Monolithic SiGe HBT Feedforward Variable Gain Amplifiers for 5 GHz Applications

Chang-Woo Kim

ABSTRACT—Monolithic SiGe heterojunction bipolar transistor (HBT) variable gain amplifiers (VGAs) with a feedforward configuration have been newly developed for 5 GHz applications. Two types of the feedforward VGAs have been made: one using a coupled-emitter resistor and the other using an HBT-based current source. At 5.2 GHz, both of the VGAs achieve a dynamic gain-control range of 23 dB with a control-voltage range from 0.4 to 2.6 V. The gain-tuning sensitivity is 90 mV/dB. At V_{CTRL}= 2.4 V, the 1 dB compression output power, $P_{1\text{-}dB}$, and dc bias current are 0 dBm and 59 mA in a VGA with an emitter resistor and -1.8 dBm and 71mA in a VGA with a constant current source, respectively.

Keywords—SiGe HBT, feedforward, variable gain amplifier, 5 GHz band.

I. Introduction

Recently, several transceivers used in the 5 GHz band have been developed actively for data transmission such as IEEE 802.11a Wireless LAN (in the USA) and HIPERLAN2 (in Europe) because they have the advantages of a high data transmission rate and spectrum availability [1], [2]. In these systems, a variable gain amplifier (VGA) can be used to control the transmitted signal power in the transmitter. To maximize the dynamic range of the system, VGAs are used as a driver amplifier embedded in front of a power amplifier. Thus, the transmitter requires a VGA with wider bandwidth, higher dB-linear gain control, and higher linearity characteristics.

There are some topologies using a current-steering scheme [3], feedback resistors [4], and a variable transconductance [5] in designing a VGA with heterojunction bipolar transistor (HBT) technology. These topologies, however, have stability disadvantages, a limitation on bandwidth, and nonlinear-in-dB gain control characteristics.

In this work, we have newly developed SiGe HBT feedforward VGAs to improve gain-control range and dB-linear gain control characteristics. The VGAs were designed and fabricated by using ST Microelectronics' SiGe MMIC design library and Si-BiCMOS process. The VGAs were measured for small signal and large signal performances. The measured results of the developed VGAs will be discussed.

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II. VGA Design and Implementation

A simplified schematic of the proposed VGA is shown in Fig. 1. The VGA consists of four major blocks, an active balun, main differential amplifier, feedforward block, and control-voltage supplier. The balun converts a single-ended input signal into two differential signals. These differential signals are amplified by the main amplifier and go out the RF out ports. The output signals of the VGA can be controlled by the gain of the main amplifier as well as the attenuation caused by the 180^o out-of-phase feedforward signal. The amplified output signal is split to form two paths: one goes into the feedforward block and the other goes to a load resistor. The outgoing (180^o out-of-phase) signal from the feedforward block is subtracted from the main signal. This subtraction process leads to the attenuation of the VGA. Consequently, the dB-linearity of the VGA can be improved easily if the amount of the attenuation can be dB-linearly controlled by the control voltage. Thus, we have proposed a new topology of the VGA with a feedforward configuration.

In Fig. 1, the balun does not have a gain for linearity. The main amplifier is a cascode configuration with a common-emitter stage feeding a common-base stage. The feedforward circuits consist of a common-emitter and collector-base shorted

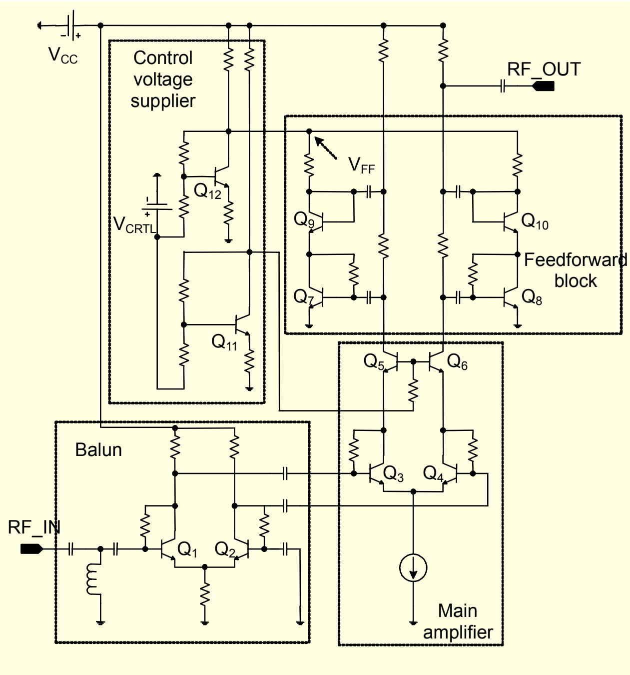

Fig. 1. A circuit schematic of the feedforward variable gain amplifier proposed in this work.

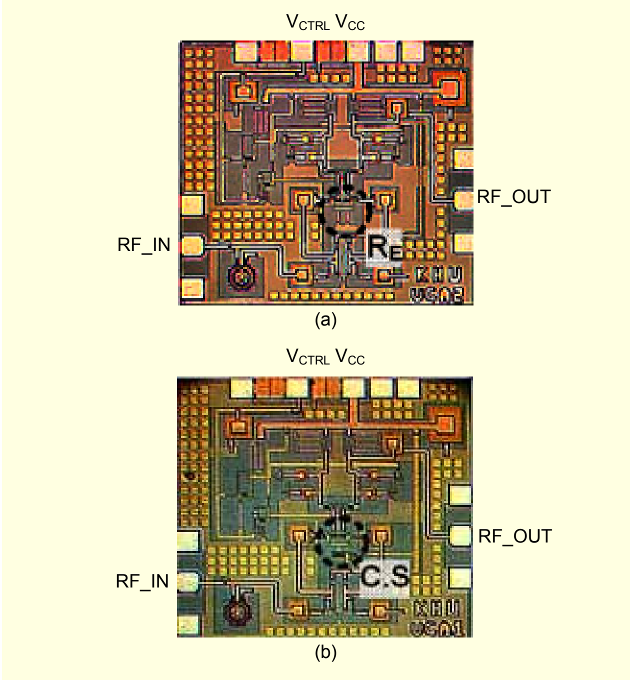

Fig. 2. Microphotographs of the VGAs: (a) VGA with an emitter resistor and (b) VGA with an HBT-based current source.

HBTs. For dc bias current control, two types of VGA have been made: one using a coupled-emitter resistor and the other using a transistor-based constant current source.

The power gain of the VGA is separately controlled by the cascode HBTs Q_5 and Q_6 in the main amplifier and Q_7-Q_{10} in the feedforward circuits. The gain-control mechanism of the VGA can be explained as follows: The control voltage V_{CTRL} increases, as does the collector current of Q_{11}, which results in an increase of the base voltages of Q_5 and Q_6. This leads to an exponential increase in the transconductances of Q_5 and Q_6 since the transconductance of the HBT depends on the collector current. Thus, the gain of the HBT increases dB-linearly with V_{CTRL} since the gain of the HBT depends linearly on the transconductance. Under this condition, the supplied voltage of the feedforward circuits (V_{FF}) decreases with increasing V_{CTRL}. Decreasing V_{FF}, the 180^o out-of-phase signal fed from the feedforward block is drastically reduced, and the amount of the attenuation decreases drastically. When V_{CTRL} = 3 V, the feedforward block does not operate and the VGA exhibits a maximum gain.

On the other hand, as V_{CTRL} decreases, V_{FF} increases and the feedforward circuit becomes activated. Under this condition, the output signals of the feedforward paths (Q_7-Q_9 and Q_8-Q_{10}) are subtracted from those of the main amplifier because of the 180° phase difference. The total output of the VGA will then decrease drastically with increasing the amount of the feedforward signal controlled by V_{CTRL}. When V_{CTRL} = 0 V, V_{FF} = 3 V and the output signal of the VGA is fully canceled out, while the gain of the VGA exhibits a maximum attenuation (minimum gain).

Using the Gummel-Poon model, small and large signal simulations have been performed by Agilent's Advanced Design System (ADS). In the VGA, three types of multifinger HBTs were used. In the main amplifier, three-finger HBTs with an emitter area of 0.4 × 20 μm^2 were used to optimize the output power and linearity characteristics. Two-finger HBTs with an emitter area of 0.4 × 10 μm^2 were used in the feedforward block to improve the linearity. In the balun and control voltage supplier, one-finger HBTs with an emitter area of 0.4 × 10 μm^2 were used. All MIM capacitors and thin film resistors have been optimized to obtain a maximum power gain of 10 dB and gain-control range of 30 dB for a 4 to 8 GHz band.

The VGA MMIC chips were fabricated using ST Microelectronics' 0.35 μm Si-BiCMOS process. Microphotographs of the developed VGA chips are shown in Fig. 2. The chip size of the VGAs is 1.0 × 0.9 mm^2. To improve the radiation loss of signal and the isolation between the signal lines, ground-shielded microstrip lines were used in all transmission lines of the VGA chips.

III. Experimental Results

For small and large signal measurements, the VGA chips were mounted on a probe station with RF connections made by 200-μm pitch coplanar probes and DC biasing applied through a GPPG probe. The results were measured with a vector network analyzer and spectrum analyzer connected to a single-ended output 50 Ω port. The collector bias voltage of V_{CC} is 3 V, and the control voltage can vary from 0 to 3 V.

Figure 3 shows the measured gain control range and input/output voltage standing wave ratio (VSWR) characteristics of the VGAs as a function of control voltage from 0.4 to 2.6 V at 5.2 GHz. The VGAs have achieved dynamic-gain-control ranges of 23.8 and 23.6 dB (–15 to 8.8 dB for the VGA with an emitter resistor and –15.4 to 8.2 dB for the VGA with a current source), respectively. The gain-control sensitivity of the VGAs is 90 mV/dB. In bipolar transistors, the gain-control voltage for 1 dB control should be much larger than the thermal voltage (26 mV/dB at room temperature) in order to be insensitive to temperature variation. The output VSWR is kept low and constant despite a change in the gain-control voltage, while the input VSWR is higher and slightly varied with a varying V_{CTRL}. Both of the VGAs also exhibit a 3 dB bandwidth of 4 GHz (4 to 8 GHz), regardless of changing V_{CTRL} from 0.6 to 2.6 V.

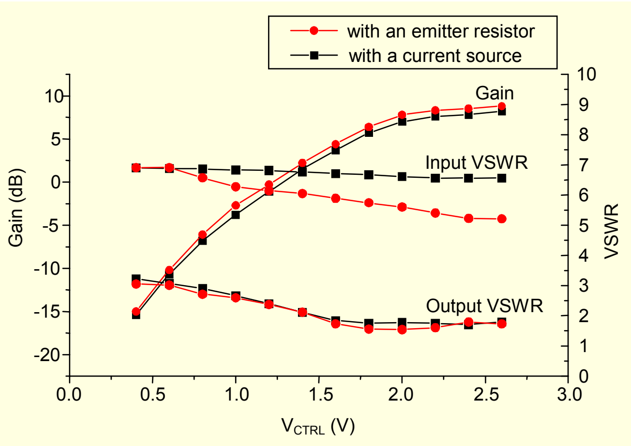

Fig. 3. Small-signal gain and input/output VSWR characteristics of the VGAs as a function of V_{CTRL} at 5.2 GHz.

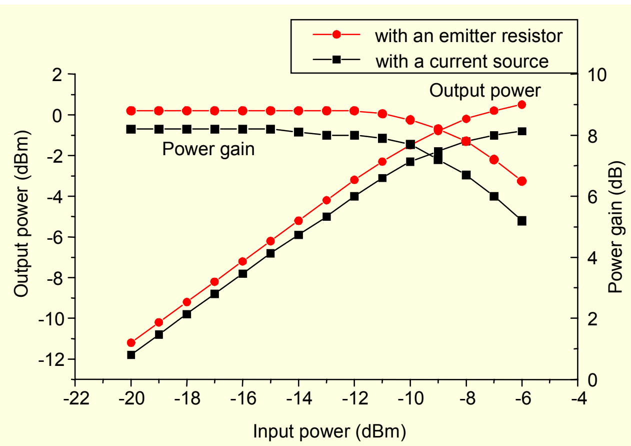

Fig. 4. Output power and gain characteristics as a function of the input power at V_{CTRL}= 2.4 V and 5.2 GHz.

Figure 4 shows the output power characteristics as a function of the input power for a high-gain condition (V_{CTRL} = 2.4 V) at 5.2 GHz. The VGA with an emitter resistor produces a 1 dB gain compression output power $P_{1\text{-dB}}$ of 0 dBm and that with a current source produces –1.8 dBm. When the control voltage varies from 0.6 to 2.6 V, a total bias current of the VGA with an emitter resistor varies from 26 to 62 mA, while that of the VGA with a current source varies from 39 to 73 mA. The current in the VGA with an emitter resistor is much less than that in the VGA with a constant current source. Thus, the VGA with an emitter resistor is superior to the VGA with a constant current source in low-power consumption operation.

IV. Conclusions

We have proposed newly developed SiGe HBT variable gain amplifiers (VGAs) with a feedforward configuration. For bias-current control, two types of the VGA were made. One used a coupled-emitter resistor and the other used a transistor-based current source. The experimental results show that the developed VGAs can be a good candidate for 5 GHz wireless applications.

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