High P_{1dB} and Low Quiescent Current SiGe HBT Power Amplifier MMIC Using Self Base Bias Control Circuit for 5.8GHz ETC Terminals

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***Abstract* — A 5.8GHz high P_{1dB} and low quiescent current SiGe HBT three-stage power amplifier (PA) MMIC using a self base bias control circuit is described. The self base bias control circuits are applied to the second and the final stage PA's, and automatically control the base current/voltage according to the output power level. As a result, high P_{1dB} is obtained at a low quiescent current condition. The simulated results show that the proposed three-stage PA MMIC achieves P_{1dB} improvement of 1.7dB compared with a conventional PA using a constant base voltage bias circuit at the same quiescent current condition. The fabricated PA MMIC achieves P_{1dB} of 15.3dBm, gain of 19.6dB with the quiescent current of 22.2mA at 5.8GHz.**

I. INTRODUCTION

Low cost and small size have been required for wireless communication terminals, such as 5.8GHz Electronic Toll Correction system (ETC) terminals in Japan [1],[2]. Si-based MMIC's have been focused as strategic devices to realize low production cost and high level of integration for these proposes [3],[4]. Recently, SiGe HBT PA's for 0.8-2GHz cellular phones have been reported, and they show the feasibility of system on a chip including PA [5]. To obtain higher gain at 5-6GHz band, the breakdown voltage of SiGe HBT becomes lower, and the P_{1dB} is not enough even for the PA's of 5.8GHz ETC terminals (P_{1dB} =13-15dBm) [2]. Therefore, circuit techniques which improve the P_{1dB} of 5-6GHz band SiGe HBT PA's are desired.

In this paper, a SiGe HBT three-stage PA MMIC using a self base bias control circuit for 5.8GHz ETC terminals is described. Since this bias circuit is small and does not need an external control circuit, it is easy to adopt it to a transceiver MMIC. The self base bias control circuits are applied to the second and the final stage PA's. Since these PA can automatically increase their base current/voltage at the high output power level, they can realize higher P_{1dB} compared with a conventional PA having a constant base voltage circuit at the same low quiescent current condition. Based on the simulated and measured transfer characteristics of final stage and three-stage PA's, P_{1dB} improvement mechanism is analyzed.

II. OPERATION PRINCIPLE

Figure 1 shows the schematic diagram of an amplifier with a self base bias control circuit. In this figure, Q1 is the RF transistor, Q2 is the bias transistor which composes a current mirror with Q1, and Q3 is the transistor for base current compensation. The dotted area shows a darlington circuit which is equivalent to a pnp bipolar junction transistor (BJT). A pair of darington circuits composes a current mirror. By using the darlington circuit, the gain factor becomes high as follows

$$\beta = \beta_1 \cdot \beta_2 + \beta_1 \quad (1),$$

where β, β_1 and β_2 are gain factor of Q4, Q4-1 and Q4-2, respectively. The current handling capability is limited for lateral-pnp BJT and several tenth μA. In order to realize pnp current mirror for PA's having several hundred μA capability, a darington circuit is applied.

When the base current I_{be} of Q1 increases to $I_{be} + \Delta I_{be}$ at the high output power level, the reference current I_{ref} increases by the pnp current mirror. The base current I_{bdc1} of Q2 also increases, and thus the additional I_{be} is supplied to Q1. Consequently, the base current also increases according to the additional I_{be}. As a result, the final current increase ΔI_{be} (final) is represented as follows

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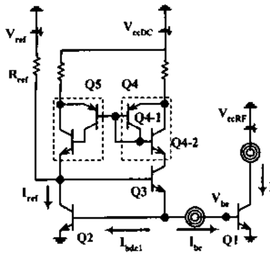


Fig. 1 Schematic diagram of an amplifier with a self base bias control circuit.

$$\Delta I_{be}(final)=\sum_{n=0}^{\infty}(\frac{M\cdot N}{\beta-M})^n\cdot\Delta I_{be} \qquad (2),$$

where N is the current mirror ratio of Q1/Q2, and M is that of Q5/Q4. The final voltage increase ΔV_{be} (final) becomes as below

$$\Delta V_{be}(final)=\frac{q}{nkT}\cdot\ln\left(1+\frac{1}{I_s\cdot e^{qV_{be}/nkT}}\cdot\sum_{n=0}^{\infty}(\frac{M\cdot N}{\beta-M})^n\cdot\Delta I_{be}\right) \qquad (3),$$

where q is electron charge, k is Boltzman's constant, T is the temperature and I_s is saturation current. In the case of a conventional amplifier with a constant voltage base bias circuit, ΔI_{be} (final) and ΔV_{be} (final) are expressed by the following equations,

$$\Delta I_{be}(final)=\Delta I_{be} \qquad (4)$$

$$\Delta V_{be}(final)=0 \qquad (5).$$

From Eqs. (2) and (4), it is shown that the additional base current occurs by the self base bias control circuit since the coefficient in Eq. (2) is always greater than unity at $\beta > M$. From Eqs. (3) and (5), it is also shown that the base voltage increases at high output power level.

Figure 2 shows the simulated I_{be} and V_{be} of a conventional and a proposed amplifiers. The current mirror ratio N is set to 10, M is set to 1. As shown in Fig. 2, I_{be} of the proposed amplifier is higher than that of the conventional amplifier at high input power level. The additional increase of I_{be} is about 10% of ΔI_{be} as shown in Eq. (2). Also, V_{be} of the proposed amplifier increases according to the output power level, whereas that of the conventional amplifier is almost constant. Therefore high P_{1dB} can be realized by applying the self base bias control circuit.

III. DESIGN AND MEASUREMENT

A. FINAL STAGE PA

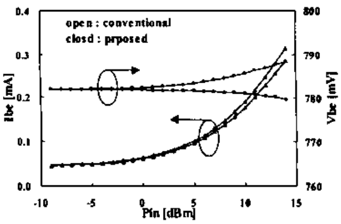


Fig. 2 Simulated I_{be} and V_{be} of a conventional and a proposed amplifiers.

Figure 3 shows the simulated transfer characteristics of the proposed and the conventional final stage PA's at 5.8GHz. Figure 3(a) shows the simulated collector current, and Fig. 3(b) shows the simulated output power and gain. The schematic diagram of the proposed final stage PA is shown in Fig. 1. The emitter size of Q1 is 192μm^2, and the quiescent current is 11.0mA, power supply voltage is 3.3V. During the simulation of the conventional final stage PA, the self base bias control circuit shown in Fig.1 is replaced with a constant voltage base bias circuit. As shown in Fig. 3(a), I_{ce} of the proposed final stage PA is higher than that of the conventional final stage PA at the high input power level. As a result, as shown in Fig. 3(b), P_{1dB} improvement of 1.8dB is realized by using the self base bias control circuit on the same quiescent current condition. The P_{1dB} of the proposed final stage PA is 16.0dBm.

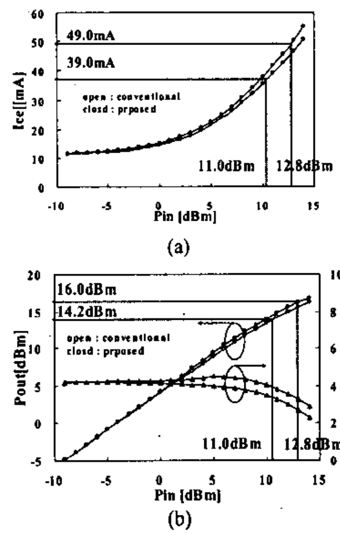


Fig. 3 Simulated transfer characteristics of the proposed and the conventional final stage PA's.

(a) collector current

(b) output power and gain

Figure 4 shows the measured transfer characteristics of the proposed final stage PA. Figure 4(a) shows the measured collector current, and Fig. 4(b) shows the measured output power and gain. The quiescent current is 11.0mA. As shown in Fig. 4(a) and (b), P_{1dB} of 15.6dBm, gain of 4.3dB and collector current of 49.8mA are achieved at 5.8GHz. These results are in agreement with the simulated results. It is confirmed that P_{1dB} is improved by applying the self base bias control circuit.

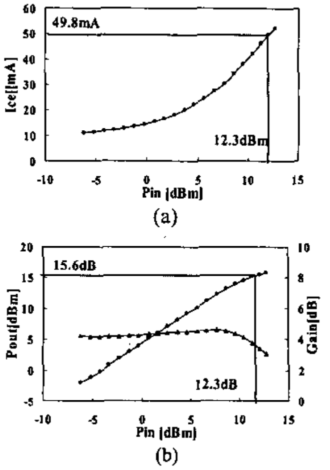


Fig. 4 Measured transfer characteristics of the proposed final stage PA.
(a) collector current
(b) output power and gain

B. THREE-STAGE PA

Figure 5 shows the schematic diagram of the proposed three-stage PA. The self base bias control circuits are applied to the second and the final stage PA's. To realize high gain at 5.8GHz, the differential types are applied for the first and second stage PA's. The emitter size of the first, the second and the final stage PA's are 32μm^2, 128μm^2 and 192μm^2, respectively. The quiescent currents are 4.4mA, 6.8mA and 11.0mA, respectively.

Figure 6 shows the simulated transfer characteristics of the proposed and the conventional three-stage PA's at 5.8GHz. Figure 6(a) shows the simulated total collector current, and Fig. 6(b) shows the simulated output power and gain. During the simulation of the conventional three-stage PA, the constant voltage base bias circuits are applied to all stages. As shown in Fig. 6(a), the total collector current of the proposed three-stage PA is higher than that of the conventional three-stage PA at the high input power level. The gain characteristic of the proposed

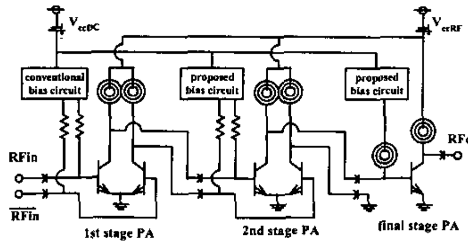


Fig. 5 Schematic diagram of the proposed three-stage PA.

three-stage PA is improved as shown in Fig. 6(b). The P_{1dB} improvement is 1.7dB, and the proposed three-stage PA realizes P_{1dB} of 15.8dB. These results agree with the simulated results of the final stage PA shown in Fig. 3.

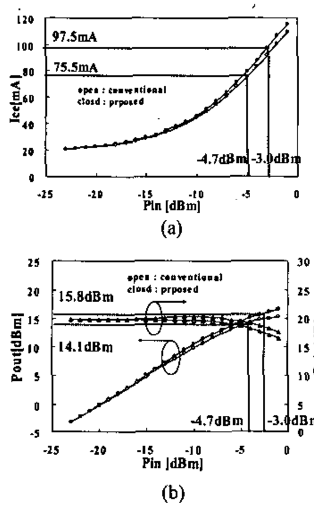


Fig. 6 Simulated transfer characteristics of the proposed and the conventional final stage PA's.
(a) total collector current
(b) output power and gain

Figure 7 shows the layout of the proposed three-stage PA. The PA is fabricated by using SiGe HBT technology. The chip size is 1mm x 2mm. The spiral inductors and poly-poly capacitors are used. To reduce the gain decrease by connecting wires between emitter electrode and ground pad, the final stage PA has four ground pads.

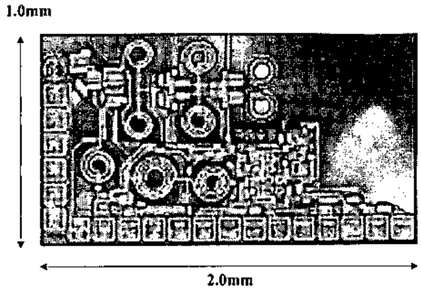
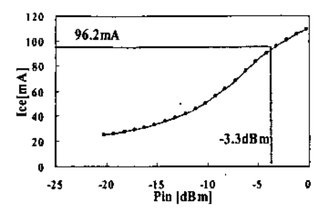
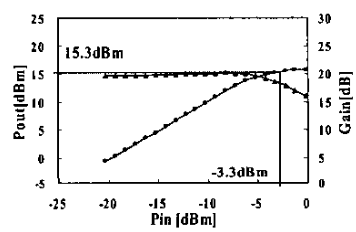


Fig. 7 Layout of the proposed three-stage PA.

Figure 8 shows the measured transfer characteristics of the proposed three-stage PA. Figure 8(a) shows the measured total collector current, and Fig. 8(b) shows the measured output power and gain. The quiescent current of the final, second and first stage PA's are 11.0mA, 6.8mA and 4.4mA, respectively. As shown in Fig. 8(a) and (b), P_{1dB} of 15.3dBm, gain of 19.6dB and collector current of 96.2mA are achieved at 5.8GHz.



(a)



(b)

Fig. 8 Measured transfer characteristics of the proposed three-stage PA.

(a) total collector current

(b) output power and gain

Table 1 shows the comparison between simulation and measurement. The measured gain, P_{1dB} and I_{ce} agree with simulation as shown in this table.

Table 1 Comparison between simulation and measurement.

			Gain[dB]	P1dB[dBm]	Ice[mA] @P1dB
Final Stage PA	Simulation	Conventional	4.2	14.2	39.0
		Proposed	4.2	16.0	49.0
	Measurement	Proposed	4.3	15.6	49.8
Three-Stage PA	Simulation	Conventional	19.8	14.1	75.5
		Proposed	19.8	15.8	97.5
	Measurement	Proposed	19.6	15.3	96.2

IV. CONCLUSION

A high P_{1dB} and low quiescent current SiGe HBT three-stage PA MMIC using the self base bias control circuit for 5.8GHz ETC terminals was described. The self base bias control circuit automatically controls base current/voltage according to the output power level and realize high P_{1dB} at a low quiescent current condition. Since this bias circuit is small and does not need an external control circuit, it is easy to adopt it to a transceiver MMIC. The simulated results showed that the proposed three-stage PA MMIC realizes P_{1dB} improvement of 1.7dB compared with the conventional PA using a constant voltage base bias circuit on the same bias condition. The fabricated PA MMIC achieved P_{1dB} of 15.3dBm, gain of 19.6dBm with the quiescent current of 22.2mA at 5.8GHz.

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