12W MONOLITHIC X-BAND HBT POWER AMPLIFIER

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ABSTRACT

Monolithic, 2-stage X-band power amplifiers have been designed and fabricated using AlGaAs/GaAs HBTs. Output power levels of up to 12.5 W cw have been demonstrated at 9.2 GHz from single-chip HBT amplifiers measuring 3.8 mm x 4.7 mm in size. To our knowledge, this is the highest cw output power level reported at X-band frequencies for any monolithic power amplifier and highlights the advantages of HBT technology for microwave solid-state power applications.

INTRODUCTION

Heterojunction Bipolar Transistors (HBT) have demonstrated strong potential for high-power, high-efficiency microwave solid-state amplifier applications[1-4]. Up to 5 W cw output power has been obtained with monolithic HBT amplifiers at X-band frequencies[4]. What makes HBTs attractive for power amplifier applications compared with other solid-state three-terminal devices are: higher power density operation [2], higher breakdown voltage which can be designed for a given frequency band of operation, higher impedance values for a given output power level, and high efficiency Class-B operation [3] due to low leakage currents. The optical lithography compatible dimensions of the HBT also makes it amenable to high yield, low-cost, volume production.

The high power density operation of HBTs results in a smaller die size for a given output power level. This makes it feasible to achieve higher output levels without resorting to circuit power combining techniques which degrade amplifier efficiency.

In this work, we report on the performance of two-stage monolithic power amplifiers designed for X-band T/R module applications. Two amplifier designs were fabricated using optimized 300μm common-emitter (CE) unit cells. Device and circuit design aspects of this work will be presented along with measured data on the performance of the power amplifiers.

HBT DEVICE DESIGN

The amplifiers reported in this work were fabricated using Texas Instruments' self-aligned AlGaAs/GaAs power HBT process[1]. The HBT epitaxial layers were grown in a non-arsine MOCVD system to assure superior AlGaAs emitter layers for efficient microwave performance. Carbon was used as the base layer dopant for reliable operation. The minimum feature size (emitter finger width) of this process is 2 μm with the base contacts self-aligned to the emitter. The HBT device layout has been optimized considering simultaneously the thermal and electrical unit-cell properties. A 300 μm emitter length, common-emitter unit-cell formed the building block of the X-band power amplifiers. This unit-cell, which typically delivers more than 1 W cw output power at 10 GHz with 7 dB gain and 65% collector efficiency, consists of ten 2 μm x 30 μm emitter fingers.

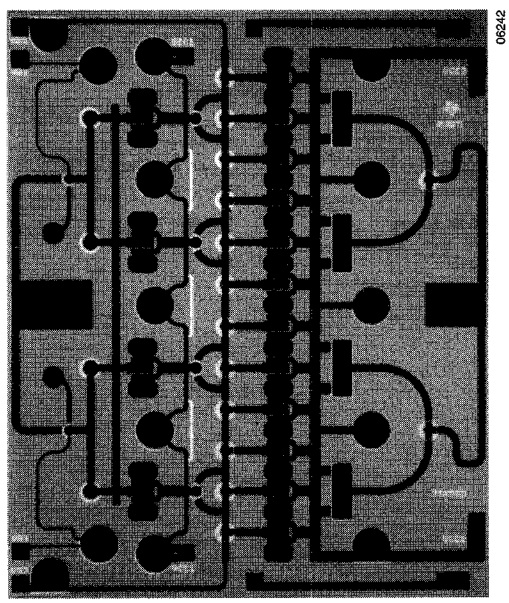

Figure 1. Photograph of the 3.6mm 2-stage X-band HBT amplifier (Amplifier-A). The die size is 3.8mm x 4.7 mm.

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AMPLIFIER CIRCUIT DESIGN

Two monolithic amplifier designs were considered in this work. The first amplifier (Amplifier-A) consisted of a 12-unit cell output stage for a total emitter length of 3.6 mm. Figure 1 shows a photograph of this amplifier. The input stage consisted of four 300 µm unit-cells to ensure proper drive level to the output stage after inter-stage circuit losses. The designs were based on large-signal impedances of the 300 µm unit cell which were determined from load/source-pull measurements at X-band. Figure 2 shows the circuit topology of Amplifier-A.

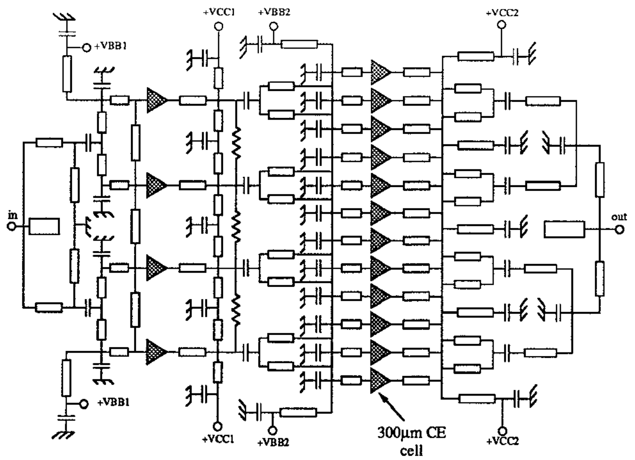

Figure 2. Schematic of the 3.6mm 2-stage HBT amplifier (Amplifier-A).

The amplifier has complete on-chip matching circuit for 50 Ω operation, and on-chip bias networks. Special attention was paid to the physical symmetry of the amplifier to minimize phase variations of the RF signal to each unit-cell. Also, care was taken to avoid odd-mode oscillations, which could arise from long lateral paths on the amplifier and due to non-symmetry. The die size of Amplifier-A was 3.8 mm x 4.7 mm.

Figure 3 shows the photograph of Amplifier-B, which consisted of an 8-cell (2.4 mm total emitter length) output stage driven by an 0.8 mm driver stage. This amplifier measures 3.8 mm x 3.3 mm in size and also includes complete on-chip matching and bias circuits. The schematic of Amplifier-B is shown in Figure 4.

AMPLIFIER PERFORMANCE

The monolithic amplifiers were tested under CW conditions at X-band. Figure 5 shows a pair of Amplifier-A chips mounted on a common carrier plate. External 100 pF capacitors were used for low-frequency by-passing of the bias lines. Bias bus lines were placed on 10-mil alumina substrates which were also mounted on the carrier plate. Figure 6 shows the cw output power vs. input power for Amplifier-A at 9.2 GHz. With a 30 dBm input drive level, 11.5 W output power was achieved with 10.5 dB associated gain and 35.5% power-added efficiency (PAE). The calculation of PAE from measured data

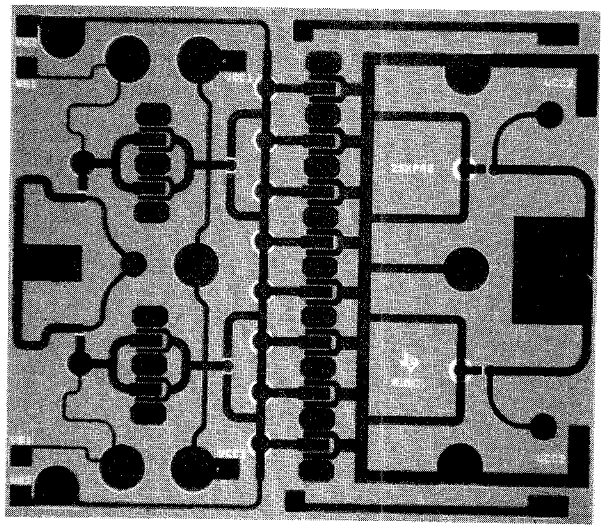

Figure 3. Photograph of the 2.4mm 2-stage X-band HBT amplifier (Amplifier-B). The die size is 3.8mm x 3.3 mm.

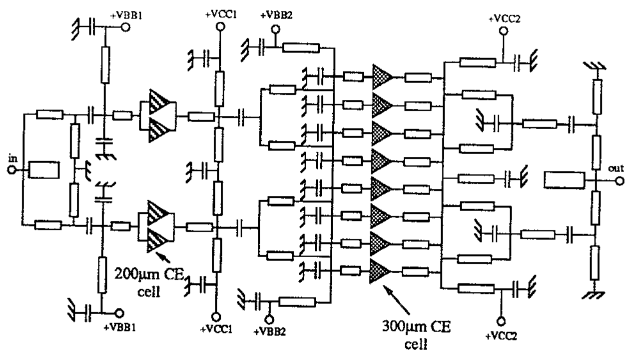

Figure 4. Schematic of the 2.4mm 2-stage HBT amplifier (Amplifier-B).

included DC power supplied to the base and the collector of both stages. The input and output VSWR was better than 1.5:1 and, therefore, no external tuning was required for optimum amplifier performance. Figure 7 shows the output power and PAE of the amplifier as a function of frequency for 30 dBm input drive level. The amplifier can deliver more than 10 W output power in a 5% bandwidth around 9.2 GHz with better than 34% PAE. The collector bias voltage for this measurement was 13V.

Under higher base bias conditions (Figure 8), Amplifier-A delivered 12.5 W cw output power with 10.8 dB associated gain and 31% PAE. *To our knowledge, this is the highest output power level achieved with any monolithic solid-state power amplifier at X-band.* This power level represents a 3.5 W/mm output power density, which is similar to the density obtained from a single 1 W unit-cell. This result indicates that the output power of HBT scales well from 1W unit-cells to at least 12.5W monolithic amplifier at X-band frequencies.

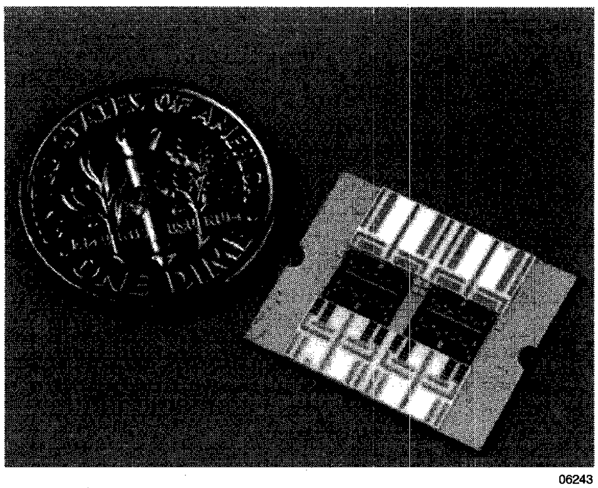

Figure 5. A pair of HBT amplifiers (Amplifier-A) mounted on a common carrier plate with external by-passing capacitors.

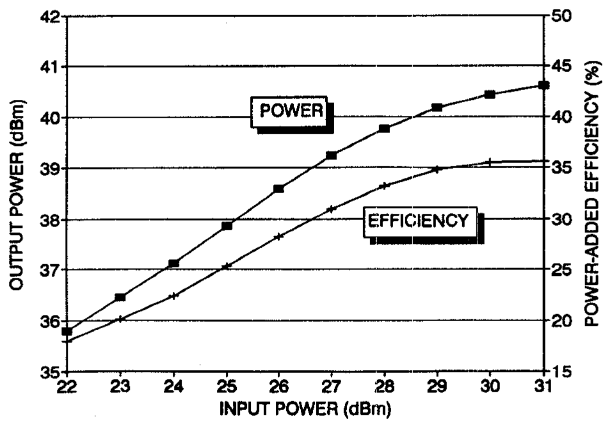

Figure 6. Measured output power and power-added efficiency (PAE) of Amplifier-A at 9.2 GHz under optimum efficiency base bias conditions.

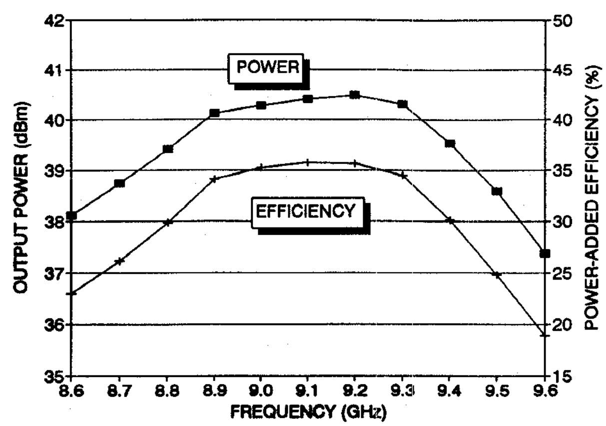

Figure 7. Measured frequency response of Amplifier-A under optimum efficiency base bias conditions. Input drive level for this measurement was +30 dBm.

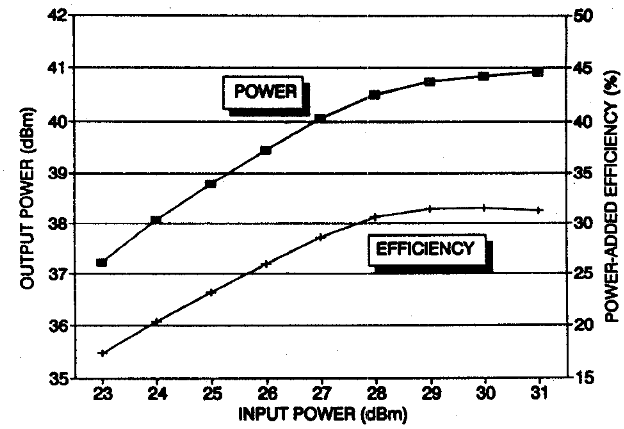

Figure 8. Measured output power and PAE of Amplifier-A at 9.3 GHz under optimum power base bias conditions.

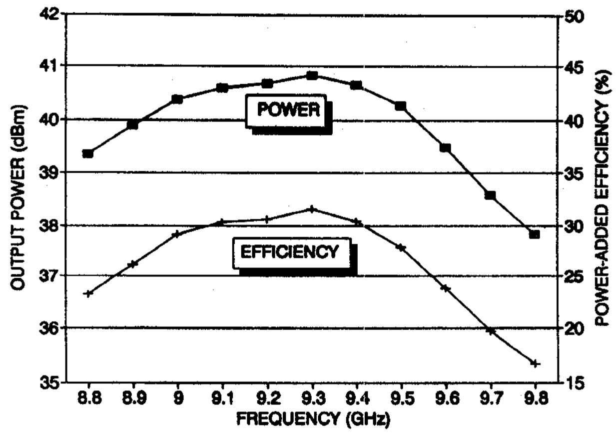

Figure 9. Measured frequency response of Amplifier-A under optimum power base bias conditions. The input drive level was +30 dBm.

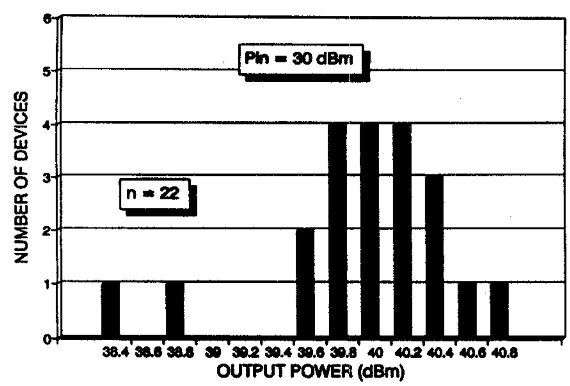

Figure 10. Output power distribution of 22 samples of Amplifier-A from 3 lots of wafers with +30 dBm input power.

Figure 9 shows the corresponding frequency response of the amplifier at the higher base bias conditions.

The statistical variation of the output power of 22 Amplifier-A chips from 3 lots are shown in Figure 10. The input drive level for the measurements were +30 dBm. The mean cw output power of the 22 samples was 10 W (10 dB gain) with a corresponding mean collector operating voltage of 12.5V. This is in contrast to 6-8 V operating voltage for ion-implanted FETs and 7-9 V for epitaxial FETs.

Figure 11 shows the typical output power and PAE vs. input power at 9.6 GHz for Amplifier-B. With 28 dBm drive level, an output power of 8.0 W was demonstrated with 11.0 dB associated gain and 37% PAE. Again, no external tuning was required for optimum performance indicating proper large-signal impedance matching. At 29.5 dBm drive level, the amplifier delivered 8.9 W output power with 35% PAE and 10 dB associated gain.

The output power density of this amplifier is again close to the discrete device performance and the power density of Amplifier-A. Figure 12 shows the frequency response of Amplifier-B at 28 dBm input drive level. The amplifier produced more than 6W cw output power across a 10% bandwidth centered at 9.6 GHz.

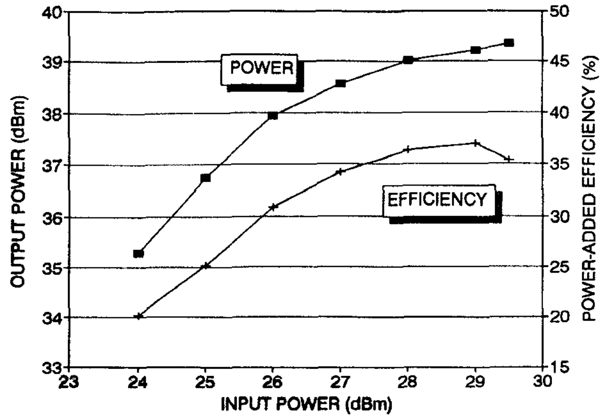

Figure 11. Output power and PAE of Amplifier-B at 9.6 GHz .

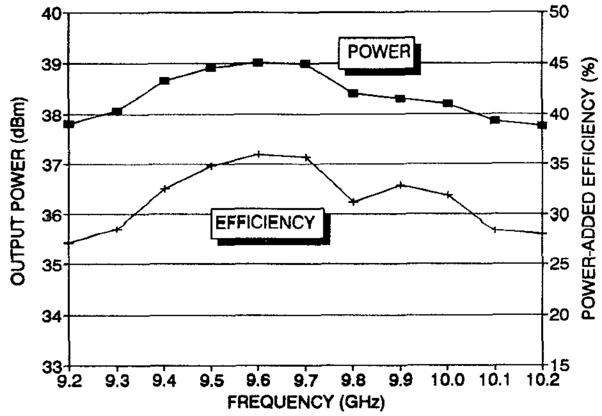

Figure 12. Frequency response of Amplifier-B at +28 dBm input drive level.

CONCLUSION

In conclusion, we have demonstrated monolithic, 2-stage, HBT X-band power amplifiers with output power levels in excess of 10 W (up to 12.5 W cw). Power-added efficiencies in the 31-37% range were achieved with these amplifiers. The results obtained indicate that the HBT output power scales very well with device size at up to 12W output power level at X-band. The high output power density of the HBT results in very compact chip size for monolithic power amplifiers. The output power density per unit chip area for the fully-matched X-band MMIC amplifiers developed in this work was 0.7 W/mm^2. For a given output power level at X-band, this represents a 2X-3X reduction in MMIC size compared to GaAs MESFET amplifiers. The operating voltages of the HBT amplifiers are also higher than the MESFET counterparts. AlGaAs/GaAs HBTs are ,therefore, well suited for efficient, high-power X-band amplifier applications, especially those requiring compact size such as in T/R modules of solid-state phased-array radars.

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