A Compact Ku-Band SiGe Power Amplifier MMIC With On-Chip Active Biasing

Y. S. Noh, M. S. Uhm, and I. B. Yom

Abstract—**A Ku-band power amplifier monolithic microwave integrated circuit (MMIC) with an output power density of 726 mW/mm^2 is demonstrated using 0.25 μm SiGe BiCMOS technology. No inductor matching scheme is applied to minimize the MMIC size, but an active biasing topology is used to enhance the power-added efficiency (PAE) and linearity of the MMIC. The fabricated one-stage cascode power amplifier MMIC, including input/output matching and biasing circuits, has a compact size of 0.384 mm^2 (0.6 mm $\times$ 0.64 mm), and exhibits a saturated output power (Psat) of 24.45 dBm and a PAE of 29.1 % at 14 GHz.**

Index Terms—**Cascode, heterojunction bipolar transistor (HBT), Ku-band, power amplifier (PA), silicon germanium (SiGe).**

I. Introduction

SILICON germanium (SiGe) BiCMOS technology has been a very attractive candidate for multi-function monolithic microwave integrated circuits (MMICs) for phased-array antenna systems from the X- to Ka-band [1], [2]. However, the low breakdown voltage (collector-emitter breakdown voltage, $\mathrm{BV_{CEO}}$) of hetero-junction bipolar transistors (HBTs) is a main drawback of the power amplifier design [2]–[5].

There have been some researches focused on overcoming the above problem. A hybrid cascode topology (a high-speed device for a common-emitter and a high-breakdown device for a common-base) [3] generated high gain and high output power characteristics. A common-base (CB) topology [5] has been introduced to increase the voltage swing for obtaining a high output power because the collector-base breakdown voltage $(\mathrm{BV_{CBO}})$ is higher than the collector-emitter breakdown voltage $(\mathrm{BV_{CEO}})$. Passive network compensation [2] enlarged the effective collector-emitter breakdown voltage.

In this letter, we propose a cascode power amplifier MMIC that is fully matched with an active bias circuit. Only high-speed HBTs are used for the cascode configuration of a small MMIC size, exhibiting a 726 mW/mm^2 output power density and 29.1 % power added efficiency (PAE). To our knowledge, these values are the highest in SiGe HBT power amplifiers.

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TABLE I
HBT Characteristics

Devices	f_T	BV_{CEO}	J_C @peak f_T
HS HBT	120 GHz	2.3 V	5 mA/μm^2
HV HBT	45 GHz	5.0 V	1 mA/μm^2

II. SiGe/Si HBT and Cascode Configuration

The hybrid cascode structure [3], which is composed of a common-emitter (CE) with high-speed (HS) HBTs, and a common-base with high-breakdown voltage (HV) HBTs, was used because the collector-base breakdown voltage $(\mathrm{BV_{CBO}})$ is higher than the collector-emitter breakdown voltage $(\mathrm{BV_{CEO}})$. Generally, the current density $\mathrm{J_C}$ for peak $\mathrm{f_T}$ of HS is 2–10 times greater than for HV devices. Thus, the emitter area of HV HBTs should be several times larger than that of HS HBTs because the collector current of both HBTs should be the same.

Table I shows the HS and HV HBT characteristics of a commercial 0.25 μm SiGe BiCMOS process. The 5 V $\mathrm{BV_{CEO}}$ of an HV HBT is helpful for high output power, but $\mathrm{J_C}$ of an HV HBT is 5 times smaller than that of an HS HBT, requiring a 5-times larger emitter area. So the output power, PAE, and output power density of HS HBT are higher than those of HV HBT with the same emitter area. The loadpull simulation results using the cascade topology with emitter area of 45.16 μm^2 reveal the saturated output power and PAE with HS (HV) HBTs of 25.0 dBm (21.63 dBm) and 40.4 % (21.12 %) under supply voltage of 4.0 V (8.0 V).

In this work, we used only HS HBTs for the cascode configuration to reduce the MMIC size, and to maximize the PAE and output power, simultaneously.

III. Ku-Band Power Amplifier Design

The Ku-band power amplifier is designed in a commercial 0.25 μm SiGe BiCMOS technology. The unit emitter area of a HS HBT is 0.42×0.84 μm^2 (0.3528 μm^2). For a cascode active core, 128 fingers of HS HBT ($128 \times 0.42 \times 0.84$ μm^2, 45.16 μm^2 in total) are used for both common-emitter (CE, Q1) and common-base (CB, Q2) transistors, as can be seen in Fig. 1. And an active base bias transistor Q3 in the bias circuit employs 8 fingers of HS HBT ($8 \times 0.42 \times 0.84$ μm^2, 2.82 μm^2 in total). Input and output matching circuits are composed of MIM capacitors and on-chip microstrip lines with top thick-metal lines. To design the power amplifier with a compact size, no spiral inductors are used for the matching circuits.

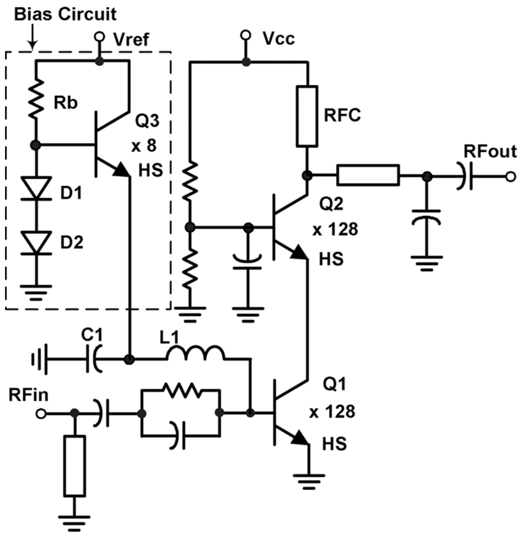

Fig. 1. Schematic diagram of a Ku-band one-stage cascode power amplifier.

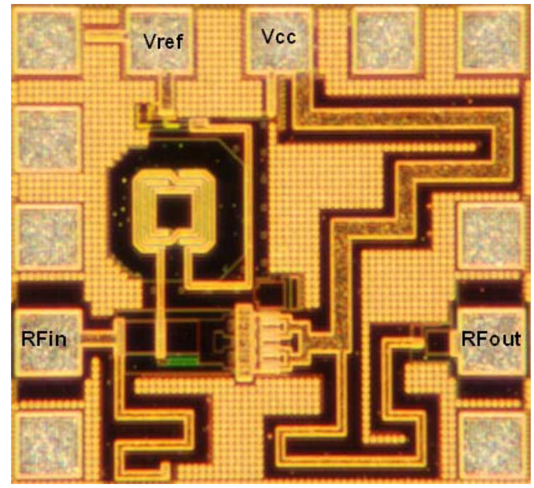

Fig. 3. Photograph of the fabricated Ku-band power amplifier MMIC.

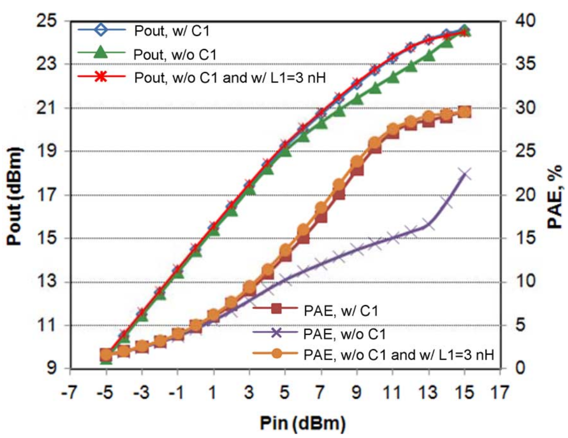

Fig. 2. Simulated output powers and PAEs of a Ku-band power amplifier at 14 GHz.

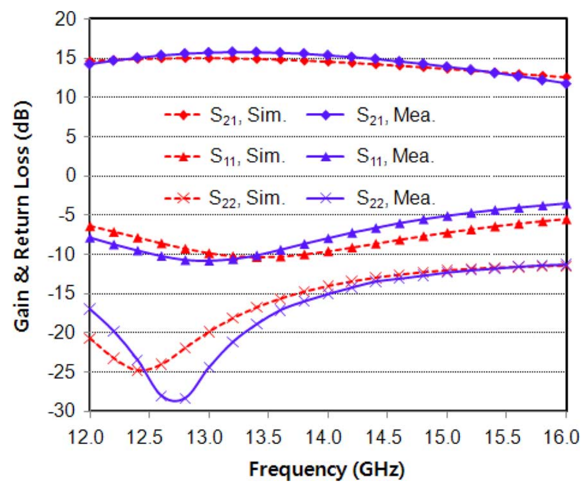

Fig. 4. Simulated and measured small-signal gain, input/output return loss (dB) as a function of frequency.

A constant base voltage for amplifying transistors to the input power has been suggested for obtaining both high output power and high efficiency of an HBT power amplifier [6]. To maintain a constant base voltage of Q1 to the input power, the simulated minimum inductance value of L1 is 3.0 nH, but a high inductance of L1 restricts a compact power amplifier MMIC design. Thus, a shunt capacitor of C1 is proposed to reduce the MMIC size with a reduced inductance of L1.

Fig. 2 shows the simulated output power (Pout) and PAE of the Ku-band power amplifier with and without capacitor C1 at 14 GHz. For the simulation, 1.2 nH for L1 and 0.4 pF for C1 are used. Without C1, the RF signal leakage to the bias transistor Q3 makes a voltage drop through the base and emitter in the negative direction, resulting in a base voltage increase of Q1 with increasing input power. Then, the increased collector current of Q1 unnecessarily lowers the Pout and PAE of the power amplifier at the high output power region.

The simulated 1 dB compression output power (P1 dB) and PAE at P1 dB are 21.3 and 20.2 dBm, and 19.5 and 11.5 %, with and without capacitor C1, respectively. The high-linear and high-efficient characteristics with C1 are mainly because the capacitor C1 bypasses the RF signal leakage coming through inductor L1, keeping constant the base voltage of Q1 to the increasing input power.

IV. Measured Results

The fabricated Ku-band power amplifier MMIC is shown in Fig. 3. The MMIC is composed of an input/output matching circuit, an active bias circuit, and probing pads, and its size is as small as 0.6 mm $\times$ 0.64 mm (0.384 mm^2).

The Ku-band one-stage cascode power amplifier MMIC was measured under a Vcc of 4.0 V and Vref of 2.0 V, and the quiescent current was 150 mA.

Fig. 4 shows the simulated and measured small-signal gain and input/output return loss for the power amplifier MMIC from 12 to 16 GHz. The simulated results and measured data are in good agreements.

The measured 1 dB compression output power (P1 dB) and saturated output power (Psat) are 21.2 and 24.45 dBm at 14 GHz, respectively, as shown in Fig. 5. The measured PAEs as

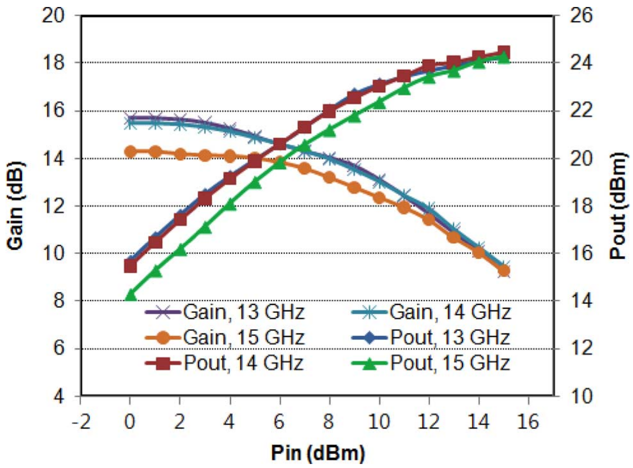

Fig. 5. Measured gains and output powers as a function of input power.

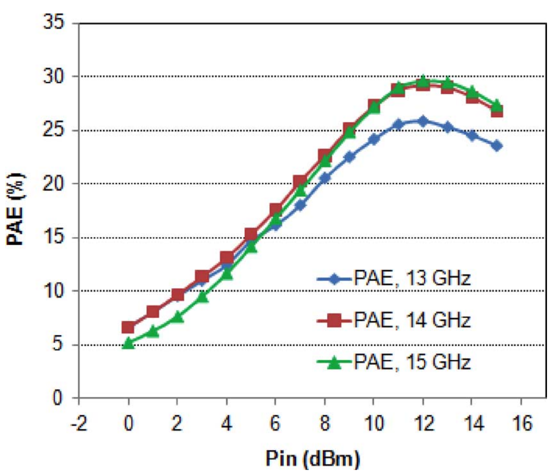

Fig. 6. Measured power added efficiency (PAE) as a function of input power (Pin).

a function of input power are also shown in Fig. 6. At 14 GHz, the peak PAE and PAE at P1 dB are 29.1 % and 19.4%, respectively. The measured performances of the Ku-band power amplifier show good agreement with the simulation, as shown in Fig. 2.

A comparison of the SiGe and GaAs power amplifiers is shown in Table II. The output power density of 726 mW/mm^2 and PAE of 29.1 % are the highest demonstrated in SiGe HBT power amplifiers. These results are also comparable to GaAs-based power amplifiers.

TABLE II
COMPARISON OF MMIC POWER AMPLIFIERS

Substrate	Psat, dBm	P_{DC}, W	PAE, %	Size, mm^2	Pout Den., mW/mm^2	Reference
SiGe	24.45	0.85	29.1	0.384	726	This work
SiGe	29.3	4.37	18.0	4.5	189	[3]
SiGe	17.5	0.46	11.2	0.72	78	[4]
GaAs	39.5	23.7	30.0	11.12	809	[7]
GaAs	39.25	36.4	22.7	20	420	[8]

V. CONCLUSION

A compact Ku-band power amplifier with on-chip active biasing circuit using a commercial 0.25 μm SiGe BiCMOS process has been demonstrated. The fully matched power amplifier MMIC exhibits an output power density of 726 mW/mm^2 and a PAE of 29.1 %, the highest values around the Ku-band to our knowledge among SiGe power amplifiers.

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