A Study of Class C Operation of GaAs Power HBTs

Fazal Ali, Aditya Gupta, Mike Salib and Brad Veasel

Westinghouse Electric Corporation, Advanced Technology Division
P.O. Box 1521, MS 3K13, Baltimore, MD 21203

ABSTRACT

GaAs power HBTs are traditionally biased in Class A or Class AB mode for power amplifiers. This paper describes the tradeoffs of operating these devices in Class C bias. We find that power-added efficiency (PAE) improves and power gain decreases in Class C when compared to Class AB bias. At 6 GHz, the PAE increased by greater than 10 percentage points (from 68.9% in Class AB to 80.6% in Class C) with concurrent loss of 4.3 dB in power gain. The efficiency improves monotonically with lower operating frequency. In a single-tone environment, the second harmonic increases by ~7 dB in Class C over Class AB. To our knowledge, this is the first report on the experimental study of Class C operation of GaAs HBTs.

INTRODUCTION

Many applications, such as amplification of CW, FM and AM (double sideband) signals, do not require linear RF gain and can therefore make use of the higher efficiency and simplicity of biasing offered by Class C operation of Heterojunction Bipolar Transistors (HBTs). GaAs power HBTs are traditionally biased in Class A or Class AB mode for power amplifiers. Khatibzadeh and Bayraktaroglu [1] have already reported a high efficiency S-band HBT amplifier where the device is operated in Class B. Adlerstein and Zaitlin [2] have compared Class B operation of HBT and MESFET amplifiers. This paper describes the tradeoffs involved in operating GaAs power HBTs in Class C bias.

The peak RF voltage amplitude for HBTs and MESFETs/PHEMTs is limited by collector-base and gate-drain breakdown voltages, respectively. However, in cutoff class operation (Class B and Class C), this limitation becomes more severe for MESFETs/PHEMTs. Under high RF drive, during the "off" portion of the RF cycle, the negative gate voltage can cause breakdown voltage (BV_{dg}) to be exceeded. The result is excessive gate and drain leakage currents and low power gain due to low g_m near pinch-off. HBTs, in contrast, have the advantage over MESFETs/PHEMTs in maintaining the collector breakdown voltage, eliminating leakage current, and exhibiting higher efficiency from the exponential dependence of g_m on base voltage. MESFET based power amplifiers are therefore, traditionally biased in Class A or Class AB mode which requires complex power supply regulator circuitry to turn off the amplifier during idle periods for prime power conservation. In Class C operation, HBTs do not require a base power supply; the RF signal is sufficient to turn the device on. The device, therefore, does not dissipate any power when the RF signal is absent even when the collector voltage is left on at all times.

CLASS C OPERATION OF HBTs

Several 160μm^2 and 480μm^2 AlGaAs/GaAs HBTs were used for this study. These devices were fabricated by a self-aligned base-emitter process and have multiple 2μm x 20μm emitters with a 5Ω thin film resistor in series with each emitter finger. A photograph of the

CH3577-4/95/0000-0721$01.00 © 1995 IEEE

common-emitter (CE) 480μm^2 HBT is shown in Figure 1. This device has 12 emitter fingers and the emitter contacts are grounded on both sides through plated via holes. Similarly, the 160μm^2 device has four emitter fingers. These devices were die-mounted on ribbed-carriers having 50Ω microstrip line alumina substrates, then assembled into a test fixture. In Class AB mode, the devices were biased at fixed base-emitter voltage (V_{be}=1.37V) and the collector potential was held at 7V. In Class C mode, the devices were biased at V_{be}=0V and V_{cc}=7V. The RF signal modulates the base-emitter junction and turns it "on".

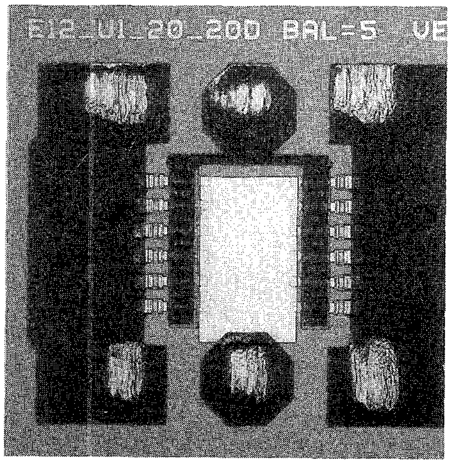

Figure 1. Photograph of a 480μm^2 CE HBT.

A computer controlled automated microwave load/source-pull tuner system (manufactured by David Sarnoff Research Lab) was used to characterize these devices at different bias conditions and frequencies. Figure 2 shows a detailed block diagram of this set-up.

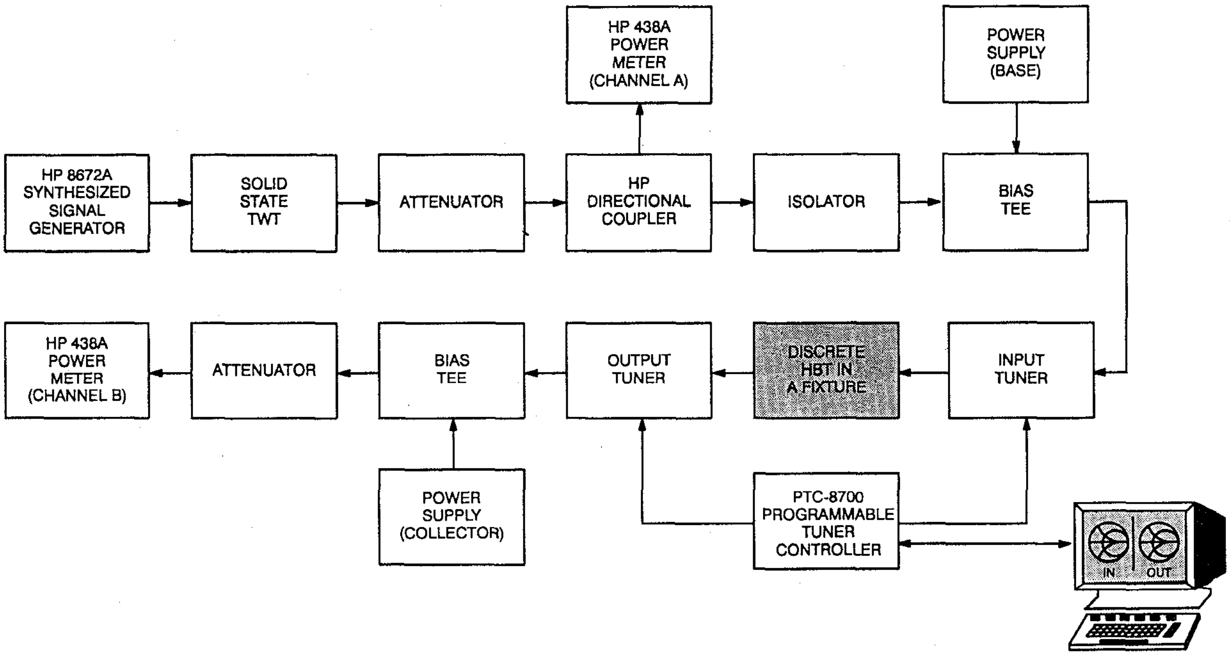

Figure 2. Computer controlled automated microwave load/source-pull tuner system.

The typical output power and PAE as a function of input drive level at 6 GHz is shown in Figure 3a for both Class AB and Class C bias modes. Figure 3b shows the variation in collector current with input power. Below 13 dBm input, the device is not turned on and the collector current is close to zero. The optimum load for maximum PAE are different under these two modes of operation. At 6 GHz, the PAE increased by greater than 10 percentage points (from 68.9% in Class AB to 80.6% in Class C) with a concurrent loss of 4.3 dB in power gain. The collector efficiency is 89.6%. At 9 GHz, the PAE increased by only 8.1% in Class C mode compared to Class AB bias condition with an associated 4.5 dB reduction in power gain. In general, the difference in PAE between Class AB and Class C increases monotonically with lower operating frequency. Tables 1 and 2 provide a

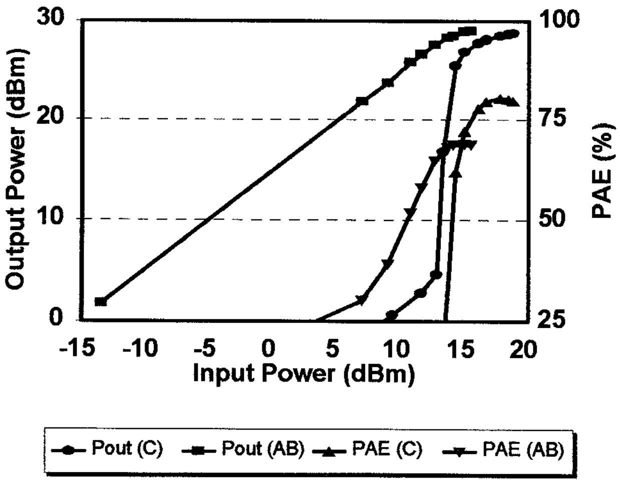

Figure 3a. Typical output power and PAE as a function of input drive @ 6 GHz for Class AB and Class C modes.

summary of the performance in Class AB and Class C for the two types of devices tested at C- and X-Band frequencies. A spectrum analyzer

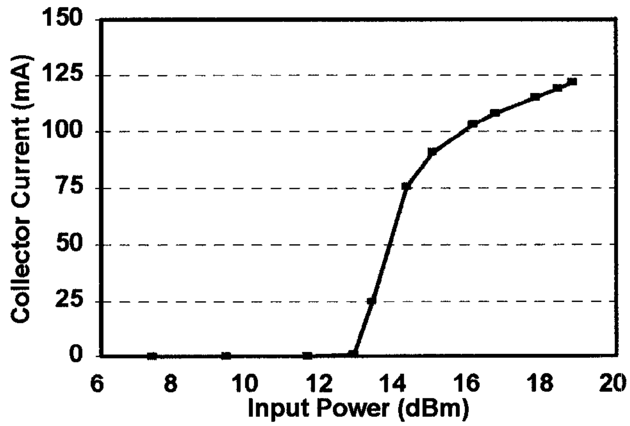

Figure 3b. Collector current variation with input drive.

was also connected to the output tuner to understand the relative harmonic contents of these devices (having no intentional harmonic traps) under peak PAE conditions in two different bias modes. For a single-tone 6 GHz signal, the second harmonic increases by ~7 dB in Class C over Class AB.

CONCLUSION

Class C operation of HBTs is attractive because of an improvement in PAE and the significant simplification in bias circuitry. However, the associated power gain is ~ 4-5 dB lower which will limit the highest frequency of operation as compared to Class AB bias conditions.

ACKNOWLEDGEMENTS

The authors are grateful to Dr. Bert Hewitt for his enthusiastic support for GaAs HBTs. Special thanks to Ms. Jackie Cellini for her kind help with manuscript preparation.

Table 1

A Comparison of Class AB and Class C Performance of a 480μm^2 HBT with 2μm x 20μm Emitters

Frequency (GHz)	Class of Operation	Power Gain (dB)	PAE (%)	Pout (dBm)	Collector Efficiency (%)
6	AB	14.4	68.9	28.6	71.9
6	C	10.1	80.6	28.6	89.6
7	AB	13.8	67.7	28.7	70.6
7	C	8.8	74.5	29.1	85.4
8	AB	12.2	65	28.5	70.9
8	C	8.3	74	28.5	89.3

Table 2

A Comparison of Class AB and Class C Performance of a 160μm^2 HBT with 2μm x 20μm Emitters

Frequency (GHz)	Class of Operation	Power Gain (dB)	PAE (%)	Pout (dBm)	Collector Efficiency (%)
8	AB	13.7	66	24.4	70.3
8	C	9.2	74.1	24.3	83.6
9	AB	13.1	66	24.8	73.1
9	C	8.9	73	24.5	83.9

REFERENCES

1. M. Khatibzadeh and B. Bayraktaroglu, "High Efficiency, Class B, S-Band Power Amplifier," 1990 IEEE MTT-S International Microwave Symp. Dig., pp. 993-996.

2. M. Adlerstein and M. Zaitlin, "Cutoff Operation of Heterojunction Bipolar Transistors," Microwave Journal, September 1991, pp. 114-125.

3. S. Wemple, et. al., "Relationship Between Power-Added Efficiency and Gate Drain Avalanche in GaAs MESFETs," Electronics Letters, Vol. 16, No. 12, 1980, pp. 459-460.

4. S. Sriram, R. Clarke, R. Messham, T. Smith and M. Driver, "High-Voltage Operation in Class-B GaAs X-Band Power MESFETs," 1989 IEEE Cornell Conference Digest, pp. 218-227.