A 50% Efficiency InGaP/GaAs HBT Power Amplifier Module for 1.95 GHz Wide-Band CDMA Handsets

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***Abstract* — A 0.1 cc high-efficiency power amplifier multi-chip module (MCM) has been developed using InGaP/GaAs heterojunction bipolar transistors (HBT) for 1.95 GHz wide-band CDMA handsets. Under 3.5 V operation, the MCM achieved an output power P_{out} of 26.3 dBm, an excellent power-added efficiency (PAE) of 50.5%, and a high associated gain G_a of 28.5 dB with an adjacent channel leakage power ratio (ACPR) of -35 dBc at a 5 MHz off-center frequency band. The MCM also exhibited excellent PAEs of more than 40% even at a low supply voltage of 1.5 V.**

I. INTRODUCTION

A wide-band CDMA (W-CDMA) system has been receiving much attention as the third generation cellular phone standard. Since the W-CDMA system requires strict distortion characteristics for transmitters, power amplifiers (PAs) with high linearity and high efficiency are greatly demanded. Operation with single bias supply and low shut-off leakage current is also needed for these PAs to make low-cost small-size PA modules that have no negative voltage or drain switches. To date a 0.2 cc MCM with a 40% PAE [1] and a 0.1 cc MCM with a 47% PAE [2] have been developed as single-voltage-operation PA modules for W-CDMA portable phones, using HBTs and enhancement-mode heterojunction field effect transistors (E-HJFET), respectively.

In this paper we describe a 0.1 cc PA MCM for W-CDMA handsets that achieved a record PAE, a high G_a and a sufficiently low ACPR.

II. InGaP/GaAs HBT

A. Device Fabrication

Figure 1 illustrates the cross section of an InGaP/GaAs HBT we fabricated. The epitaxial layer structure of the HBTs was grown by MOCVD on a S. I. GaAs substrate. The layer structure includes an InGaAs cap layer, an InGaP emitter layer (Si: 3×10^{17} cm^{-3}, 30 nm), a GaAs base layer (C: 4×10^{19} cm^{-3}, 80 nm), a GaAs collector layer, and a GaAs subcollector layer. An HBT with a 3 μm × 20 μm emitter showed a DC current gain h_{FE} of about 150 at a collector current density J_C of 1×10^4 A/cm^2 and a high collector-emitter breakdown voltage BV_{CEO} of 20 V. A mean time to failure (MTTF) extrapolated to a junction temperature T_j of 135ºC was 3.6×10^8 h at a J_C of 4×10^4 A/cm^2 and a collector-emitter voltage V_{CE} of 3.6 V. The failure was defined as a reduction in h_{FE} to 90% of the initial unstressed value.

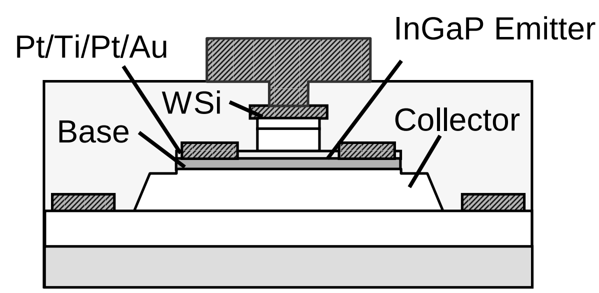

Fig. 1. Cross-sectional view of the InGaP/GaAs HBT

B. Single-Stage HBT Performance

A 3 μm × 20 μm double-emitter configuration was employed for a unit cell of PAs to reduce collector-emitter offset voltage V_{offset} as well as base-collector capacitance C_{bc} per unit emitter area and thereby increase the PAE, the power gain, and the r.f. stability. The V_{offset} was as low as 63 mV, resulting from reduced base-collector junction area and small conduction band discontinuity at the InGaP/GaAs heterointerface. The substrate was thinned to 35 μm and plated with 15 μm-thick Au on the backside to reduce thermal resistance. Via holes were also formed through the backside process. The f_t and f_{max} of the HBT were 32 GHz and 53 GHz, respectively at a V_{CE} of 2 V.

Figure 2 shows the shut-off collector leakage current vs. V_{CE} plots which were obtained for an HBT with a large

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emitter area S_E of 9,600 μm^2. Even at 85 Cº, the leakage current of the device was less than 2 μA at a V_{CE} of 3.5 V.

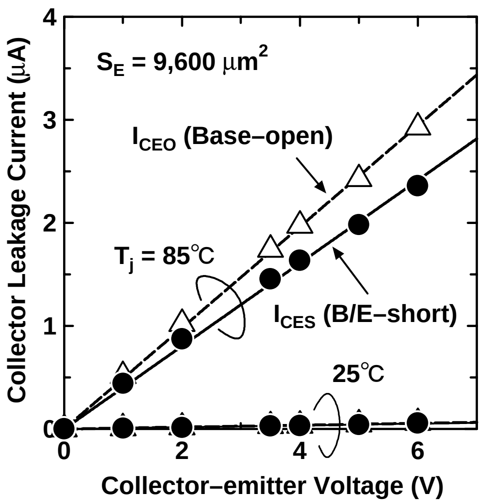

Fig. 2. Collector leakage current as a function of V_{CE}.

W-CDMA power performance was evaluated with a 3.84 Mcps HPSK modulated signal at 1.95 GHz. The load and source impedances were optimized with computer controlled tuners. The device was biased at a V_{CE} of 3.5 V and a quiescent current I_q of 30 mA. Figure 3 shows the P_{out}, the gain, the PAE and the ACPR as a function of input power P_{in}, which were obtained for a single-stage HBT with 24 unit cells (S_E = 2,880 μm^2). Measured at an ACPR of -35 dBc of, the HBT exhibited a P_{out} of 26.3 dBm, a PAE of 52.5%, and a G_a of 16.9 dB. The operation current density was 7×10^3 A/cm^3.

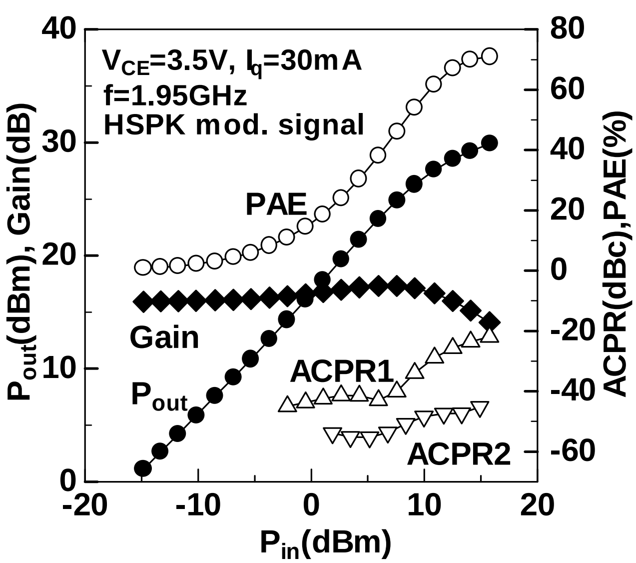

Fig. 3. W-CDMA power performance of the HBT

III. MCM DESIGN AND PERFORMANCE

A. Circuit Design

Figure 4 shows the circuit diagram of the 2-stage power amplifier MCM. The emitter sizes of the first and the second HBT were 480 μm^2 and 2,880 μm^2, respectively. The optimum input and output impedance of the HBTs were determined by load-pull measurements. To stabilize I_qs of the HBTs, a base-bias stabilizing circuit (BC) based on the Wilson current mirror type circuit was employed. The operation voltage for the bias circuit is supplied from the MCM supply voltage to reduce extra terminals.

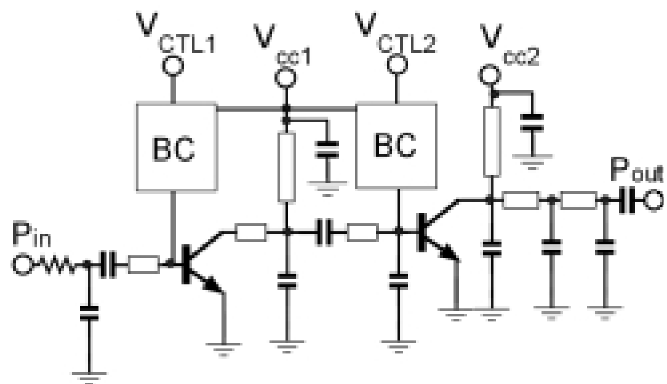

Fig. 4. Circuit diagram of the MCM.

Figure 5 shows quiescent currents for the 1st (I_{q1}) and the 2nd (I_{q2}) stage HBT as a function of MCM supply voltage V_{cc}. As shown in Fig. 5, the bias circuit is not sensitive to supply voltage. The $I_{q1,2}$ variations are within 6% from 2.5 V to 4.8 V V_{cc}.

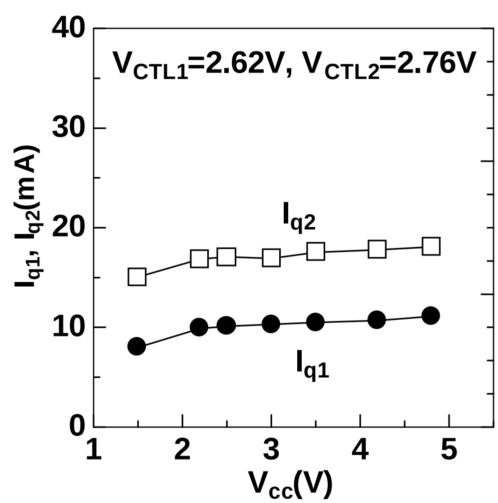

Fig. 5. I_{q1} and I_{q2} of the MCM as a function of V_{CC}.

B. MCM Structure

Figure 6 shows a cross sectional view of the developed MCM using a multi-layer substrate. The substrate consists of three resin and four conductor layers and has thermal via holes. The module structure is same as that of our commercially available MCMs [3]. All components, i.e., the chip elements and RF lines, were on the top resin layer with a dielectric constant of 10.5. DC bias voltage was supplied through the third conductor layer. The top view photograph is shown in Fig.7. The MCM size is $7 \times 7 \times 1.9$ mm^3 (0.1cc).

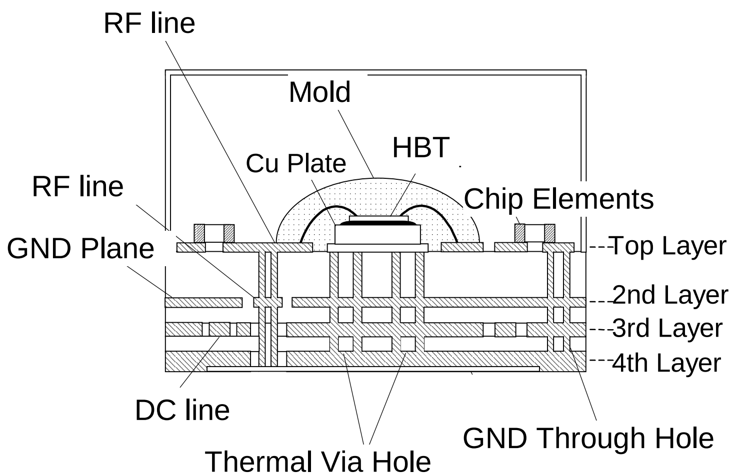

Fig. 6. Cross sectional view of the MCM.

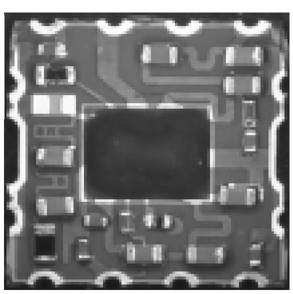

Fig. 7. Photograph of the developed power MCM

C. Power Performance

Figure 8 shows a 1.98 GHz W-CDMA power performance of the MCM. The bias condition was V_{CC} of 3.5 V with I_{q1} = 10 mA and I_{q2} = 25 mA. The MCM exhibited a P_{out} of 26.3 dBm, a record PAE of 50.5% and an G_a of 28.5 dB with ACPR of -35 dBc.

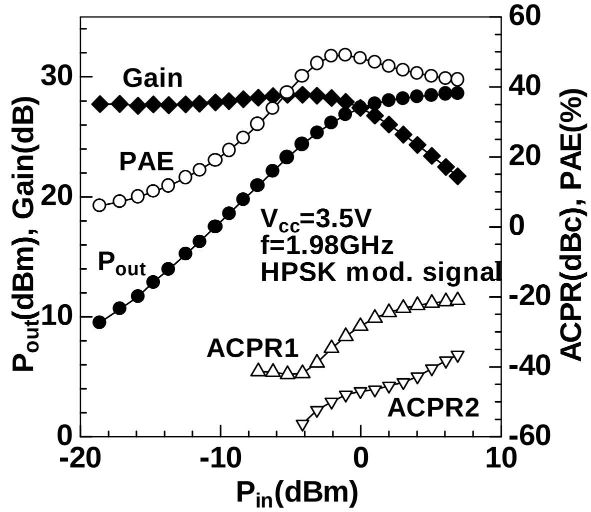

Fig. 8. W-CDMA power performance of the MCM

Figure 9 shows the frequency characteristics of the MCM measured at a constant P_{out} of 26 dBm. The MCM maintains less than -37 dBc ACPR and more than 46% PAE with a small gain deviation less than 0.1 dB from 1.92 GHz to 1.98 GHz.

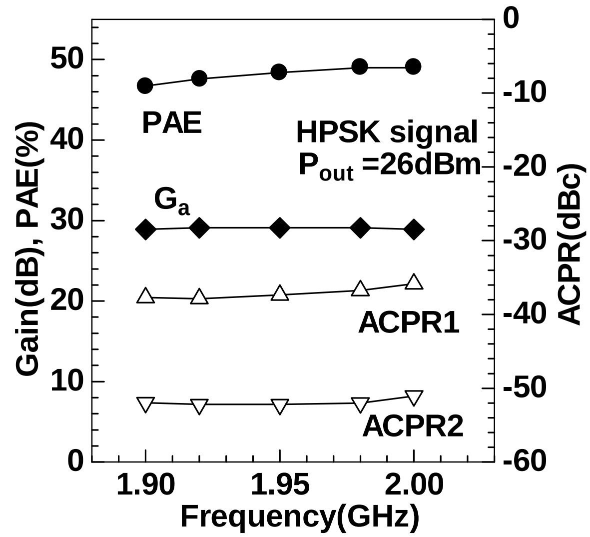

Fig. 9. P_{out}, PAE and G_a as a function of frequency.

The performances of the MCM are also evaluated with a V_{cc} range from 1.5 V to 4.8 V. Figure 10 shows P_{out}, PAE and G_a of the MCM measured at a constant -35 dBc APCR as a function of V_{cc}. The MCM exhibited more than 40% of PAE at such a low V_{cc} of 1.5 V. This fine low voltage operation characteristic is due to the small V_{offset} and stabilized I_{qs} enabled by the BC. Excellent power performance can also be expected for the developed MCM even under power supply modulation, e.g., using a DC-DC converter [4].

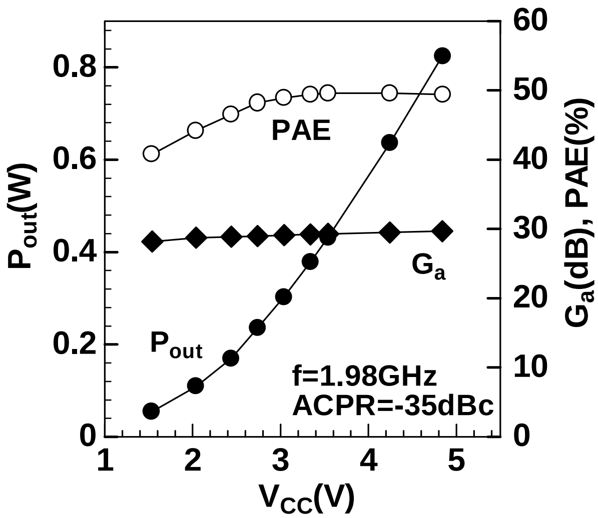

Fig. 10. P_{out}, PAE and G_a as a function of V_{cc}.

IV. Summary

A 0.1 cc high-efficiency 2-stage power amplifier MCM, employing InGaP/GaAs HBTs, has been successfully developed for 1.95 GHz W-CDMA handsets. Under 3.5 V operation, the MCM exhibited a 26.3 dBm output power, a record 50.5% power-added efficiency and a 28.5 dB associated gain with a –35 dBc adjacent channel leakage power ratio at a 5 MHz off-center frequency. The MCM also demonstrated excellent PAE of over 40% at low bias voltage of 1.5 V.

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References

[1] N. Miyazawa, H. Itoh,, Y. Nakasha, T. Iwai, T. Miyashita, S. Ohara and K. Johshin, "0.2 cc HBT power amplifier module with 40% power-added efficiency for 1.95GHz wide-band CDMA cellular phones,"*1999 IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 3, pp. 1099-1102, June 1999.

[2] Y. Bito, T. Kato, T. Kato and N. Iwata, "High efficiency power amplifier module with novel enhancement-mode heterojunction FETs for Wide-Band CDMA handsets,"2000 IEEE GaAs IC Symposium, pp. 255-258, Nov. 2000.

[3] T. Saso, Y. Hasegawa, Y. Saito and Y. Kakuta, "0.1 cc 60% efficiency power amplifier multi-chip modules for personal digital cellular phones,"*1999 IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 3, pp. 1099-1102, June 1999.

[4] T. B. Nishimura, N. Iwata and G. Hau, "Wide-band CDMA highly-efficient heterojunction FET over wide range output power with DC-DC converter,"1999 IEEE MTT-S Int. Microwave Symp. Dig., vol. 2, pp. 1091-1094, June 1999.