A 5–10 GHz, 1-Watt HBT Amplifier With 58% Peak Power-Added Efficiency

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***Abstract*—Four 0.25-W GaAs Heterojunction Bipolar Transistors (HBT's) were combined in a single-stage hybrid microstrip amplifier. An output power of minimum 1 Watt (W) was achieved over the 5.5–9.5 GHz band with > 48% power-added efficiency (PAE). The peak PAE was 58% at 7 and 9.5 GHz with an average efficiency of 52% over the 5–10 GHz band. This result was reproduced on two more units with a minimum efficiency of 48% and an average efficiency of 51%. To our knowledge, this is the highest efficiency obtained from any 1-W amplifier covering 5–10 GHz bandwidth.**

I. Introduction

GALLIUM ARSENIDE (GaAs) heterojunction bipolar transistors (HBT's) are well suited for applications requiring high efficiency at high output power levels [1], [2]. Previously reported C-X Band 1-Watt HBT power amplifiers covered 6.5–9 GHz [3], and 6–10 GHz [4], respectively. Table I provides a comprehensive comparison of the 1-W HBT amplifiers in the 5–10 GHz frequency band with Westinghouse's present work.

The objective of this effort was to demonstrate the feasibility of a 1-W amplifier with > 50% PAE over an octave frequency band extending from 5 to 10 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. Each common-emitter HBT has four 2 μm × 20 μm emitter fingers, a dc-current gain (β) of 10–30 at operating currents (20–50 kA/cm^2), and BVcbo =20 V. Typical f_T and $f_{\max}$ at a collector potential (V_{CE}) of 7 V are 30 and 55 GHz, respectively. The substrate thickness is 4 mils. A 5-Ω-thin film ballast resistor is placed in series with each emitter finger to minimize the possibility of device burnout due to current hogging. The power performance of this ballasted unit cell measured at 10 GHz using tuners is: 280 mW output power, ~10 dB associated gain, and 55–62% PAE. The devices are biased for Class AB operation at V_{CE} = 7 V. The optimum load for the device across 5–10 GHz was determined using Sarnoff's automated load-pull tuner setup.

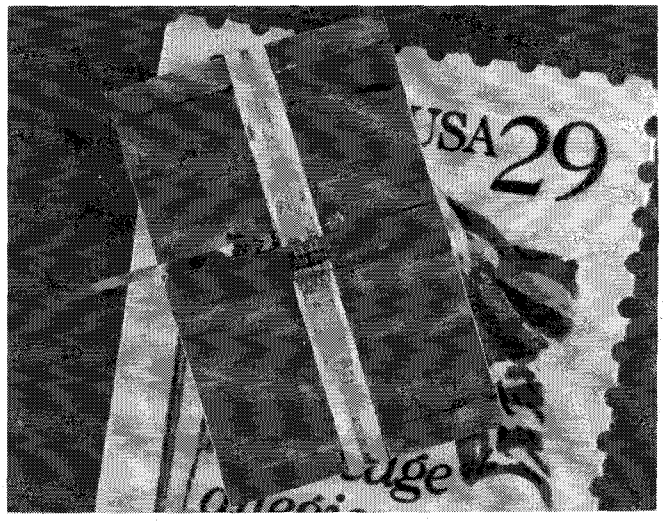

Fig. 1. Photograph of the hybrid HBT amplifier.

The hybrid amplifier, Fig. 1, employs low-loss multi-section impedance transforming networks, high-Q chip capacitors, and bondwires to provide RF matching and biasing. All the distributed networks were fabricated on 10-mil alumina substrates. Chip resistors, also fabricated in the alumina substrate, are used for biasing and stability. Bondwires were used for input and output RF connections and as tuning elements. Miniature parallel plate caps were utilized for RF matching and by-passing. The alumina substrates were assembled in a carrier having a 5-mil-high rib in the middle for discrete HBT device assembly. The gold-plated carrier is made of CM15, a material with a good thermal coefficient-of-expansion match to GaAs. The four HBT's were placed at an optimum position in the rib to accommodate the required input and output bondwire lengths. Three such amplifiers were built for evaluation.

III. Circuit Performance

The measured small signal gain performance of the amplifier is depicted in Fig. 2. The amplifier has an average of 11.5 dB gain from 4–10 GHz. The output power and efficiency of the amplifier over the 5–10 GHz band are plotted in Fig. 3. These data have been corrected only for 0.15 dB connector insertion loss at both ports. The output power is >1 W and the PAE is > 48% over 5.5–9.5 GHz. The mid-band power

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TABLE I
A DETAILED COMPARISON OF PUBLISHED
5–10 GHz, 1-W HBT POWER AMPLIFIERS

COMPANY	Circuit Configuration	BW (GHz)	Freq. (GHz)	P_{out} (dBm)	PAE (%)	G_{power} (dB)
Pacific Monolithics/ Hughes/ Rockwell (Ref. 3)	Cascode 1 Stage (MMIC) (Rockwell's HBT Process)	6-10	6	30	33	12
			6.5	31	43.5	13
			7	31	43	13
			7.5	31	46	13
			8	31	45	13
			8.5	30.5	42	12.5
			9	30	35	12
			9.5	29	28	11
			10	28.5	26	10.5
Martin-Marietta (E-Lab) (Ref.4)	Cascode 1 Stage (MMIC)	6-10	6	32.5	43	12.5
			6.5	32	40	12
			7	31.5	33.5	11
			7.5	31	31	10.7
			8	31	31	11
			8.5	30.8	30	11
			9	31	34	11
			9.5	31.5	40.5	10.8
			10	31	46	9.5
Westinghouse (This Work)	Common - emitter 1 Stage (Hybrid)	5-10	5	28.5	40	11.5
			5.5	30.5	50	11.3
			6	31	52	11
			6.5	31	56	11
			7	31	58	11.2
			7.5	30.7	48	10.7
			8	31	50	10.9
			8.5	30.7	52	10.6
			9	30.7	55	10.6
			9.5	30	58	10.3
			10	28.5	52	9.2

gain is 10.5 dB. The peak PAE is 58% at 7 and 9.5 GHz. The power performance is lower at the band edges: 28.5 dBm and 40% PAE at 5 GHz and 28.7 dBm and 52% PAE at 10 GHz. Performance comparable to that shown in Fig. 3 was obtained on two other amplifiers. Fig. 4 compares the PAE of this work with previously published 1-W HBT amplifiers in the 5–10 GHz frequency range. There is no published data available on 1-W, 5–10 GHz Power amplifier with > 50% power-added efficiency using MESFET or PHEMT device technologies.

The main problem encountered in fabricating the hybrid amplifier involved amplitude and phase matching of the four 0.25-W HBT channels and in realizing the precise values of the required passive circuit elements. A monolithic implementation would minimize these problems.

IV. SUMMARY

The circuit approach and performance of a single-stage wideband amplifier employing four high efficiency HBT's have been described. An output power of >1 W was achieved over the 5.5–9.5 GHz band with > 48% power-added efficiency. The peak PAE was 58% at 7 and 9.5 GHz with an average efficiency of 52% over the 5–10 GHz band. The same average efficiency was obtained on all the three amplifiers fabricated. To the best of our knowledge, this is the highest efficiency reported for any 1-W amplifier covering the 5–10 GHz frequency band.

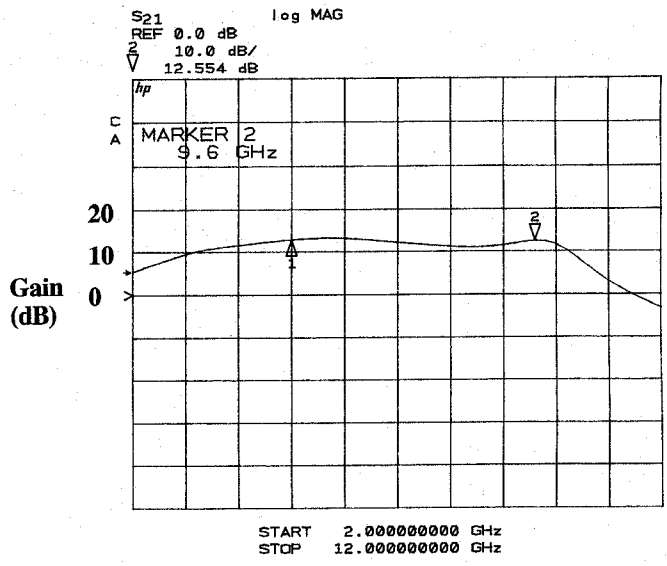

Fig. 2. Small signal gain performance of the HBT amplifier.

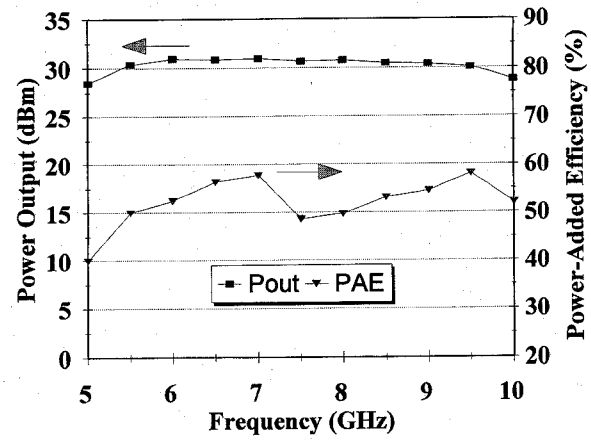

Fig. 3. Output power and efficiency of one of the three 5–10 GHz, 1-W HBT hybrid amplifiers fabricated.

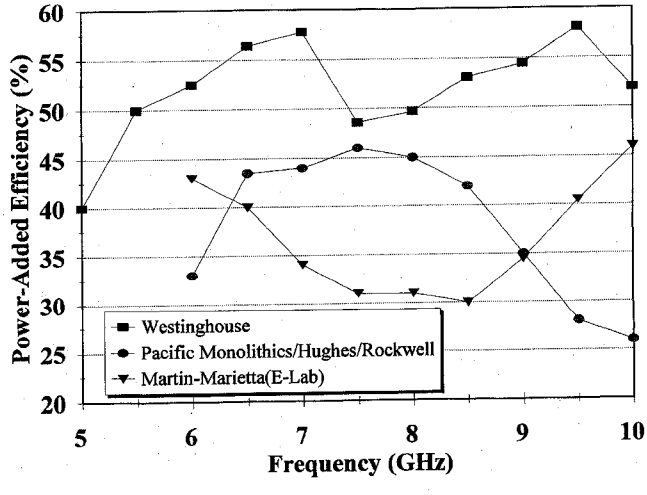

Fig. 4. Power-added efficiency comparison of 5–10 GHz, 1-W HBT amplifiers.

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