Temperature Insensitive PA Bias Circuit With Digital Control Interface Using InGaP/GaAs HBT Technology

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***Abstract*— This paper demonstrates a new temperature insensitive bias circuit using a Wilson current mirror for the InGaP/GaAs HBT power amplifier. The Wilson current mirror has a high impedance node for connecting an on/off digital interface and a stable voltage node for injection of feedback signals to achieve a temperature insensitive bias. The fabricated output stage of the power amplifier with the feedback through the Wilson current source shows a stable bias current with current variation from 186 mA to 182 mA for the temperature range from 25 °C to 200 °C. A bias circuit without the feedback through the Wilson current source is also fabricated for comparison and shows a strong bias current variation over temperature.**

Keywords—InGaP/GaAs HBT, temperature insensitive, power amplifier, Wilson current mirror.

I. Introduction

It is well known that InGaP/GaAs heterojunction bipolar transistors (HBTs) with high current density are widely used for radio frequency (RF) power amplifiers to achieve high output power and high linearity performance. A power amplifier dominates the power consumption in a wireless system and thus gets heated up significantly because of the large power dissipation. It is desirable to keep the bias current constant even at elevated temperature to maintain the power performance. Several researches proposed different design methods to maintain the bias current when self-heating effect and the ambient temperature variation occur [1]-[4].

It is also desirable to have a digital interface for standby and power-down modes of the power amplifier in many applications. In this work, we propose a temperature insensitive bias circuit with an on/off digital interface to bias an InGaP/GaAs HBT power amplifier at a constant collector current for a wide range of temperature variation. The circuit design is described in section II and the experimental results for temperature range from 25 °C to 200 °C are given in section III.

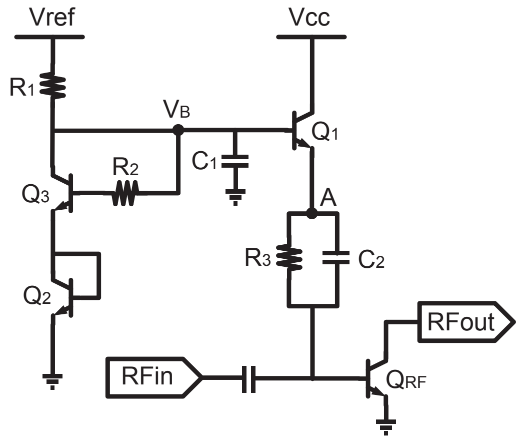


Fig. 1. Schematic of a typical linearization and temperature-insensitive biasing circuit for a power amplifier.

II. Circuit Description

Fig.1 shows a typical temperature insensitive bias network with the power amplifier stage Q_{RF}. Here, the Darlington connected Q_1 and Q_{QF} together with the shunt capacitor C_1 and and bypass C_2 are employed to improve the linearity of the power amplifier by increasing both the base-emitter voltage and the collector current of Q_{RF} while input power increases [3]-[5]. Q_3 is in series with the diode-connected Q_2 to form twice of the base-emitter junction voltage at the base of Q_1 to guarantee the base-emitter junctions of Q_{RF} and Q_1 are sufficient to be operated. Thus, Q_1 and Q_3 form a current mirror to provide the base current of the Q_{RF}. The biasing resistors, R_1, R_2 and R_3, in the biasing path also provide the temperature insensitive function for the collector current of Q_{RF}. A large collector current due to high temperature is compensated by the increasing voltage drop over the resistors to bring down the collector current. The bypass capacitor of C_2 restores the linearizing mechanism and the resistors of R_2 and R_3 are designed to maintain the current mirror function.

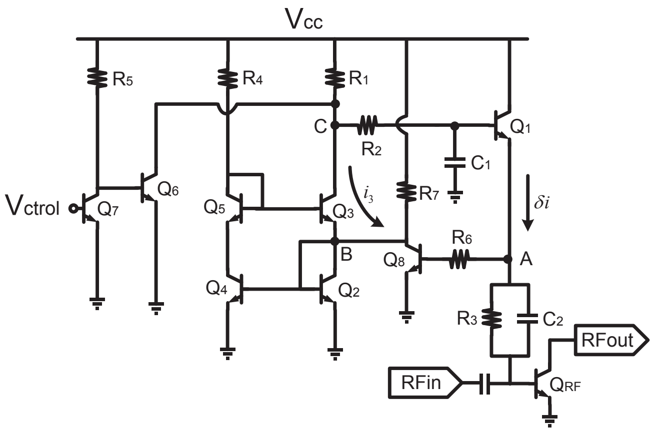


Fig. 2. Schematic of the proposed temperature insensitive biasing circuit with an on/off digital interface. The temperature insensitive feedback is injected at the collector of the diode-connected transistor in the Wilson current mirror.

The biasing circuit in Fig. 1 can be turned on and off through the Vref terminal. However, it normally takes tens mA and about 2.8 V (two times of base-emitter junction voltage) to turn on the power amplifier and thus the Vref terminal is incompatible with the low-current digital interface. Thus, a new temperature-insensitive biasing circuit with an on/off digital interface for InGaP/GaAs HBT technology is proposed and shown in Fig. 2. The Wilson current source formed by Q_2, Q_3, Q_4 *and* Q_5 plays an important role to stabilize the collector biasing current of Q_{RF} at the elevated temperature. The Q_7/R_5 and Q_6/R_1 form digital inverters based on the common emitter topology and connect to the high impedance node of the Wilson current source as an on/off digital interface. The biasing path through R_4 and base-emitter junctions of Q_2, Q_3, Q_4 *and* Q_5 makes the voltage at point B less sensitive to temperature. Moreover, the diode-connected configuration in point B forms a low impedance node. Thus, point B is employed as a feedback injection point for temperature insensitive feedback circuit.

The feedback is formed by sampling the voltage at node A, passing through a common emitter amplifier of Q_8 and R_7 and injecting to point B of constant voltage. The temperature insensitive feedback mechanism is as follows. The voltage at node *A* increases when the biasing current of Q_{RF} increases due to the temperature increase. The bias voltage at the base of sensing transistor Q_8 increases and drives more collector current. Yet the voltage at node *B* is fixed. Thus, the collector current of Q_3 increases to bring the voltage at node C down. Consequently, the biasing current of Q_{RF} is lowered through the feedback mechanism.

Fig. 3 shows the simulated result of the proposed feedback biasing circuit. For the temperature ranges from 0 °C to 200 °C, the variation of the collector current Ic of the PA core cell is less than 4% when compared with the desired current while the supply voltage Vcc is varied from 4.9V to 5.1V. Moreover, it has to take process variations into consideration. Fig. 4 shows the simulated performance under different values of dc current gain β. It shows that by the feedback topology, when β varies ±20%, the variation of Ic is less than 5.5% at all temperatures. Thus, the bias circuit can properly give the insensitive value of Ic against temperature, supply voltage, and process variation at the same time.

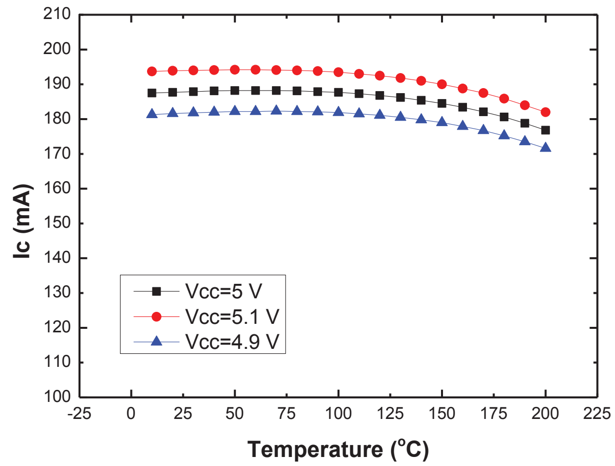


Fig. 3. Simulated collector bias currents for different temperatures at different values of Vdd.

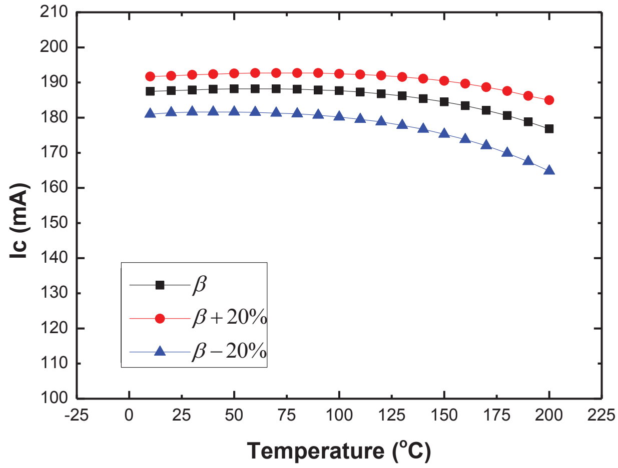


Fig. 4. Simulated collector bias currents for different temperatures at different variations of beta.

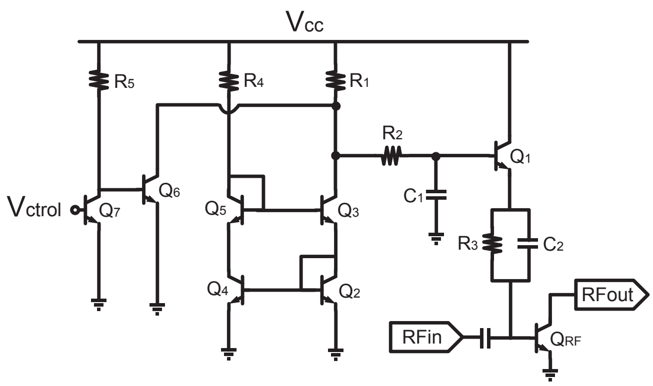
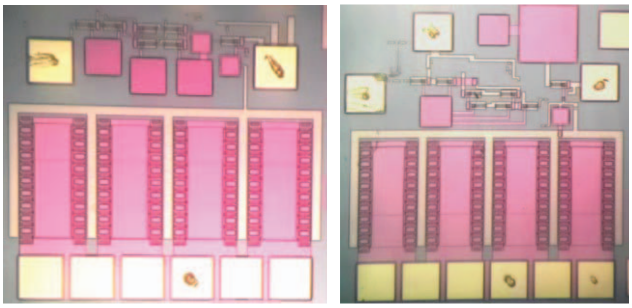


Fig. 5. Schematic of the proposed temperature insensitive biasing circuit with an on/off digital interface when the temperature insensitive feedback is taken away.

III. Measurement Result

The biasing circuit shown in Fig. 2 is fabricated and a biasing circuit without the feedback mechanism as shown in Fig. 5 is also fabricated in this paper for comparison purpose. Both of the two bias topologies employ the on/off switch function and Wilson current mirror. The die photo of the temperature insensitive bias circuits with/without feedback for power amplifier are shown in Fig. 6. The power stage Q_{RF} of InGaP/GaAs HBT is demonstrated using transistor of 80 fingers. The emitter size of each finger is 1×20 um^2. The supply voltage is 5 V and the desirable collector current is set at 183 mA for the power amplifier design. The DC collector current of the power stage HBT was measured over a temperature range from 25 °C to 200 °C and is shown in Fig. 7. As shown in Fig. 7, the bias current without feedback shows 38% variation from 25 °C to 200 °C and declines considerably after 125 °C. The bias current variation is about 5.8% from 25 °C to 100 °C. On the other hand, the bias circuit with temperature insensitive feedback shows less than 2% variation in collector current from 25 °C to 200 °C. Moreover, the on/off switch is successfully functional as shown in Fig. 8 and Fig. 9. The V_{ctrol} voltage shown in Fig. 8/Fig. 9 is compatible with the low-current digital interface. Finally, table I shows the comparison of different works.



(a) (b)

Fig. 6. Die photo of the proposed temperature insensitive bias circuits (a) without feedback and (b) with feedback topology.

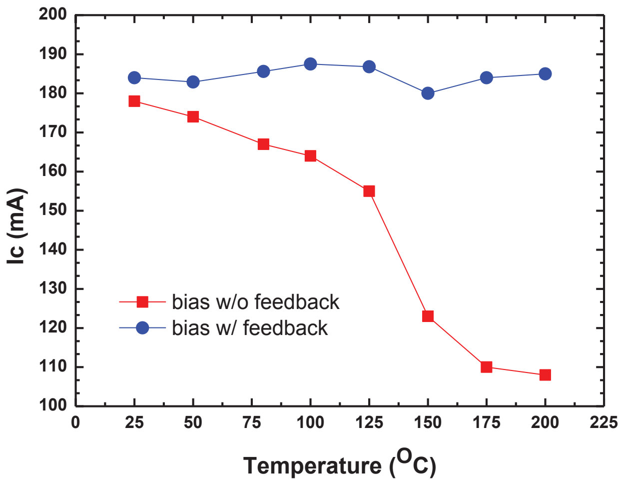


Fig. 7. Measured collector bias currents for different temperatures.

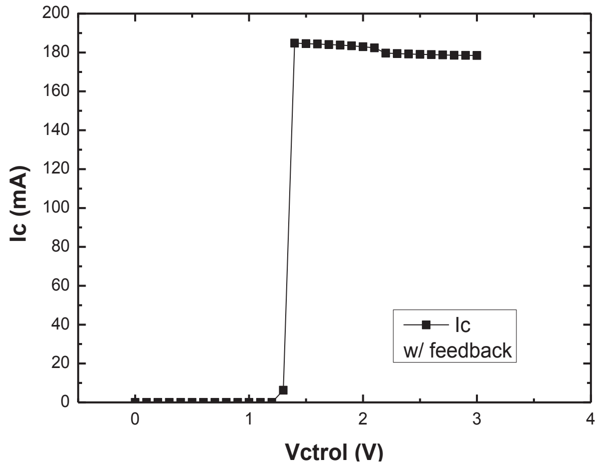


Fig. 8. Measured collector current as a function of V_{ctrol} for the bias circuit with feedback.

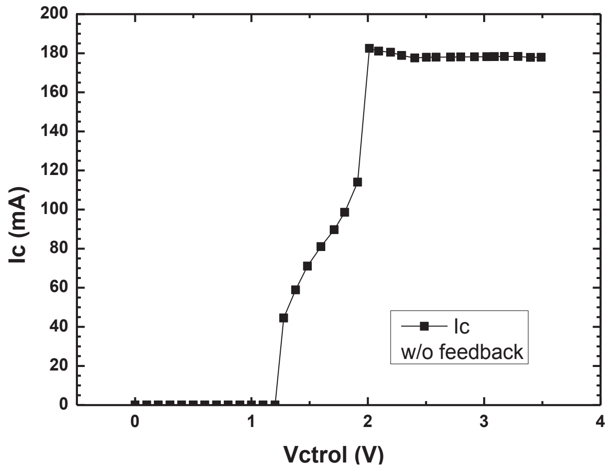


Fig. 9. Measured collector current as a function of V_{ctrol} for the bias circuit without feedback.

TABLE I

PERFORMANCE COMPARISONS

Reference	Technology	Temperature variation (℃)	Current Deviation (%)
w/ feedback	**GaAs HBT**	**25~100/ 25~200**	**<2/<2**
w/o feedback	**GaAs HBT**	**25~100/ 25~200**	**<5.8/<38**
[4]	GaAs HBT	-10~90	<8.3
[2]	GaAs HBT	-25~85	<10.9
[1]	SiGe HBT	0~85	<10

IV. Conclusion

A temperature insensitive bias circuit for power amplifiers based on feedback through a Wilson current source is analyzed and implemented using InGaP/GaAs HBT process. With this temperature compensation circuit, the resulting current variations is less than 2% over temperature range of 25 ^{o}C to 200 ^{o}C.

Acknowledgment

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