Bias Circuits for GaAs HBT Power Amplifiers

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***Abstract* — This paper discusses the effects of process and temperature variations on the performance of GaAs HBT power amplifier bias circuits. A novel feedback bias circuit, which overcomes these problems, is presented. The measured variation from 54 to 60 mA in the bias current, over the temperature range of –25 to +85°C, agrees well with the simulations. The circuit is insensitive to variations in the regulated voltage which is a desirable feature in a case when the amplifier is biased to a constant current. On the other hand, a smooth bias and gain control can be achieved by adding an extra resistor connected to a separate control voltage.**

I. INTRODUCTION

The potential of the GaAs HBT power amplifiers for cellular phones has been clearly seen in 1990's [1] and today the technology is mature and ready for mass production.

The vertical structure of HBT is beneficial in achieving high current density. This provides higher power density and smaller device size compared to MESFET and HEMT amplifiers. However, the high power density emphasizes the role of the thermal design. One important aspect of the HBT power transistor design is the use of ballasting to avoid the collapse of current gain caused by the unbalance of the parallel cells [2]. Another issue, which can not be underestimated, is the design of bias circuits to fully utilize the excellent RF performance of the GaAs HBT technology. A modified current mirror type of bias circuit with a current sensing transistor has been used in [3] to provide an optimum condition for the power device as a function of temperature and output power.

In this paper we describe the properties of typical power amplifier bias circuits and present a novel feedback bias scheme which is insensitive to temperature, process, and bias voltage variations.

II. CIRCUIT DESCRIPTION

Fig. 1 shows a typical GaAs HBT power amplifier stage with a current mirror type of biasing, where the collector current I_c is controlled by the control current I_{pc}. The benefit of this one-V_{BE} circuit is its ability to operate from a low control voltage. The control characteristics of the circuit can be further improved if together with the control voltage V_{pc} also the regulated voltage available in the phone is utilized [4].

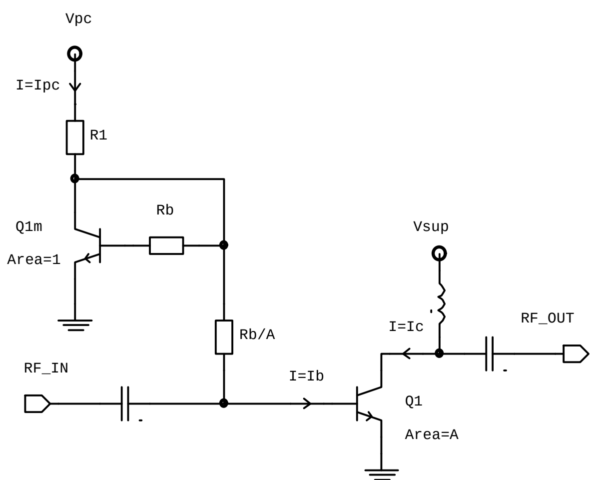

Fig. 1. A power amplifier stage with a current mirror bias circuit.

This circuit is more stable against temperature variations than the simple resistive biasing. However, the performance is affected by the mirror ratio A, temperature difference between the RF and bias transistors, and the operating current I_c.

Because of the large size of the power transistor the value of the base current is often so high that it exceeds the current feeding capability of the control source V_{pc}. In order to increase the current driving capacity of the bias circuit, a base current driver transistor Q_2 is used in the circuit of Fig. 2. A typical temperature compensation circuit is realized by employing two diode-connected transistors in series from the base of Q_2 to the ground [5]. If the layout is made carefully, this circuit keeps the quiescent current constant as a function of the temperature. This is, however, not necessarily the desired property, because usually the gain is the parameter, which should remain constant when temperature varies. This

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can be achieved by connecting a mirror transistor Q_{1m} as shown in Fig. 2. This circuit tends to increase I_c as temperature increases compensating the roll-off in dc-beta of the AlGaAs/GaAs HBT. This circuit works well in practise as has been demonstrated earlier in a push-pull GSM power amplifier [6].

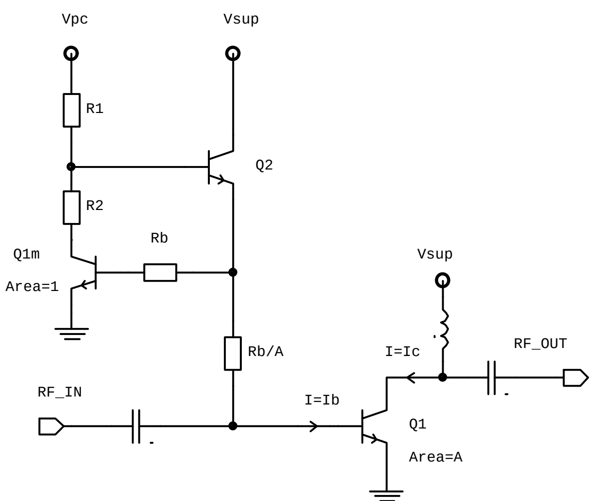

Fig. 2. A power amplifier stage with a base current driver [6].

The bias circuits described above have some useful properties but both of them are still lacking the precise control over temperature and process variations. Depending on the layout there can be a considerable temperature difference between the bias and RF transistors, which causes error to the bias current. These circuits have also another drawback, because the bias current I_c is sensitive to variations in the control voltage V_{pc}. For example, a GSM power amplifier output stage typically biased to the fixed bias current close to class B by using the regulated voltage V_{reg}, would suffer from variations in the bias current. To overcome these problems a new type of bias circuit based on the feedback has been proposed [7].

The core of this circuit, shown in Fig. 3, is similar to the one shown in Fig. 2. The base current I_b for the power transistor Q_1 is fed by the driver Q_2. Around this circuit there is a feedback loop which stabilizes the operating point. The basic version sets the current of Q_1 constant.

The power stage consists of transistors Q_1 and Q_{1m}, and Q_{1m} is used for sensing the bias current I_c. Because the base nodes of the transistors Q_{d1} and Q_{d2} forming a differential amplifier are at same potential, $V_1 = V_2$, and the collector current of Q_{1m} is

$$I_m = (V_{reg} - V_1)/R_3 \qquad (1)$$

where V_1 is the reference voltage defined by R_1, R_2, and V_{reg}. The collector current of Q_1 is as a first approximation $I_c = AI_m$, obtained by scaling the current of Q_{1m} by the mirror ratio A. An important issue, the stability of the control loop, is guaranteed by a proper selection of the values for R_f and C_f.

The current sensing cell formed by the base resistor R_b and the transistor Q_{1m} is identical to the power transistor cell formed by the unit cell transistor and the base resistor R_b that also serves a ballasting function. In the layout it is advantageous if Q_{1m} is a part of the power transistor, which guarantees that it is at the same temperature as the power transistor.

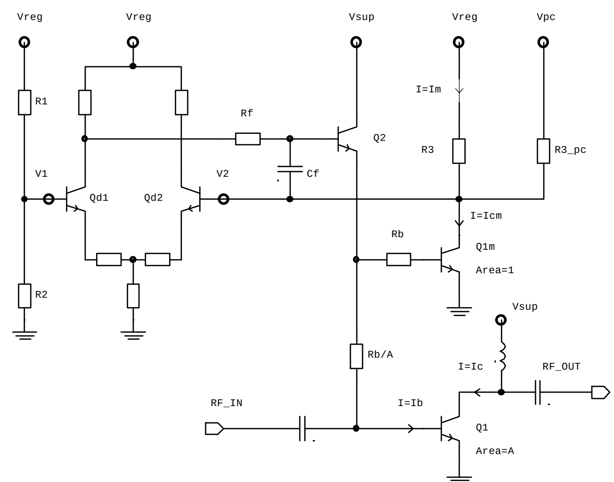

Fig. 3. A power amplifier stage employing feedback bias circuit.

The basic configuration sets a constant bias current, but by adding an extra resistor R_{3pc} in parallel with R_3 and connecting it to the control voltage V_{pc}, it is possible to vary the bias current and gain of the stage. In this case I_c is defined by the equation

$$I_c = A\,(V_{reg} - V_1)/R_3 + A\,(V_{pc} - V_1)/R_{3pc}. \qquad (2)$$

With this type of bias scheme it is possible to realize simultaneously an effective power switch-off operation and a smooth gain control without compromises [4].

Fig. 4 shows the simulated performance of the feedback bias circuit over the temperature range of –20 to +85°C when the value of regulated voltage is varied from 2.7 to 2.9 V. At a nominal V_{reg} value of 2.8 V the variation of the current over the whole temperature range is below 5 mA. Taking into account both temperature and V_{reg} variations the bias current I_c remains in the range of 52 – 60 mA. This guarantees that the output stage operates in the proper bias region in all conditions.

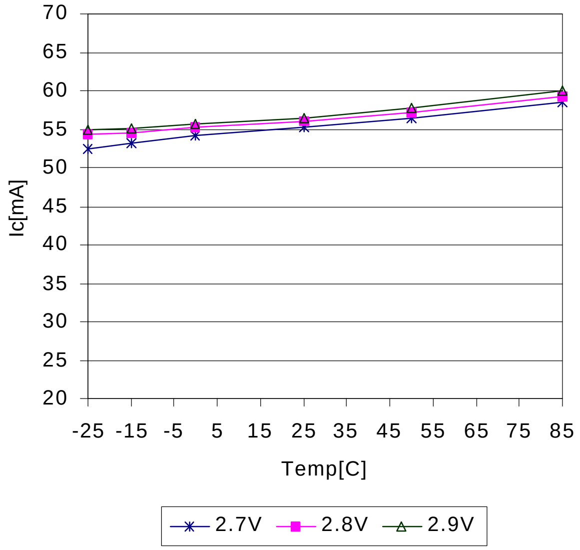

Fig. 4. Simulated bias current of the circuit in Fig. 3 as a function of temperature at three different values of Vreg.

The effect of the process variations is presented in Fig. 5, which shows the simulated performance when the dc current gain β_0 varies within the limits of the process variations.

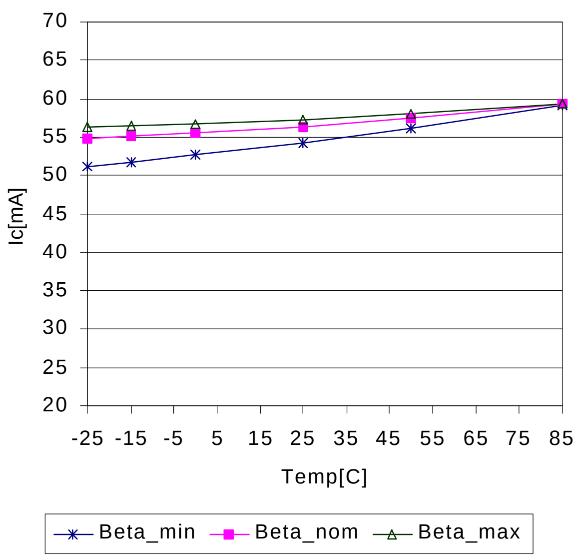

Fig. 5. Simulated bias current of the circuit in Fig. 3 as a function of temperature at minimum, nominal, and a maximum value of dc current gain.

The value of I_c is almost constant at high temperatures and the highest variation of 5 mA occurs at -25°C.

III. RESULTS

Measurements were made for all the three bias topologies described in the previous chapter. These circuits have been used in push-pull WCDMA power amplifiers fabricated in a commercial GaAs HBT process.

Fig. 6 shows the measured performance as a function of the temperature. The supply voltage has been 3.5 V in all measurements. The simple current mirror bias shows a high sensitivity to temperature and the bias current drops from 69 mA (-25°C) to 27 mA (+85°C). The change vs. temperature is larger than the simulated one and it is also in the wrong direction.

The circuit of Fig. 2 shows also a considerable variation of 36 mA, but it is in the right direction compensating the gain drop of the transistor at high temperatures. In this case the simulated and measured performance agreed well. It was therefore possible to utilize this feature in the WCDMA amplifier design despite the fact that the circuit slightly overcompensates the gain roll-off.

The best performance was achieved with the feedback bias circuit as can be expected from the simulated performance. Also in this case the measured performance agrees very well with the simulated one (Fig. 4) and the bias current varies from 54 mA (-25°C) to 60 mA (+85°C).

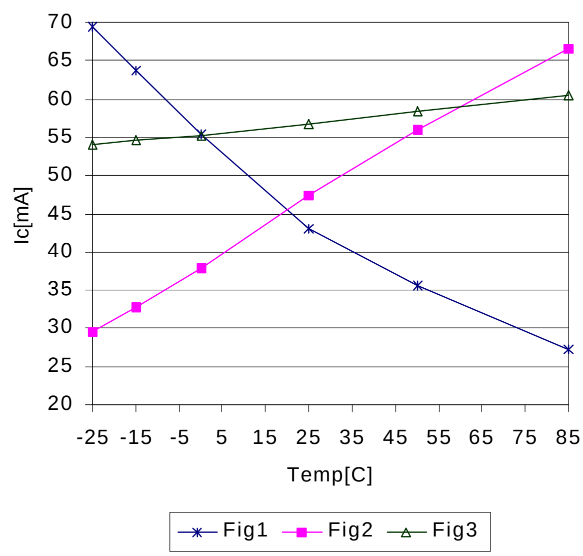

Fig. 6. Measured bias current of the circuits in Figs. 1-3 as a function of temperature.

Typically the output stage of a WCDMA power amplifier is biased to class AB with a fixed bias current. In that case it is desirable if the quiescent current is insensitive to bias voltage variations. Fig. 7 shows the sensitivity of the bias circuits to the variations in the bias voltage, which in this case has been the regulated voltage. The circuit of Fig. 2 has the highest variation of 31 mA when the regulated voltage has been varied from 2.7 to 2.9 V. The simple current mirror shows a reasonable performance, the variation is only 5 mA. The performance of the feedback bias circuit is excellent as the bias current remains constant (57 mA) over the whole voltage range.

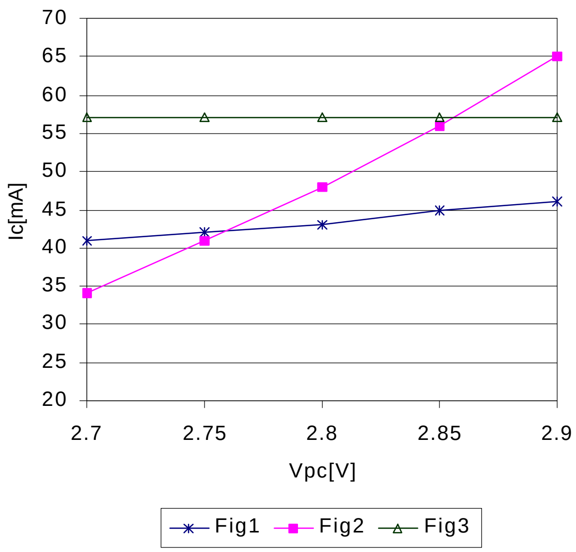

Fig. 7. Measured bias current of the circuits in Figs. 1-3 as a function of bias voltage at room temperature +25 °C.

IV. CONCLUSION

A new bias circuit for power amplifiers was presented. The circuit is less sensitive to process and temperature variations than the conventional solutions. The measured bias current of the output stage of a WCDMA power amplifier varied from 54 mA to 60 mA over temperature range of -25°C to +85°C. The circuit is also insensitive to variations in the regulated voltage which is a desirable feature in the case when the amplifier is biased to a constant current. On the other hand, a smooth bias and gain control can be achieved by adding an extra resistor connected to a separate control voltage.

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REFERENCES

[1] F. Ali, A. Gupta, A. Higgins, "Advances in GaAs HBT power amplifiers for cellular phones and military applications," *1996 IEEE MTT-S Microwave Symp. Dig.*, pp. 61-66, June 1996.

[2] W. Liu, A. Khatibzadeh, J. Sweder, H-F. Chau, "The use of base ballasting to prevent the collapse of current gain in AlGaAs/GaAs heterojunction bipolar transistors," *IEEE Trans. Electron Devices*, vol. ED-43, no. 2, pp. 245-251, February 1996.

[3] P. Walters, P. Lau, K. Buehring, J. Penney, C. Farley, P. McDade, K. Weller, "A low cost linear AlGaAs/GaAs HBT MMIC power amplifier with active bias sensing for PCS applications," *IEEE GaAs IC Symposium Digest*, pp. 67-70, October 1995.

[4] E. Järvinen, "GaAs HBT power amplifier with smooth gain control characteristics," *Proceedings of the 1998 IEEE Radio and Wireless Conference.* Colorado Springs, Colorado, pp. 321-324.

[5] H. Asano, S. Hara, S. Komai, "A 900 MHz HBT power amplifier MMICs with 55% efficiency, at 3.3 V operation," *1998 IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 1, pp. 205-208, June 1998.

[6] M. Matilainen, K. Nummila, E. Järvinen, S. Kalajo,"An integrated 900-MHz push-pull amplifier for mobile applications," *2000 IEEE MTT-S Microwave Symp. Dig.*, vol. 2, pp. 861-864, June 2000.

[7] E. Järvinen, "Radio frequency amplifiers," US Patent 6,052,032, April 18, 2000.