

A 2.4-V Low-Reference-Voltage Operation HBT-MMIC Power Amplifier Module for CDMA Applications

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1. Introduction

This paper describes the circuit design and measurement results of the prototype HBT MMIC power amplifier module which operates with a low reference voltage of 2.4 V. The module has been developed for 900-MHz band CDMA handset applications in response to CDMA's needs for low-voltage operation.

2. Background

Recently, gallium arsenide based heterojunction bipolar transistor (GaAs-based HBT) amplifiers have been widely used for code division multiple access (CDMA) mobile handsets. To extend the battery life of such handsets, the HBT amplifier and peripheral circuits should consume minimal power. We aimed to develop a low-voltage bias circuit, which can lower the battery's end-of-discharge voltage in the handset and thus effectively prolong the battery life. However, this is not easy to achieve because the reference voltage for an emitter follower circuit generally needs to be at least twice the base-emitter voltage (V_{be} : +1.3 V).

This paper presents our new power amplifier for CDMA mobile handset applications that operates with a low reference voltage of 2.4 V. It has been made possible by: (i) dividing the RF signal power stage into two AC-coupled blocks and providing one block with a voltage and current drive bias, and the other a current

drive bias; and (ii) adding a diode linearizer to the power stage with the voltage and current drive bias to prevent deterioration of adjacent channel leakage power at low temperatures.

3. Circuit Design

Figure 1 shows a circuit block diagram of the power stage with a bias circuit for low reference voltage operation. The design target for the reference voltage was set to 2.5 V or lower so that the Si-LDO (low voltage drop out regulator) can operate even at the battery's end-of-discharge voltage of 2.7 V.

If the reference voltage is set to 2.6 V or lower, it is not sufficiently greater than twice the base-emitter voltage, and thus satisfactory operation is not expected with the emitter follower circuit used as a bias circuit for the amplifier. Therefore, a current-drive bias circuit is added to the power stage so that the desired idle current can be supplied.

In addition, in order to reduce the amount of changes in the power gain and the phase with respect to the output power and to obtain smooth and monotonic gain and phase characteristics, the power stage for amplifying RF signals is divided into two AC-coupled blocks, Tr1 and Tr2, as shown in Fig. 1. Smooth gain and phase characteristics of the power stage are important for minimizing the distortion of the amplifier,

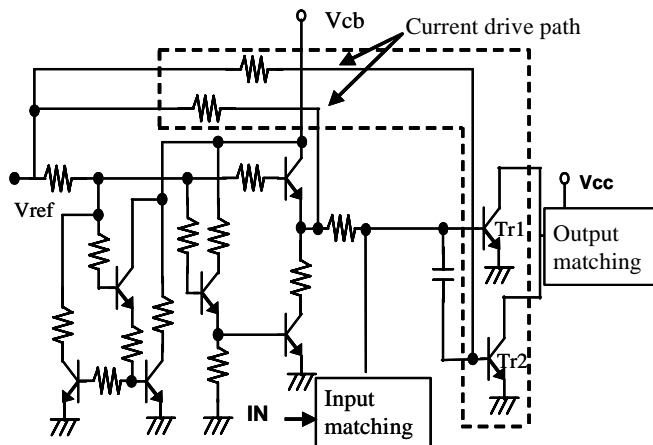


Fig. 1 Circuit configuration used for the low reference voltage operation

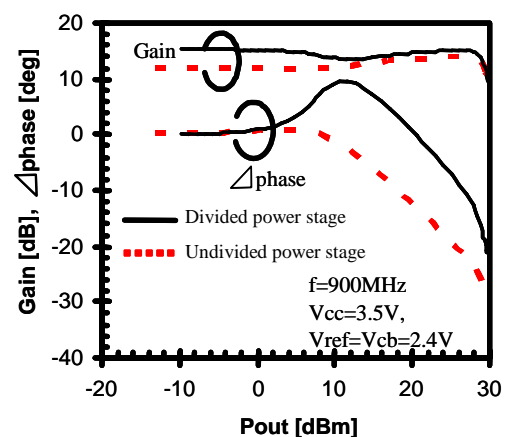


Fig. 2 Calculation results (Input-output characteristics): Comparison of divided and undivided power stages

which is a key parameter for CDMA applications. As depicted in Fig. 1, one of the divided power stage blocks, Tr1, is supplied with a base bias current through the emitter follower circuit as well as the resistor in the added current-drive supply circuit, resulting in high output operation. The other power stage block, Tr2, is supplied with a base bias current through the current-drive circuit only, to ensure the desired amount of idle current.

It was confirmed by simulation that the power stage with two kinds of bias supply circuit can achieve output characteristics having only small changes in the power gain or phase by adjusting the individual amount of supply from each current-drive base-bias circuit.

Figure 2 compares the output characteristics calculated for the circuit configurations with divided power stage (Fig. 1) and undivided power stage (Fig. 3). In these simulations, the frequency was set to 900 MHz; and as the bias conditions, the reference voltage and power supply voltage for the bias circuit were set to 2.4 V, and the collector voltage of Tr1 and Tr2 was set to 3.5 V. Figure 2 clearly shows that the divided power stage provides smooth gain and phase characteristics with respect to the output power.

However, computer simulation of the temperature dependency indicated that at low temperatures below 0°C, the circuit in Fig. 1 exhibited concave-shaped gain characteristics and convex-shaped phase characteristics similar to those of the circuit without a divided power stage. These characteristics at low temperatures were caused by the HBT's built-in base-emitter voltage that became higher than that at normal temperature, resulting in a condition similar to that when lowering the reference voltage at normal temperature.

To prevent these changes in the power gain and phase at low temperatures, a linearizer consisting of a diode and a resistor is added to the power stage as shown in Fig. 4.

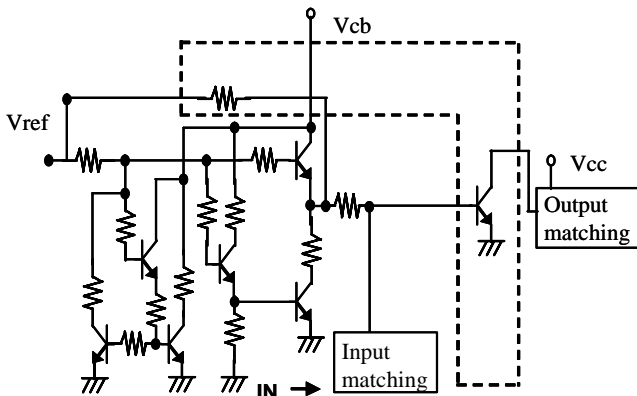


Fig. 3 Circuit configuration with an undivided power stage

Figure 5 compares the simulated output characteristics of the power stage at -10°C with and without a diode linearizer. It was confirmed that the changes in the gain and phase were effectively suppressed by adding a diode linearizer even at low temperatures.

As described above, it was confirmed by simulation that the HBT amplifier fabricated by the conventional HBT process can operate with a low reference voltage over a wide temperature range by means of the divided power stage with different bias supply methods and a diode linearizer.

4. Evaluation Results

Based on the simulation results described above, a prototype HBT monolithic microwave integrated circuit (MMIC) power amplifier module was fabricated and evaluated for the 900-MHz band J/WCDMA. A block diagram of the power amplifier module is shown in Fig. 6. The amplifier module was evaluated using 900-MHz band JCDMA (1S-95B) and WCDMA (3GPP-R99) modulation signals, and with the bias conditions of a power stage collector voltage of 3.5 V, and a power supply voltage for the bias circuit including reference voltage of 2.4 V.

The input-output characteristics with the JCDMA modulation signal are shown in Fig. 7. Results with the JCDMA modulation obtained at an output power (Pout) of 27.5 dBm were: power gain (Gp) = 26.5 dB, power added efficiency (PAE) = 40%, and adjacent channel power ratio (ACPR) = -50 dBc. These results adequately satisfy the key output characteristics required for JCDMA transmitter power amplifiers. Measurement results with the WCDMA modulation signal were Pout = 28.0 dBm, Gp = 26.7 dB, PAE = 42%, and adjacent channel leakage ratio (ACLR) = -42 dBc.

Figure 8 compares the input-output characteristics measured with and without the diode linearizer at the case temperature (Tc) = -10°C.

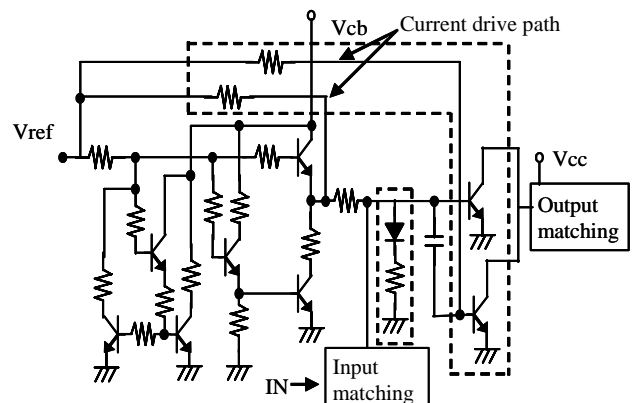


Fig. 4 Circuit configuration with a diode linearizer

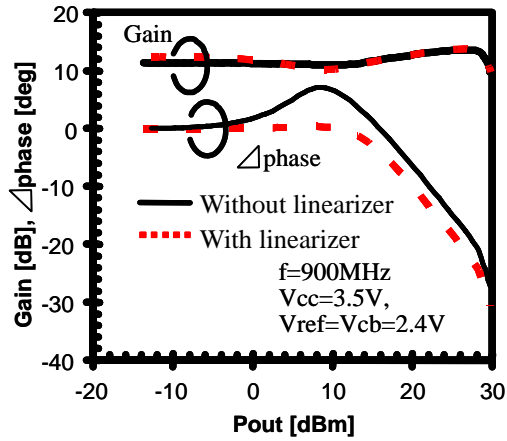


Fig. 5 Calculation results (Input-output characteristics): Comparison of characteristics with and without diode linearizer (Temperature: -10°C)

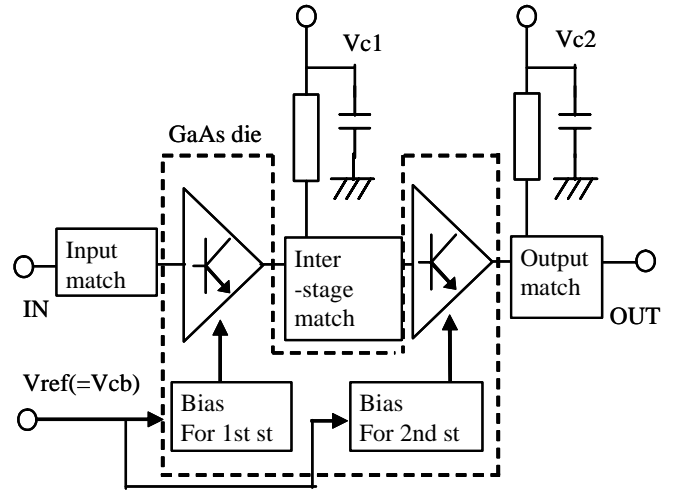


Fig. 6 Block diagram of amplifier

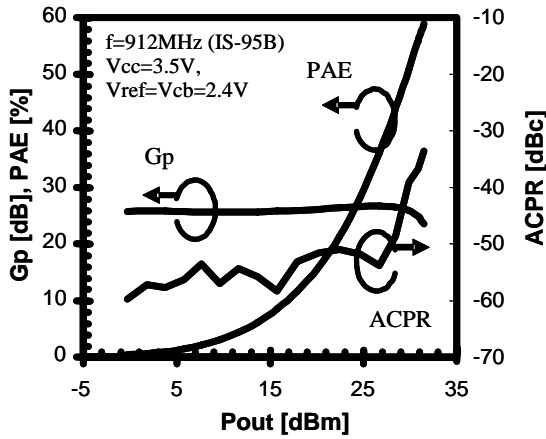


Fig. 7 Evaluation results (Input-output characteristics): JCDMA modulation ($T_c = 30^{\circ}\text{C}$)

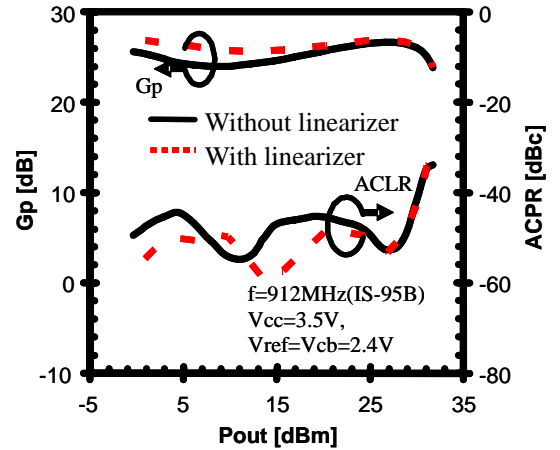


Fig. 8 Evaluation results (Input-output characteristics): Comparison of characteristics with and without diode linearizer (Temperature: -10°C)

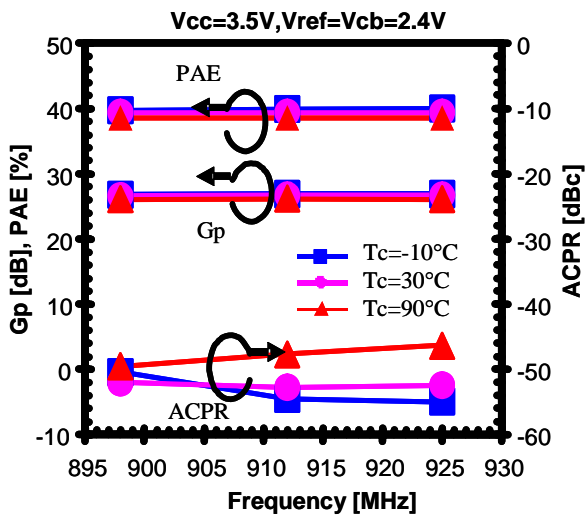


Fig. 9 Frequency characteristics with JCDMA modulation ($P_{out} = 27.5 \text{ dBm}$ [$T_c = -10^{\circ}\text{C}, 30^{\circ}\text{C}, 90^{\circ}\text{C}$])

As predicted by the previously described simulation results, if the diode linearizer is not built on the chip, the power gain significantly changes, which is associated with a significant deterioration of ACPR. In contrast, when a diode linearizer is added, flat gain characteristics are obtained with respect to the output power and ACPR is improved.

The above evaluation results clearly show, as predicted by the simulation, that our bias circuit and power stage configuration enable a lower reference voltage to be used over a wide temperature range ⁽¹⁾. We will improve the circuit design and strive to develop new amplifiers, in response to the needs for low power supply voltage.

Reference

- (1) K. Yamamoto et al., "A CDMA InGaP/GaAs-HBT MMIC Power Amplifier Module Operating with a Low Reference Voltage of 2.4 V," IEEE J. SSC, Vol. 42, No. 6, pp. 1282-1290, June 2007.