Use of Self Bias to Improve Power Saturation and Intermodulation Distortion in CW Class B HBT Operation

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Abstract—**It is shown that the dc base bias circuit can be used to control the RF performance of an HBT operating under CW conditions near class B mode. By a careful choice of base bias resistance, gain can be linearized, output power at 1-dB gain compression increased, and intermodulation distortion reduced. Measurements on HBT's biased near class B operation showed a 10-dB improvement in 1-dB gain compression point and 10-dB reduction in intermodulation distortion for moderate power levels. Results for various values of dc base resistance for a typical HBT are presented.**

I. Introduction

Over the past ten years, significant progress has been made toward the development of microwave heterojunction bipolar transistors (HBT's). Output powers as high as 5 watts have been obtained for a 6 cell monolithic HBT amplifier [1] and intermodulation intercept points as high as 35 dBm have been reported [2]. Through the use of self aligned base technology, values of $f_{\max}$ exceeding 100 GHz have become possible [3]. These excellent figures of merit have prompted the use of HBT's in a number of power applications.

In situations where efficiency is an issue, it is often desirable to bias the transistor in class B mode. The bias scheme in this case can strongly influence the RF performance. This effect has been utilized in the past when optimizing FET and homojunction BJT amplifiers. More recently, it has been shown that by biasing a common emitter HBT with a constant base voltage, the collector current increases more sharply than when biasing with a constant base current [4]. Furthermore, the gain tends to increase with input power for the constant base voltage case [4] because the bias point shifts.

Output power, efficiency, and bias currents were the main emphasis in [4]. In this work, we take a detailed look at gain linearity, gain compression point, and third-order intermodulation distortion for a common emitter HBT biased near class B mode. We show that by controlling self bias effects via the base biasing circuit, these quantities can be improved for HBT's operating under continuous wave (CW) conditions.

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II. Measurement Systems

Using a computer controlled microwave tuner system (Focus Microwaves [5]), gain and intermodulation distortion were measured as a function of input power. For the gain compression measurements, a 12-GHz sinusoidal signal was applied to the input of the HBT (the base in this case). The source impedance was nominally 50 Ω. The load impedance was set to its optimal small signal value using the output tuner. Input and output power were measured and recorded using a dual head power meter. A second source with frequency f_2 was added to the system to measure third-order intermodulation distortion. Its amplitude was equal in magnitude to the first source (f_1) but its frequency was offset by about 5 MHz. The intermodulation distortion (IMD3) was measured using a spectrum analyzer to detect the power level of a signal at a frequency $2f_1 - f_2$. Before measuring the HBT, the intermodulation distortion of a thru line was tested to make sure the system IMD3 was well below detectable limits.

III. Results

For class A operation, the biasing scheme had very little effect on power saturation or intermodulation distortion. However, in class B mode, the measured device performance depended on how the base was biased. To investigate this effect further, we measured several common emitter HBT's from various sources. Fig. 1 shows the measured transducer gain as a function of input power for various values of dc base resistance, R_b, for a typical device [6]. The doping profile for this device is given in Table I. In all our graphs, $R_b = 0$ corresponds to an ideal voltage source base bias and $R_b =$ infinite corresponds to current source bias on the base. The collector current with no RF power, denoted I_{co} in all plots, was 0.9 mA.

Because bias tees were used to supply dc power to the device, the RF and dc circuits were effectively decoupled. Notice that in the constant current source case, the gain compressed quickly. On the other hand, for the constant voltage source case, the gain increased slightly before compressing at a much higher input power than the current source case. At an intermediate value of dc base resistance, in this case about 100 Ω, flat gain was achieved with a 10-dB improvement in 1-dB gain compression point as compared with the constant current source case. It turns out that this value of R_b is about

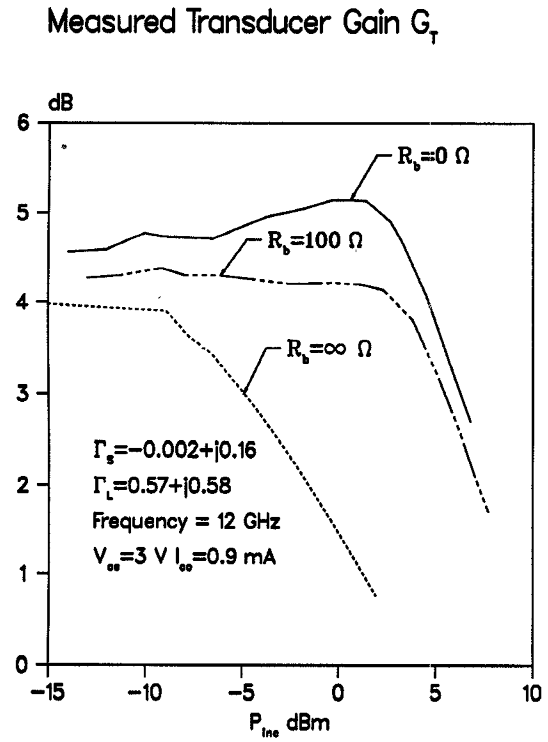

Fig. 1. Measured transducer gain $G_T = \frac{P_{\rm load}}{P_{\rm inc}}$ at 12 GHz as a function of power incident at the input of the HBT for various values of base bias resistance R_b. $R_b = 0$ corresponds to a voltage source connected directly to the base of the HBT and $R_b = \infty$ corresponds to a current source. The load and source impedance are fixed during all the measurements. Under no RF drive, the device is biased with collector current I_{co} of 0.9 mA and collector voltage V_{ce} of 3 Volts.

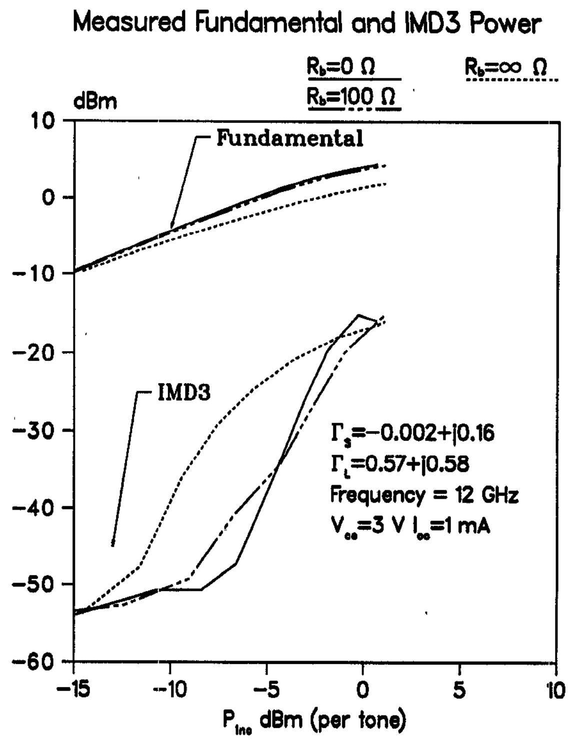

Fig. 2. Measured fundamental and third-order intermodulation power at 12 GHz for the same conditions as in Fig. 1.

TABLE I
MEASURED DEVICE (2 × 10-μm EMITTER STRIPE) [6]

Region	Al frac	dop	dop (cm^{-3})	μm
Contact	0.0	n+	3.E18	0.1
Emitter	0.3	n	5.E17	0.2
Spacer	0.0	i	undoped	0.02
Base	0.0	p+	5.E19	0.1
Collector	0.0	n	3.E16	0.5
Subcollector	0.0	n+	3.E18	0.5

the same as the dc base resistance $\frac{\partial V_{be}}{\partial I_b}$ computed from the dc gummel plot (80 Ω).

Similar improvement was observed for the third-order intermodulation distortion (IMD3), shown in Fig. 2. At moderate power levels, the IMD3 for the constant voltage source bias and the $R_b = 100$ ohms case was over 10 dB better than the constant current source case. Since the measured IMD3 was not linear even at low power levels, as was the case for the class A bias points we measured, calculation of a meaningful intercept point was not possible.

To understand the reason for these results, one must look at the dc bias currents shown in Fig. 3. For the constant voltage source case, as the input power increased, the base and collector bias currents also increased, resulting in a shift of the dc bias point. At an input power of -16 dBm, the bias point was $V_{ce} = 3$ V, $I_c = 1$ mA. However, at 6.5 dBm input power, the bias point was $V_{ce} = 3$ V, $I_c = 6.5$ mA. This shift in bias point can be attributed to a rectification process at the base-emitter junction. As the input power increased, it caused the RF base-emitter voltage amplitude to increase. Since the dc base-emitter voltage was fixed at the junction turn on voltage for the constant voltage source case (class B bias), the average base current increased with an increase in input power. In the constant current source case, the bias point shifted less because the base current was fixed. Increases in input power resulted in a decrease in base-emitter dc voltage in order to keep the dc base current constant.

By using an external bias resistor, R_b, we were able to control the amount of bias point shift in such a way that the gain was linearized with respect to input power and the intermodulation distortion was reduced. We should point out that one could, in principle, manually adjust the base bias at each power level using a constant current source and achieve the same result. To verify this, we remeasured the gain as a function of input power. At each input power level, we manually adjusted the base bias current to be the same as that measured in the constant voltage source case. We found that the gain as a function of input power was the same for the manually adjusted bias and the constant voltage source case. What is different about this work is that we used the rectification process and base bias resistance to *automatically* control the shift in bias point. However, the overall efficiency of the device was decreased slightly due to power dissipation in the bias resistor.

IV. CONCLUSION

Under CW class B operating conditions, the HBT RF performance is strongly dependent on the base bias conditions.

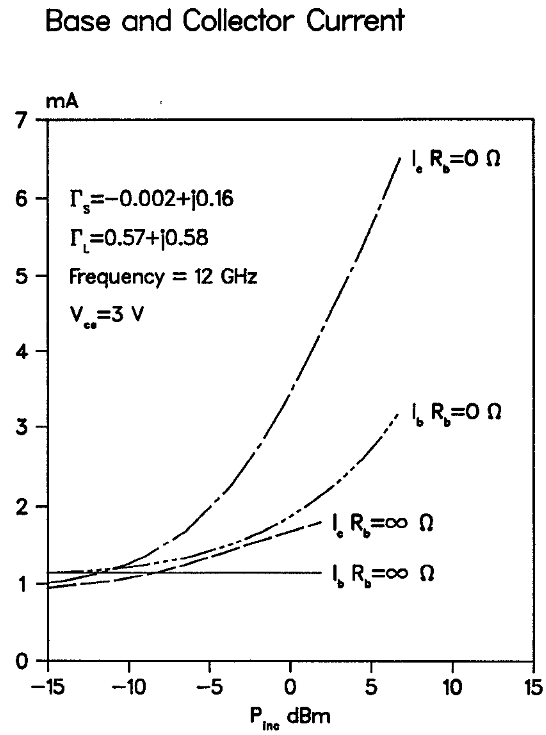

Fig. 3. Measured base and collector bias currents as a function of incident power for the single tone case described in Fig. 1.

An optimal value of base bias resistance, corresponding to the dc input resistance of the HBT, can be chosen which linearizes the gain, increases the input power for saturation, and reduces the third-order intermodulation distortion. This improvement is caused by device self bias effects which cause a shift in the dc bias point. Varying the base bias resistor provides a means to automatically control the amount of bias point shift with input power.

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[6] Device provided by Raytheon Company, Research Division.