An on-chip temperature compensation circuit for an InGaP/GaAs HBT RF power amplifier*

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Abstract: A new on-chip temperature compensation circuit for a GaAs-based HBT RF amplifier applied to wireless communication is presented. The simple compensation circuit is composed of one GaAs HBT and five resistors with various values, which allow the power amplifier to achieve better thermal characteristics with a little degradation in performance. It effectively compensates for the temperature variation of the gain and the output power of the power amplifier by regulating the base quiescent bias current. The temperature compensation circuit is applied to a 3-stage integrated power amplifier for wireless communication applications, which results in an improvement in the gain variation from 4.0 to 1.1 dB in the temperature range between –20 and +80 ℃.

Key words: GaAs HBT; power amplifier; temperature compensation; on chip

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1. Introduction

The potential of GaAs HBT power amplifiers for wireless communication was clearly seen in the 1990s[1, 2], and today the technology is mature and has entered mass production[3]. With the development of information technology, there have been increasing demands for power amplifiers with a small variation in gain and output power with temperature. However, it is known that GaAs HBT RF power amplifiers are seriously affected by ambient temperature variation resulting in gain spread of several dB for amplifiers[4]. Therefore it is necessary to improve the temperature characteristics of power amplifiers.

To date, in order to compensate gain variation with temperature, off-chip regulators, such as low dropout regulators (LDOs), were applied to control the bias current or input signal widely. As a result, the modules have become larger. To improve the integration density and realize small modules, the preferable solution is an amplifier with an on-chip temperature compensation circuit[4–6].

In this paper, an on-chip temperature compensation circuit is presented to apply to a GaAs HBT RF power amplifier for wireless communication. The circuit utilizes the temperature characteristics of GaAs HBT and TaN thin film resistors to control the base quiescent bias current. The gain variation is compensated by regulating the base quiescent bias current of the power amplifier. For the smallest temperature compensation circuits, the integration density of the amplifier is improved significantly.

2. GaAs HBT VBIC equivalent network

The VBIC model applied in this paper is a commercial model provided by WIN Semiconductors Corporation[7]. This includes an intrinsic transistor based on the Gummel–Poon model and a parasitic substrate transistor. Based on modifications and enhancements to that model, many second-order effects of modern transistors can be covered with the VBIC model. Figure 1 shows the equivalent circuit of a VBIC large signal model for the employed GaAs HBT. Advantages of the VBIC model include:

(1) accurate implementation of the base width modulation;

(2) parasitic substrate transistor;

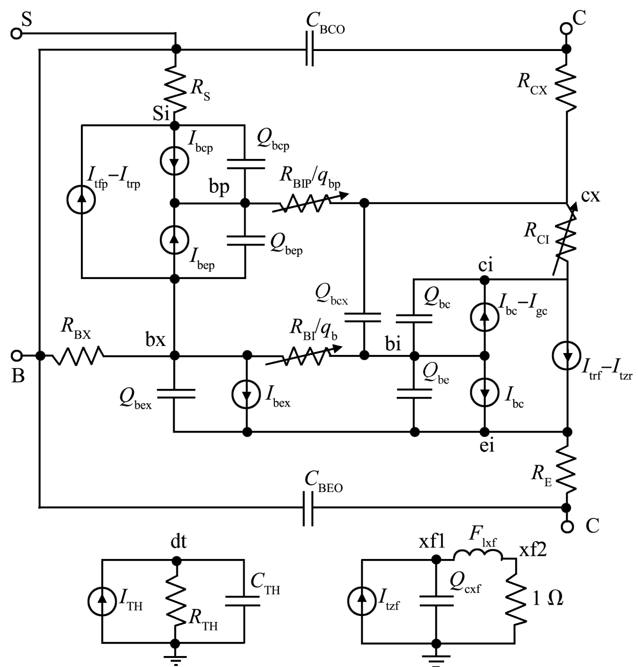

Fig. 1. The equivalent circuit of the VBIC large signal model.

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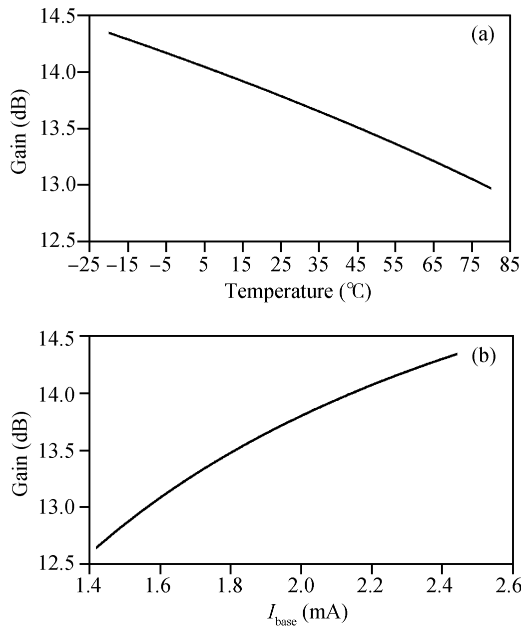

Fig. 2. (a) Small signal gain of an amplifier as a function of the ambient temperature. (b) Small signal gain of an amplifier varied with the base quiescent bias current.

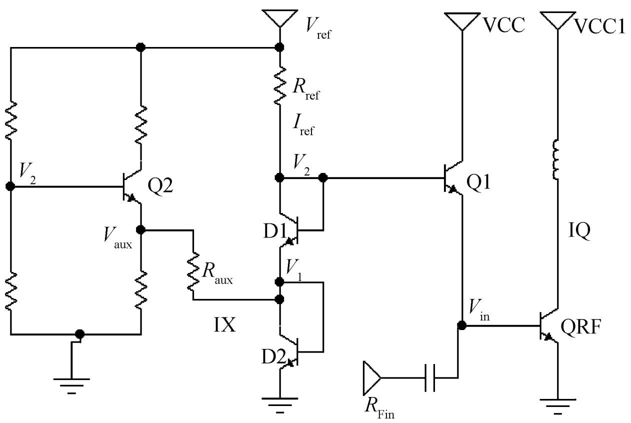

Fig. 3. Schematic of the emitter follower type of bias circuit with a temperature compensation circuit.

(3) improved Kull model for quasi-saturation;

(4) enhanced transit time modeling;

(5) approximation of the distributed base;

(6) weak avalanche current effects;

(7) consistent treatment of the additional phase shift at small-signal and transient analysis;

(8) improved space charge capacitance model;

(9) self-heating;

(10) improved temperature modeling.

In order to precisely describe the self-heating effect due to power dissipation and external ambient temperature change, the VBIC model includes a thermal network to link temperature dependent model parameters and the change in junction temperature, though the VBIC's completeness necessarily adds to the complexity of building the model.

3. Temperature compensation circuit

For thermal sensitivity of the InGaP/GaAs HBT, the gain of an RF power amplifier based on the InGaP/GaAs HBT will be impressible to the ambient temperature. Figure 2(a) shows the small signal gain of a single stage amplifier as a function of the ambient temperature. The gain declined rapidly with increasing ambient temperature, which is due to the trans-conductance of the HBT at the quiescent bias point decreased at higher temperature and increased at lower temperature. Figure 2(b) shows the small signal gain of the amplifier which operated at class AB varied with the base quiescent bias current. The gain increased significantly with the base quiescent bias current increasing appreciably, as a result of higher HBT trans-conductance at higher base quiescent bias current for the amplifier operated at class AB. Therefore, the trans-conductance must be varied to achieve constant gain in a temperature range between –20 and +80 ℃ by regulating the base bias current. For a power amplifier the temperature compensation circuit at the base bias terminal must be employed to vary the base quiescent current.

Figure 3 shows an InGaP/GaAs HBT power amplifier with a typical emitter follower type of bias circuit and an additional new temperature compensation circuit that is enclosed in a dashed box. For the emitter follower type of bias circuit, the base quiescent bias current of the amplifier is mainly controlled by voltage V_2 and input impedance of the emitter follower transistor Q1. The temperature compensation circuit regulates the voltage V_1 across the diode-connected transistor D2 in the bias circuit, so that the base voltage V_2 of the transistor Q1 and the base–emitter voltage V_{in} of the power transistor QRF vary sufficiently as the temperature changes. Appropriate values of the resistors are employed in the temperature compensation structure to ensure that V_{aux} is equal to V_1 at room temperature. V_{aux} decreases less than V_1 as the temperature increases, so additional current flows into node 1 from node aux owing to the voltage difference. Compared with the circuit without temperature compensation, the supplied current from node aux causes the decreased V_1 to rise, which in turn causes V_2 and the base–emitter voltage V_{in} of the transistor Q1 to increase. So the input impedance of the emitter follower transistor Q1 decreases. As a result, more base current of transistor Q1 is distributed from the reference current I_{ref}, though I_{ref} decreased for the lower V_2. Consequently, the base quiescent bias current of the power transistor QRF can be increased to the expected value at high temperature. On the other hand, as the temperature decreases, V_{aux} has a lower value than V_1, so the current flows from node 1 to node aux, and V_1, V_2, and V_{in} decrease in turn. Less base current of the transistor Q1 is distributed from the reference current I_{ref}. Hence, the increased quiescent current at low temperatures can be reduced. Additionally, to get the expected gain value at high temperature and/or low temperature, it is very important to employ an appropriate value for the auxiliary resistor R_{aux}, which is necessary to adjust the voltage difference of V_1 and V_{aux}.

4. Results and discussion

The presented temperature compensation circuit is applied to a wireless communication application power amplifier. Fig-

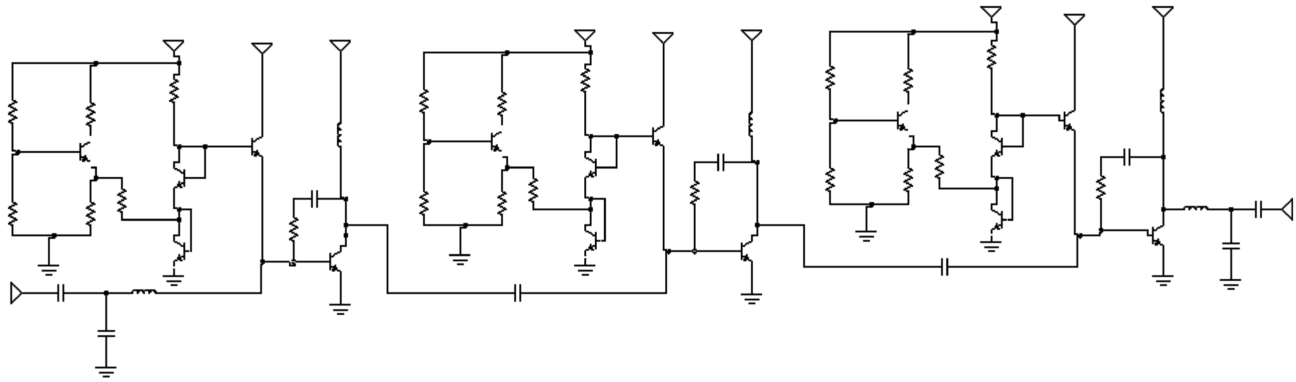

Fig. 4. Schematic of 3-stage integrated circuit power amplifier.

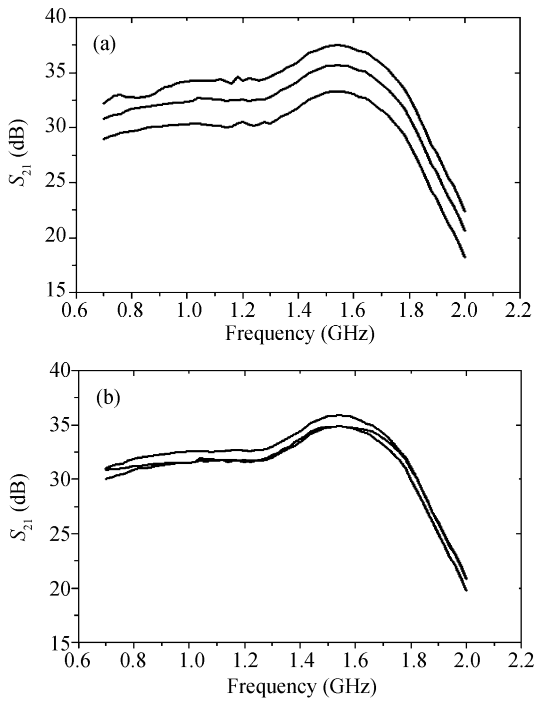

Fig. 5. Variation of small signal gain (S_{21}) at different temperatures.

ure 4 is a schematic diagram of a 3-stage integrated circuit power amplifier with the new temperature compensation circuit. It is necessary for the amplifier to simultaneously achieve both high efficiency and high gain. To achieve high efficiency, each of the 3 stage circuits is operated at class AB. The emitter area of each HBT is chosen to achieve high efficiency and low power consumption simultaneously. The compensation circuit is integrated into the power amplifier on a single InGaP/GaAs chip.

To verify the validity of the proposed temperature compensation circuit, the temperature characteristics of the on-chip power amplifier are measured. The measured small signal gain (S_{21}) of the MMIC amplifier with and without a temperature compensation circuit at ambient temperatures of –20, 25 and +80 ℃ is shown in Fig. 5. This clearly shows that the designed circuit compensates the gain variation with temperature. Figure 6 shows the measured gain variation with ambient temperature at a center frequency of 1540 MHz. Figure 6 shows that the gain variation of the power amplifier is improved from 4.0

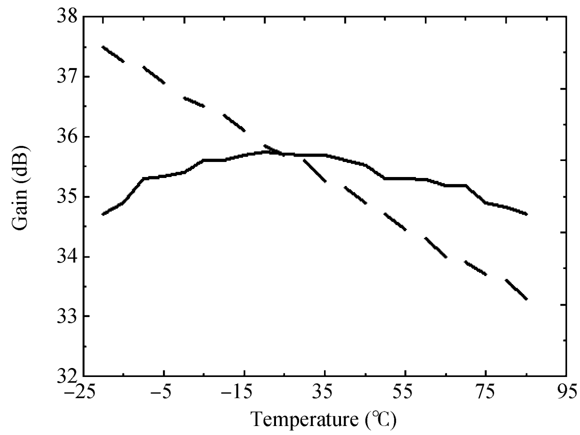

Fig. 6. Variation of small signal gain with temperature with and without a temperature compensation circuit (the solid line with a temperature compensation circuit, and the dashed line without a temperature compensation circuit).

to 1.1 dB in the temperature range between –20 and +80 ℃ by using the temperature compensation circuit. Therefore, the compensation circuit is suitable to compensate the gain variation of a RF power amplifier within a wide temperature range. Figure 7 shows the measured gain, efficiency and output power with temperature at the center frequency with and without temperature a compensation circuit. The variation in gain, efficiency and output power with temperature is reduced across a wide range of input power by using the presented new temperature compensation circuit. The power amplifier with temperature compensation has achieved saturation power of more than 36 dBm and operating power gain of more than 34 dB in the temperature range between –20 and +80 ℃.

5. Conclusion

The design of a temperature compensating circuit applicable to GaAs HBT RF power amplifiers is presented. The advantage of this circuit lies in the simplicity and on one chip with an amplifier, which allows the power amplifier to achieve better thermal characteristics with little degradation in performance. The variation in the gain of the amplifier with temperature is compensated by regulating the quiescent bias current at various temperatures. As a result of the temperature compen-

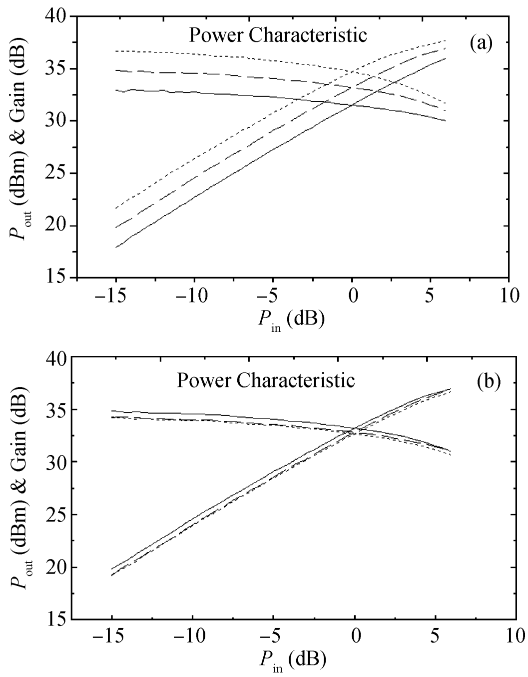

Fig. 7. Gain and output power at various temperatures with and without a temperature compensation circuit.

sation, the gain variation improves effectively. For a 3-stage integrated power amplifier with a small gain of 35.7 dB at the center frequency, the gain variation decreased from 4.0 to 1.1 dB in the temperature range between –20 and +80 ℃. It is suitable for the presented new compensation circuit to compensate the gain variation of any RF power amplifier, especially a wireless communication application power amplifier, within a wide temperature range.

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