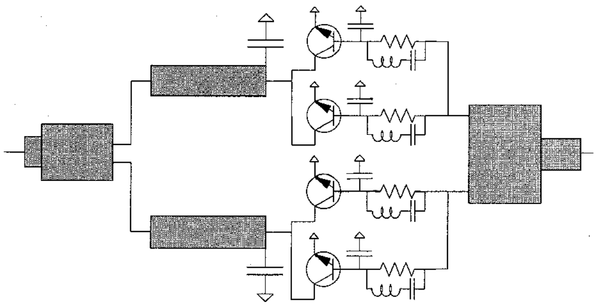

Fig. 3. Schematic circuit diagram of the hybrid amplifier. Shaded areas are microstrip transmission lines while the inductors are lengths of 1-mil gold wire.

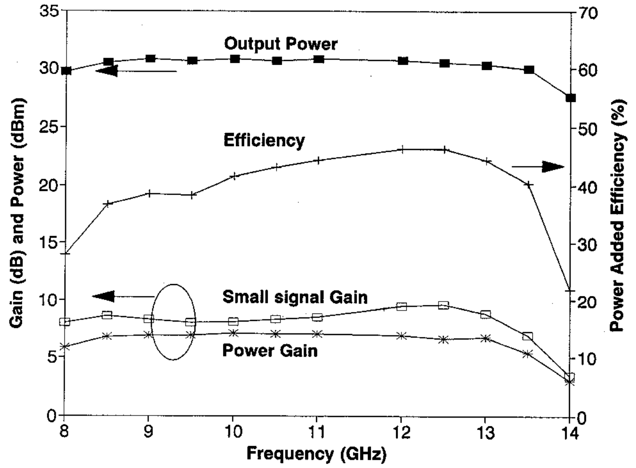

Fig. 4. Gain, power, and efficiency of one of the three hybrid amplifiers fabricated.

PAE over 8–11 GHz was 30–35% and >35% over 11–14.5 GHz. The output power was maintained at 1 W.

The results achieved with the hybrid amplifier lead us to believe that it is indeed feasible to build a 1 W amplifier with >35 % PAE over 8–14 GHz with the HBT's available. The main problem encountered in fabricating the hybrid amplifier involved amplitude and phase matching of the four 0.25 W channels and in realizing the precise values of the required passive circuit elements. A two-stage monolithic version of this amplifier, where these problems would be minimized, is currently under development.

IV. Summary

The circuit approach and performance of a single-stage wide-band amplifier employing four high efficiency HBT's have been described. An output power of >1 W was achieved over the 8.5–13.5 GHz band with >35% power-added efficiency. The peak PAE was 45.4% at 12.5 GHz. This result was repeated on a second unit that was subsequently tuned for improved performance at the upper end of the band. The PAE at 14 GHz increased to >43% with 1 W output while, at 8 GHz, it remained at ~30%. To the best of our knowledge, this is the highest efficiency reported for a 1 W HBT amplifier with 6-GHz bandwidth in the X–Ku Band.

Acknowledgment

The authors acknowledge the enthusiastic support of B. Hewitt, Manager, Microwave Technology, the processing staff at ATL, P. Smith and T. Cunningham who carefully (and patiently) reworked the hybrid amplifiers until they worked correctly.

References

[1] F. Ali and A. Gupta, Eds., *HEMT's 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, M. Nijjar, A. Podell, E. Stoneham, S. Mitchell, N. L. Wang, W. J. Ho, M. F. Chang, G. J. Sullivan, J. A. Higgins, and P. M. Asbeck, "A high-efficiency HBT MMIC power amplifier," *IEEE GaAs IC Symp. Dig.*, Oct. 1990, pp. 357–360.