THE EFFECT OF SOURCE IMPEDANCE ON LINEARITY IN InGaP/GaAs POWER HBTS

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ABSTRACT

L-band power amplifiers operating with high efficiency and linearity at a single, low supply voltage are in strong demand in mobile communication systems. This paper reports the effect of source impedance on the phase distortion and the adjacent channel power (ACP) for a $\pi/4$-shift QPSK modulated signal in the InGaP/GaAs power heterojunction bipolar transistors (HBTs). Our results show that the phase distortion and the ACP of our HBTs are improved by adding a positive reactance to a gain-matched source impedance. The ACP for a 50 kHz offset is -49.2 dBc with a power-added efficiency (PAE) of 56 % at a output power (P_{out}) of 31 dBm under a supply voltage of 3.5 V.

INTRODUCTION

HBTs are one of the most promising devices for future mobile communication handsets because of their superior power characteristics even at low-bias voltage with a only single supply and the higher power handling capability for a smaller chip size [1]. In addition, the advantages of InGaP/GaAs HBTs over AlGaAs/GaAs HBTs for low-voltage-operation amplifiers are their smaller knee voltage, due to the smaller collector-emitter offset voltage less than 0.1 V, and the higher reliability even at a high current density. The large current handling capability enables high output power with low supply voltage and at low cost [2],[3].

Moreover, recent digital communication systems require power amplifiers with much higher linearity. The linearity of HBTs, however, has not been studied in detail so far. In particular, the effects of load and source impedance on the ACP for a $\pi/4$-shift QPSK-modulated signal are not well known. We discuss the effect of source impedance on linearity, and present a new self-linearized matching technique using the non-linear input conductance of the device itself and additional reactance to the gain-matched source impedance.

PHASE DISTORTION ANALYSIS

The origin of ACP is a non-linearity of device. Power gain compression and phase distortion cause an increase in ACP when the output power increases.
The nonlinear effect of device parameters on the phase distortion is discussed here using the simplified equivalent circuit of a common-emitter HBT shown in Fig. 1.

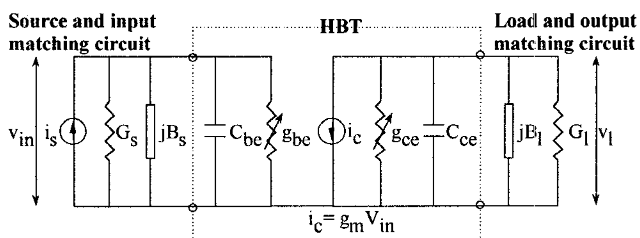

Figure 1. Equivalent circuit of common-emitter HBTs.

In our analysis, we assume that (a) a feedback capacitance, C_{bc}, and conductance, g_{bc}, are ignored due to their small values, (b) a non-linearity in output capacitance, C_{ce}, is ignored, (c) input and output conductances, g_{be} and g_{ce}, increase as output power increases, and (d) the non-linearity of g_{be} is larger than that of input capacitance C_{be} when the base-emitter is forward-biased.

The relationship between a signal source current, i_s, and output voltage, v_l, is as follows.

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$$v_l = \frac{g_m \, i_s \exp j(\pi - \theta_l - \theta_s)}{\sqrt{(g_{ce} + G_l)^2 + (\omega C_{ce} + B_l)^2}\sqrt{(g_{be} + G_s)^2 + (\omega C_{be} + B_s)^2}} \quad (1)$$

$$\tan\theta_l = \frac{\omega C_{ce} + B_l}{g_{ce} + G_l} \quad (2)$$

$$\tan\theta_s = \frac{\omega C_{be} + B_s}{g_{be} + G_s} \quad (3)$$

$$\Delta\phi = -\Delta\theta_l - \Delta\theta_s \quad (4)$$

where G_s is the signal source conductance, B_s the source susceptance, G_l the load conductance, B_l the load susceptance, and $\Delta\phi$ the phase distortion.

The gain compression is explained by Eq. (1). As input power increases, g_{ce} increases and g_m decreases. This causes a compression of the output voltage swing v_l.

The phase distortion, $\Delta\phi$, is explained by the change in θ_l. When the input circuit is conjugate-matched for maximum gain, θ_s is zero. As the output matching circuit is tuned for maximum output power or efficiency, θ_l is not zero because the load impedance deviates from the conjugate-matched impedance. As the output power increases, θ_l decreases by increasing g_{ce} in Eq. (2). The phase distortion is mainly caused by the non-linearity of g_{ce}. The same discussion has also been made for GaAs MESFET [4].

In this paper, we propose that the output phase deviation, $\Delta\theta_l$, can be canceled by the input phase deviation, $\Delta\theta_s$, in Eq. (4). By optimizing the input matching, B_s, in Eq. (3), a sign of $\Delta\theta_s$ can be set opposite to that of $\Delta\theta_l$. In HBTs, the non-linearity of the input conductance, g_{be}, is large when the input circuit is forward-biased, and the sign of $\omega C_{be}+B_s$ in Eq. (3) can be set either a positive or a negative value by the susceptance, B_s. That is to say, the phase distortion is self-linearized by the non-linear input conductance of the device itself and the reactive component of a matching source impedance. We can reduce the phase distortion $\Delta\phi$ and obtain a superior ACP performance using this self-linearized-matching technique.

FABRICATION AND BASIC CHARACTERISTICS

The InGaP/GaAs HBT structure grown by MOCVD consists of an n^+-InGaAs cap layer, an n-InGaP emitter layer, a C-doped p^+-GaAs base layer, and n/i-structure collector layers[1].

Table 1 summarizes the DC and small-signal characteristics of HBTs with an emitter area of 2μm×20μm. We use a ballasting resistance of 2.5 Ω for thermal stability[3]. The collector emitter offset voltage, $V_{ce\text{-}offset}$, is 80 mV, which is 0.1 - 0.3 V lower than that of the AlGaAs/GaAs HBTs we fabricated. BV_{ceo} is 14 V. f_T and f_{max} of the InGaP/GaAs HBT are 40 GHz and 110 GHz, respectively, at a collector current I_c of 16 mA and a collector bias V_{ce} of 2.5 V. The MTTF of our HBTs is 1×10^6 hours with a current density of 6×10^4 A/cm^2 at a junction temperature T_j of 200 °C [2] .

Emitter size	2μm×20μm
$R_{ballast}$	2.5 Ω
$V_{ce\text{-}offset}$	80 mV
BV_{ceo}	14 V
h_{fe}	73
f_T	40 GHz
f_{max}	110 GHz
MTTF	1×10^6 hours @200 °C, Jc=6×10^4 A/cm^2

Table 1. DC and small-signal characteristics of the unit HBT for power amplifier

The fabricated power HBTs have 64 fingers of 2 μm ×20 μm emitter. The total emitter area is 2560 μm^2 and the structure of the HBT is so-called a plated heat sink (PHS) with via holes.

EXPERIMENTAL RESULT AND DISCUSSION

Figure 2 shows the source-pull measurement results of the constant contour lines of ACP at a 50 kHz offset (solid lines) and the CW power gain (dashed lines) for a Japanese Personal Digital Cellular (PDC) 1.5-GHz π/4-shift QPSK signal with a P_{out} of 31 dBm, a V_{ce} of 3.5 V under class A-B and I_{cdc} of 400 mA. The load impedance is set to a minimum of ACP with a PAE of over 50% when a source impedance is gain-matched. The ACP is sensitive to the source impedance. Point A is a gain-matched impedance but at this point the ACP is not so good. Point B denote an impedance where positive reactive component is added to gain-matched impedance A to obtain a better ACP with enough gain.

Figure 3 shows the ACP at a 50 kHz-offset frequency as a function of output power at source impedance A (dashed lines) and B (solid lines). V_{ce} is 3.5 V and I_{cdc} is 400 mA under class A-B operation. The 50 kHz offset ACP value is improved at source impedance B when the output power is over 29 dBm.

Figure 4 shows the phase distortion as a function of output power at source impedance A (dashed line) and B (solid line). The phase distortion is lower at impedance B.

At the gain-matched impedance A, the phase distortion, $\Delta\phi$, increases with output power. According to our analysis, the output phase deviation, $\Delta\theta_l$, has a negative value because the input phase deviation, $\Delta\theta_s$, is almost zero due to the conjugate matching of source impedance, as shown in Eq. (4). To suppress the phase distortion, $\Delta\phi$, the $\Delta\theta_s$ values must be positive. Because g_{be} increases with output power, the $\omega C_{be}+B_s$ term in Eq. (3) must be negative. This means that an additional inductive component must be added to the gain-matched impedance to suppress the phase distortion.

At impedance B where the inductive component is added to gain-matched impedance A, the phase distortion and ACP were suppressed. This result is explained well by our analysis. At the self-linearized matching impedance where a reactive component is added to the gain-matched source impedance, phase distortion can be improved and the 50-kHz-offset ACP can be also suppressed.

H. Hayashi et al. discuss the phase distortion of GaAs MESFETs[4]. Even in FETs, phase distortion is dominated by g_{ds}. But the non-linearity of g_{gs} is smaller compared to C_{gs}, so it is difficult to compensate for the output phase distortion by source impedance. A gate-common FET with a negative phase deviation is used in the input circuit to compensate for the positive output phase deviation from common-source FETs. On the contrary in HBTs, the phase distortion can be improved by setting a source impedance to the self-linearlized matching only.

Figure 5(a) shows the output power and PAE. Figure 5(b) the ACP at offset frequencies of 50 and 100 kHz as a function of input power at the self-linearlized-matching

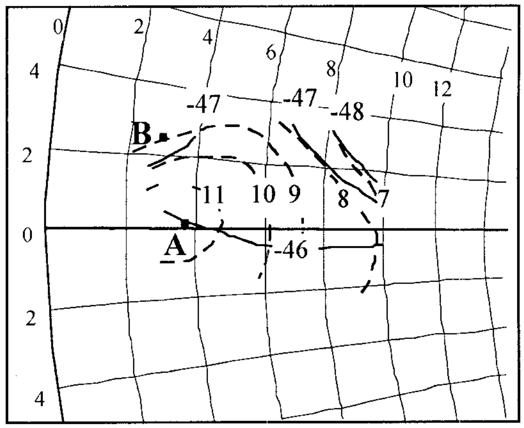

Figure 2. Source-pull measurement of gain (dashed lines) and ACP (solid lines).

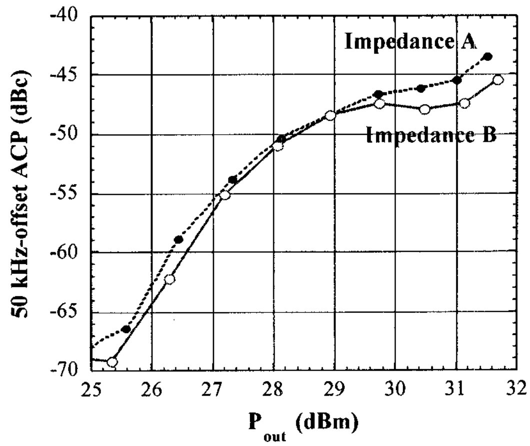

Figure 3. 50 kHz-offset ACP versus output power for impedances A and B.

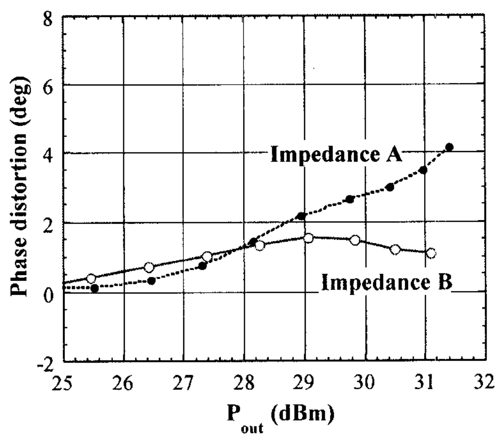

Figure 4. Phase distortion versus output power for impedances A and B

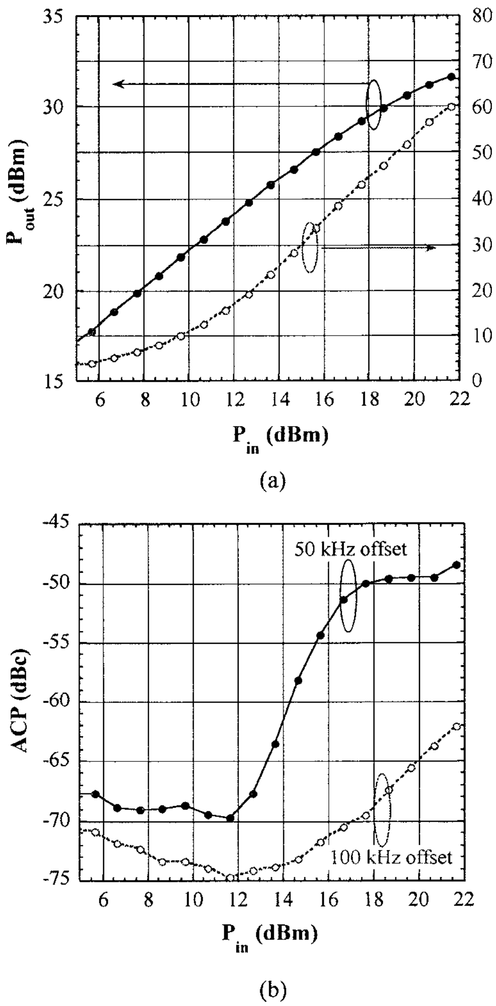

Figure 5. Output power and PAE versus input power (a) and 50 kHz-offset and 100 kHz-offset ACP versus input power (b) for an optimum impedance.

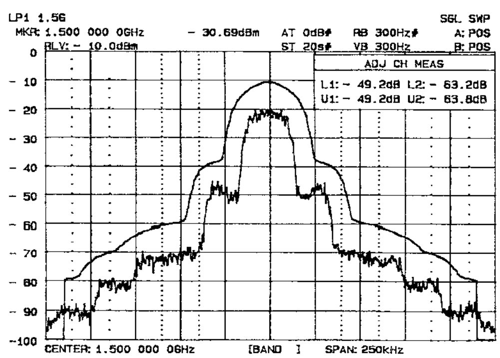

Figure 6. Output spectrum at output power of 31 dBm for 1.5 GHz modulation input.

source impedance for an other efficiency-matched load impedance. Figure 6 shows the output power spectrum at an output power of 31 dBm for a 1.5-GHz-modulated input. As a result, the ACP with a Pout of 31.0-dBm shows -49.2 dBc and -63.2 dBc at a 50 kHz offset and a 100 kHz offset, respectively, with a PAE of 56% at a bias of 3.5V.

CONCLUSION

We have discussed the effect of source impedance on linearity in InGaP/GaAs HBTs, and presented a self-linearized-matching technique using the non-linear input conductance of device itself and an additional reactance to gain-matched source impedance. Using this technique, our HBT shows that a 50-kHz-offset ACP with a Pout of 31.0 dBm shows -49.2 dBc with power added efficiency of 56 % at a bias of 3.5 V.

ACKNOWLEDGMENT

The authors wish to thank J. Fukaya, M. Takikawa, H. Nishi, T. Sugihara, and K. Odani for their encouragement. They also wish to thank N. Furutani, K. Matsumoto, H. Mimino and Y. Tateno for their technical discussion.

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