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HIGH-EFFICIENCY, CLASS-B, S-BAND POWER AMPLIFIER

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ABSTRACT

A class-B, high-efficiency, S-band heterojunction bipolar transistor (HBT) amplifier has been developed for potential applications in phased-array radar and mobile communication systems. The amplifier achieves an output power level of 1.1 W with an associated power-added efficiency of 61% and 12.3 dB power gain at 3.0GHz (10% bandwidth). The amplifier is turned ON with the input RF signal and dissipates no DC power when idle even though it is biased at all times. This feature which is characteristic of true class-B operation is a significant requirement for high-efficiency T/R module and portable radio systems.

INTRODUCTION

Solid-state power amplifiers used in phased-array radar and mobile communication systems must meet a number of requirements among which are high-efficiency, low 3rd-order intercept point and low DC power consumption when idle. For T/R module applications, single-bias high voltage operation is also desirable. At UHF and L-band (1-2 GHz), Si bipolar transistors have been successfully inserted in phased-array T/R modules and mobile radio systems. However, the performance of Si bipolar transistors at S-band (2-4 GHz) and higher frequencies is marginal and GaAs FETs are currently being considered for such applications [1,2]. Although GaAs power FET technology has matured over the past few years, a number of handicaps remain in their use for high power, high efficiency applications. High-efficiency modes of operation (class-B and class-C) of FET power amplifiers are difficult due to low breakdown voltage and high degree of leakage current near pinch-off [3]. GaAs FET power amplifiers are often designed for class-A or class-AB operation which consume DC power during idle period and thus require special circuit provisions for their shut-off when no RF power is demanded. Power FETs operate at about 0.7 W/mm which makes it difficult to achieve multi-watt output power levels without circuit combining techniques.

AlGaAs/GaAs HBTs have demonstrated potential for high power, high efficiency applications at microwave frequencies [4,5]. In addition to high output power density and large breakdown voltages, HBTs have other features that make them attractive for use as power amplifiers in microwave transmitters. Those include higher 3rd-order intercept points due to the linear characteristics of HBT and low 1/f noise which minimizes added AM/PM and AM/AM upconversion noise.

In this paper, we report on the true class-B operation of an HBT power amplifier at S-band. Device parameters and characteristics that make HBTs suitable for class-B operation are discussed and power/efficiency performance results are presented.

HBT DEVICE DESIGN AND CHARACTERISTICS

The S-band hybrid power amplifier was designed around an HBT with 400 μm total emitter length. The device consisted of 20 emitter fingers arranged in a compact unit cell. The unit cell is designed such that the junction temperature rise above the base-plate temperature remains below 150 C at 2 W/mm (of emitter length) power dissipation. The HBTs were fabricated using a previously reported self-aligned process [4]. Since efficient class-B operation of transistors require large operating voltages, 1.5 μm of nominally undoped collector layer was used in the HBTs. The common-emitter (CE) breakdown voltage (BV_{CEO}) was typically > 25 V at a current gain value of 20. Figure 1

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shows the CE current-voltage characteristic of an 100 μm HBT. As shown in Figure 1, the output conductance is very low even at low current levels due to the very low leakage current of the reverse-biased base-collector junction. This along with the ability to achieve high breakdown voltages make HBTs suitable for high efficiency modes of operation.

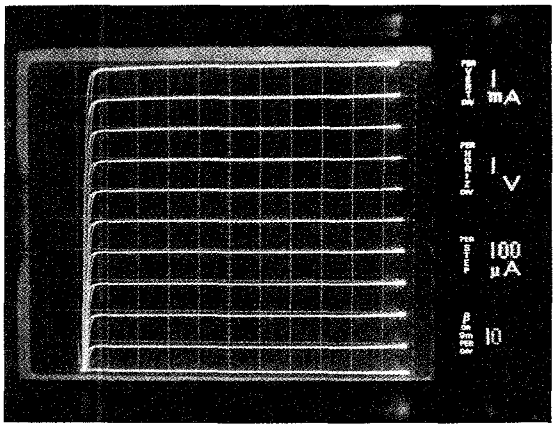

Figure 1: *Common-emitter current-voltage characteristic of an 100 μm HBT.*

Another important device criterion for class-B operation is the ability to maintain high power gains even at very low current levels. In other words, the device must have sufficient average power gain as the current swings between its maximum and minimum values under large-signal conditions. This is difficult to achieve with ion-implanted GaAs MESFETs, since the device transconductance drops sharply near pinch-off and specially tailord MBE doping profiles are often required to provide gain flatness over certain drain current range. Since HBTs are vertically oriented devices, with proper material and process conditions, they can demonstrate flat current gains over large range of operating currents. Figure 2 shows the measured CE current gain of a 40 μm HBT versus base current over six decades of collector current. Therefore, under large-signal operation, the average current gain is fairly independent of the drive level. Since the output conductance is also independent of the collector current, the voltage gain and thus the power gain do not significantly change with input power. Figure 3 shows the measured current gain cut-off frequency (f_t) and the maximum frequency of oscillation (f_{max}) versus collector current for a 40 μm HBT. As shown in Figure 3, the cut-off frequencies of the device remain high at low

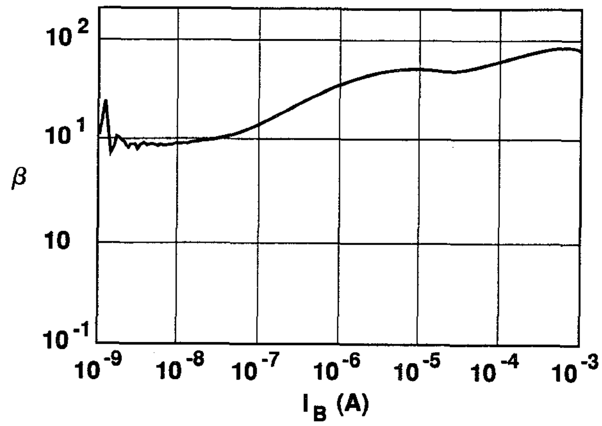

Figure 2: *Current gain versus base current for a 40 μm HBT.*

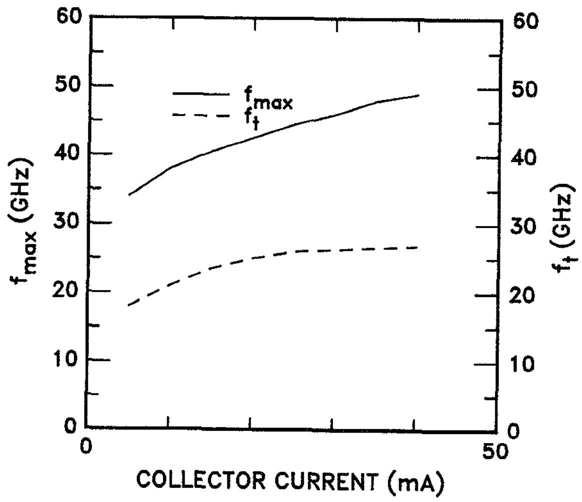

Figure 3: *Measured current gain cutt-off frequency (f_t) and maximum frequency of oscillation (f_{max}) versus collector current.*

collector currents. The linearity in HBT parameters also improves the 3rd-order intermodulation distortion of HBT power amplifiers.

AMPLIFIER DESIGN AND PERFORMANCE

A single-stage hybrid amplifier was designed based on small-signal and load-pull measurements of the 400 μm HBT. Figure 4 shows the circuit diagram of the amplifier designed for narrow-band (10 %) operation at 3.0 GHz. The input and output matching circuits were fabricated on 10 mil Alumina substrate whereas discrete capacitors and inductors (RF chokes) were used for the bias network. Figure 5 shows the assembled amplifier with SMA input/output connectors. The power/efficiency characteristics of the class-B amplifier at 3 GHz are shown in Figure 6. In the absence of input RF signal, the amplifier is biased at V_{CC} = 9 V , V_{BB} = 1.0 V , and I_C = 0 mA. As seen from Figure 6, below +10 dBm input power, the amplifier is completely turned OFF. Above +10 dBm, the amplifier turns ON with the power gain expanding to 13 dB and then compressing to 12.3 dB at the 1.1 W output power level. The gain expansion and compression is characteristic of class-B amplifiers. The associated collector and power-added efficiencies at the 1.1 W output power level are 66% and 61%, respectively. More than 40% power-added efficiency is maintained over 6 dB output power range. These results do not account for circuit losses or other losses associated with SMA-to-microstrip transitions. Figure 7 shows the average collector current versus input power for the amplifier indicating NO DC power dissipation at less than 0 dBm input power levels. With proper optimization of the collector layer structure operating voltages as high as 20 V can be possible at S-band frequencies.

SUMMARY

Class-B operation of AlGaAs/GaAs NPN HBT power amplifiers have been demonstrated at S-band (3.0 GHz). A single-stage, hybrid power amplifier using a 400 μm HBT was designed and fabricated. At 3.0 GHz, an output power level of 1.1 W with associated 12.3 dB gain and 61% power-added efficiency were achieved. The amplifier is turned on with the input RF signal and dissipates no DC power when idle. This makes it attractive for use in the phased-array T/R modules since synchronous gating of the bias voltages of the amplifier with the RF signal is not required.

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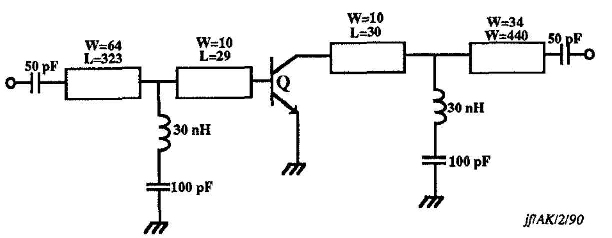

* Dimensions are in mils for 10 mil alumina substrate

Figure 4: *Circuit diagram of the class-B S-band amplifier.*

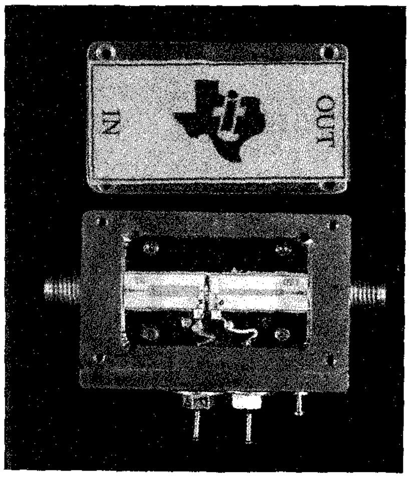

Figure 5: *Photograph of the assembled amplifier.*

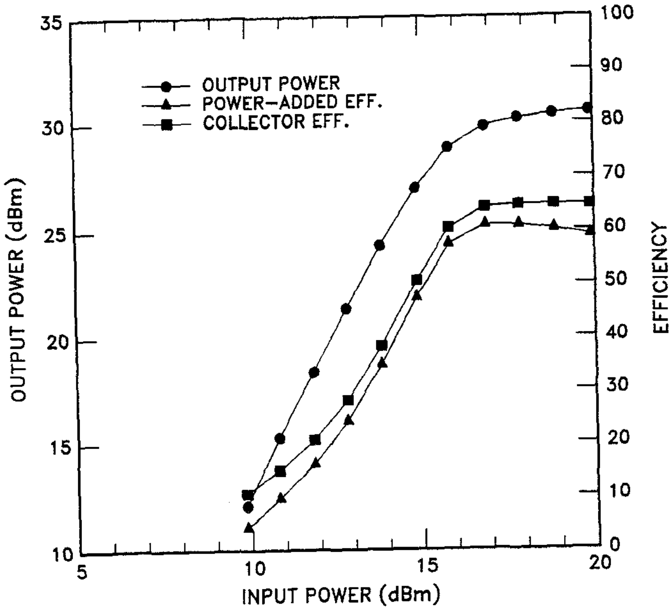

Figure 6: *Measured output power, collector efficiency, and power-added efficiency versus input power at 3.0 GHz.*

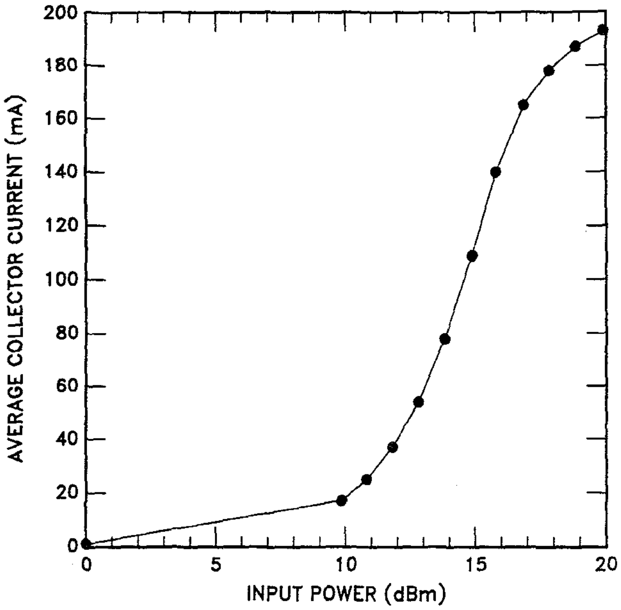

Figure 7: *Measured average collector current versus input power at 3.0 GHz.*