Improved Technique for Reflection Performances in Broadband Variable Gain Low Noise Amplifiers

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***Abstract* — We propose an improved technique for reflection performances in broadband variable gain low noise amplifiers that does not require preamplifiers and buffer amplifiers. This technique controls the feedback circuit and main amplifier simultaneously to obtain constant input and output impedance values. When the amplifier's gain changed, the reflection performance remained good. Amplifiers ranging from 750 MHz to 6 GHz fabricated using this technique showed an $|S_{22}|$ of less than -10 dB, a $|S_{11}|$ of less than -8 dB, and a variable gain range of more than 33 dB @ 2 GHz. Compared with conventional techniques, the $|S_{22}|$ showed a 6 dB improvement, the $|S_{11}|$ showed a 3 dB improvement, and the variable gain range showed an 8 dB improvement.**

I. Introduction

There are a variety of mobile communication standards in use worldwide. Software-defined radio (SDR) can realize multi-standard terminals that can flexibly adapt to various mobile communication systems by simply rewriting their software [1]-[2]. To achieve such terminals, we require multi-band RF front-end components, such as amplifiers and mixers, which must also have broadband characteristics. The direct conversion architecture [3] shown in Fig. 1 is a more suitable tool for SDR, because terminals using this architecture do not require image-rejection filters or IF-channel filters. In terminals with direct conversion architecture, however, we need a low noise amplifier (LNA) with a gain-control mechanism in the RF-stage, because SDR can be adapted to systems with various specifications, such as sensitivity, maximum received power level, and so on.

Gain-control mechanisms for LNA include variable gain amplifiers (VGAs) and amplifiers that have attenuators. Amplifiers that have attenuators occupy a large area. In contrast, VGAs occupy a much smaller area than the amplifiers with attenuators, thus helping to lower production costs. However, when we control the gain of conventional VGAs, the reflection performances over broadband deteriorate. Therefore, conventional VGAs need pre-amplifiers and buffer amplifiers, which increase their power consumption.

In this paper, we propose an improved technique for reflection performances in variable gain LNAs. We will demonstrate that the proposed technique is suitable for variable gain LNAs. To confirm the effectiveness of the proposed technique, we fabricated a variable gain LNA. We will discuss the measurement results obtained from the fabricated monolithic microwave integrated circuits.

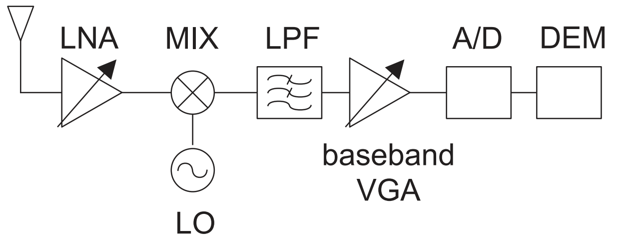

Fig. 1. Block diagram of a receiver using direct conversion architecture.

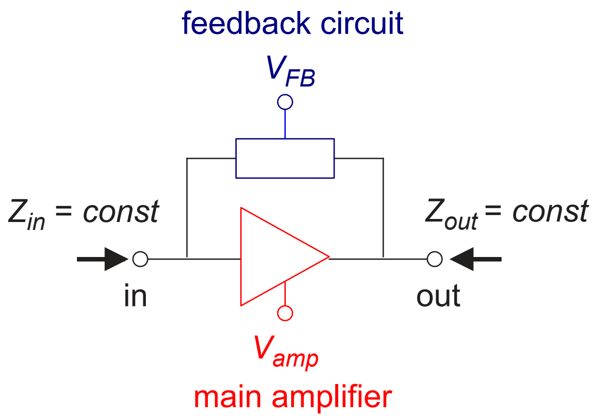

Fig. 2. Simplified block diagram of a feedback amplifier using proposed technique.

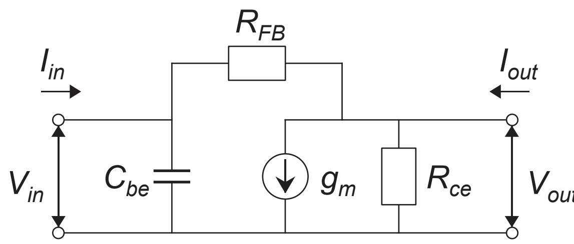

Fig. 3. Simple equivalent circuits of a feedback amplifier using proposed technique.

II. Improved Technique For Reflection Performances

Conventional variable gain techniques include a base (gate) voltage control [4] and a feedback control technique (in feedback amplifiers) [5]. In amplifiers without pre-amplifiers and buffer amplifiers, when the gain is tuned down using conventional technologies, the matching amplifier conditions change and the reflection performances are degraded. In amplifiers with pre- and buffer amplifiers, power consumption increases.

Therefore, we propose an improved technique for the reflection performances of variable gain LNAs. We used a feedback amplifier as a variable gain LNA. Figure 2 shows a simple block diagram of a feedback VGA. This amplifier consists of a main amplifier and a feedback circuit that uses a variable resistor. We assume that the equivalent BJT is a combination of the base-to-emitter capacitance (C_{be}), the transconductance (g_m), and the collector-to-emitter resistance (R_{ce}), ignoring the matching circuits and the bias circuits. A simple equivalent amplifier circuit that uses the proposed technique is shown in Fig. 3. The R_{FB} shown in Fig. 3 is the feedback resistor. In this technique, the input impedance (Z_{in}) and the output impedance (Z_{out}) are

$$Z_{in} = \frac{1}{j\omega C_{be} + \dfrac{R_{ce} g_m + 1}{R_{ce} + R_{FB}}} \text{ , and} \tag{1}$$

$$Z_{out} = \frac{1}{\dfrac{1}{R_{ce}} + \dfrac{g_m / j\omega C_{be} + 1}{1/j\omega C_{be} + R_{FB}}} \text{ .} \tag{2}$$

Here, f and g are defined as follows:

$$f = \frac{R_{ce} + R_{FB}}{R_{ce} g_m + 1} = \frac{1 + R_{FB}/R_{ce}}{g_m + 1/R_{ce}} \text{ , and} \tag{3}$$

$$g = \frac{1/j\omega C_{be} + R_{FB}}{g_m / j\omega C_{be} + 1} = \frac{1 + R_{FB} j\omega C_{be}}{g_m + j\omega C_{be}} \text{ .} \tag{4}$$

By substituting equations (3) and (4), we can rewrite equations (1) and (2) as follows:

$$Z_{in} = \frac{1}{j\omega C_{be} + \dfrac{1}{f}} \text{ , and} \tag{5}$$

$$Z_{out} = \frac{1}{\dfrac{1}{R_{ce}} + \dfrac{1}{g}} \text{ .} \tag{6}$$

Equation (5) means that C_{be} and a component with impedance f are connected in parallel. Similarly, equation (6) means that R_{ce} and a component with impedance g are connected in parallel.

When the base voltage of the main amplifier is controlled and g_m is tuned down, $j\omega C_{be}$ and $1/R_{ce}$ physically decrease. When the feedback circuit is controlled and the feedback level is tuned up, R_{FB} decreases. Then, the base voltage of main amplifier and the feedback circuit are controlled simultaneously, f and g decrease with the reduction in R_{FB}. Therefore, by controlling the base voltage of the main amplifier and the feedback circuit simultaneously as

$$\left| j\omega C_{be} + \frac{1}{f} \right| \approx const \text{ , and}$$

$$\left| \frac{1}{R_{ce}} + \frac{1}{g} \right| \approx const \text{ ,}$$

Z_{in} and Z_{out} become closer to constant values. Therefore, our technique can improve the reflection performances of variable gain LNAs.

III. Experimental Results

To confirm the effectiveness of the proposed technique, we fabricated a broadband variable gain LNA using SiGe BiCMOS technology. Figures 4 and 5 show the circuit configuration and a chip photograph of a fabricated amplifier. The chip size was 1.1 x 1.3 mm^2. The fabricated amplifier was a two-stage common-emitter amplifier and used anti-series connected CMOS feedback circuits [6]. To confirm the basic performance, Gain control was obtained by controlling the 2nd stage (the base voltage (V_{b2}) of the main amplifier (red frame in Fig. 4) and the gate voltage (V_{cont2}) of CMOS used in the feedback circuit (blue frame in Fig. 4)). The base voltage (V_{b1}) and gate voltage (V_{cont1}) of the 1st amplifier

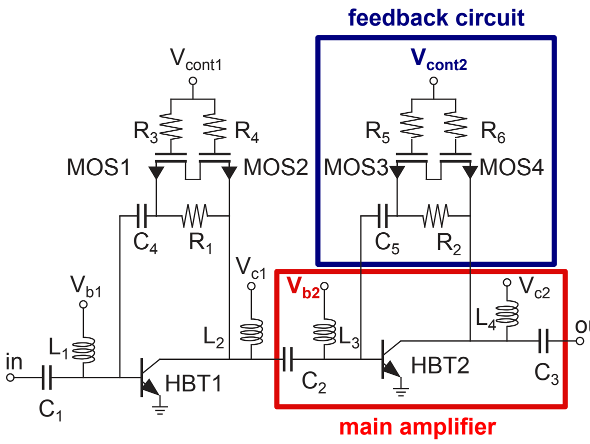

Fig. 4. Circuit configuration of fabricated variable gain LNA.

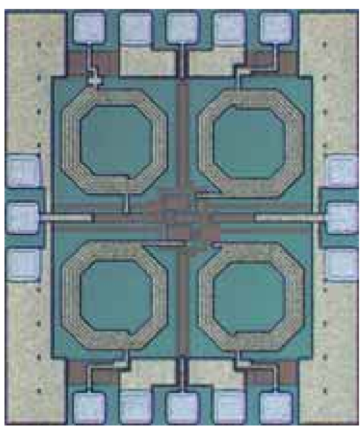

Fig. 5. Chip photograph of fabricated variable gain LNA.

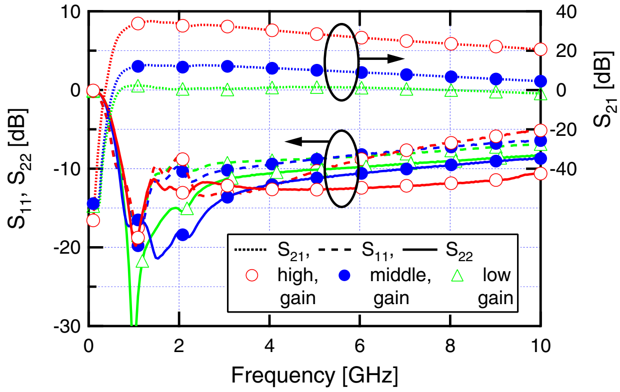

Fig. 6. Measured S-parameters of fabricated amplifier using the proposed technique.

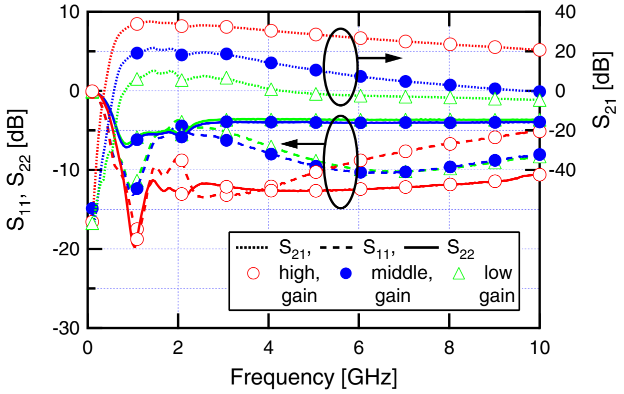

Fig. 8. Measured S-parameters of fabricated amplifier using the conventional technique to control only V_{b2}.

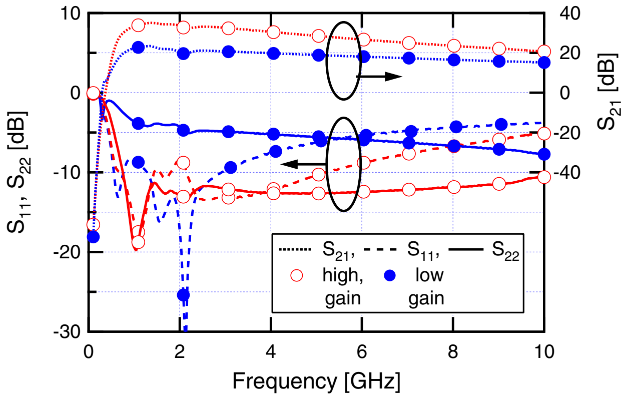

Fig. 7. Measured S-parameters of fabricated amplifier using the conventional technique to control only V_{cont2}.

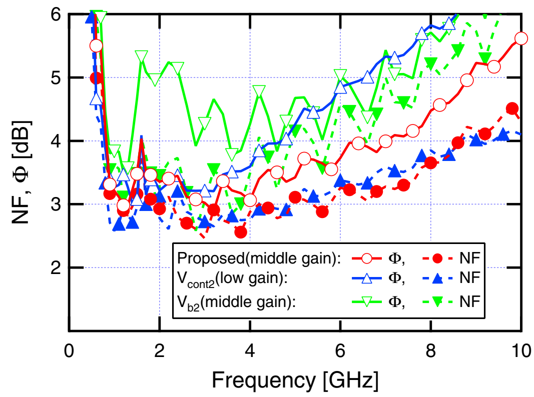

Fig. 9. Measured noise figure and calculated figure of merit of fabricated amplifier.

were set as constant values. To broaden the frequency band, the feedback level was set as high. As a result, the impedance change in the 2nd stage affects the input impedance.

The measured S-parameters of the amplifier fabricated using the proposed technique are shown in Fig. 6. In this technique, both V_{b2} and V_{cont2} in Fig. 4 were controlled. Amplifiers ranging from 750 MHz to 6 GHz, fabricated using the proposed technique, showed an $|S_{22}|$ of less than -10 dB, an $|S_{11}|$ of less than -8 dB, and a variable gain range of more than 33 dB @ 2 GHz.

The measured S-parameters of the fabricated amplifier that controlled only V_{cont2} showed an $|S_{22}|$ of less than -2.4 dB, an $|S_{11}|$ of less than -4.9 dB, and a variable gain range of more than 13 dB @ 2 GHz in the 750 MHz to 6 GHz range, as shown in Fig. 7. The measured S-parameters of the fabricated amplifier that controlled only V_{b2} showed an $|S_{22}|$ of less than -3.6 dB, a $|S_{11}|$ of less than -3.8 dB, and a variable gain range of more than 25 dB @ 2 GHz in the 750 MHz to 6 GHz range, as shown in Fig. 8. As compared with the amplifier that controlled only V_{cont2} or V_{b2}, the amplifier using the proposed technique showed an improved $|S_{22}|$, $|S_{11}|$, and variable gain range.

Here, in order to evaluate the improvement of *NF* and S_{11} together, we introduce a new parameter, the calculated figure of merit, Φ, shown in Fig. 9, including degradation by reflection loss (RL) as follows:

$$\Phi[dB] = NF[dB] + RL[dB] \ ,$$

$$RL[dB] = -10 \times \log_{10}\left(1 - 10^{(S_{11}[dB]/10)}\right).$$

Figure 9 shows the measured noise figure (*NF*) and Φ. As compared with the amplifier that controlled only V_{cont2} or V_{b2}, our amplifier showed an overall improvement of Φ.

Therefore, our technique is effective for broadband variable gain LNAs.

Table 1 summarizes the measured results.

IV. Conclusions/Summary

This paper describes an improved technique for broadband variable gain LNAs that controls the feedback circuit and the main amplifier simultaneously, to obtain constant input and output impedance values. This amplifier controls the gain by referring to the bias table prepared beforehand. We confirmed an improved reflection performance over conventional techniques. In conclusion, compared with conventional techniques, we

TABLE I
SUMMARY OF MEASURED $|S_{11}|$, $|S_{22}|$, VARIABLE GAIN RANGE, CALCULATED FIGURE OF MERIT Φ

Control terminal	V_{cont2} and V_{b2} (proposed, Fig. 6)	V_{cont2} (Fig. 7)	V_{b2} (Fig. 8)
$\|S_{11}\|$ 0.75–6 GHz	-8 dB	-4.9 dB	-3.8 dB
$\|S_{22}\|$ 0.75–6 GHz	-10 dB	-2.4 dB	-3.6 dB
variable gain range (2 GHz)	33 dB	13 dB	20 dB
figure of merit Φ (NF+RL)	4.2 dB@0.8 GHz (Gain:9.9 dB, NF:3.9 dB, RL:0.3 dB)	4.9 dB@6 GHz (Gain:18 dB, NF:4.0 dB, RL:0.9 dB)	5.3 dB@1.6 GHz (Gain:21 dB, NF:4.1 dB, RL:1.2 dB)

believe the proposed technique is effective for broadband variable gain LNAs.

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REFERENCES

[1] J. Mitola, “The Software Radio Architecture,” *IEEE Commun. Mag.*, vol. 33, no. 5, pp. 26-38, May 1995.

[2] H. Tsurumi and Y. Suzuki, "Broadband RF stage architecture for software-defined radio in handheld terminal applications," *IEEE Commun. Mag.*, vol. 37, no. 2, pp. 90-95, February 1999

[3] A. Abidi, "Direct-conversion radio transceivers for digital communications," *IEEE J. Solid-State Circuits*, vol. SC-30, no. 12, pp. 1394-1410, February 1999.

[4] A. Pascht, I. Kallfass, R. Obergfell, and M. Berroth, "Variable gain SiGe HBT Amplifier with low noise figure," *2000 8th IEEE Int. Symp. Electron Devices for Microwave and Optoelectronic Applications*, pp. 20-25, November 2000.

[5] M. Muraguchi and M. Aikawa, "A linear limiter: A 11 GHz monolithic low distortion variable gain amplifier," *Proc. IEEE 1991 Int. Microwave Symp.*, pp.525-528, June 1991.

[6] M. Kawashima, T. Nakagawa, H. Hayashi, K. Nishikawa, and K. Araki, "A 0.9-2.6 GHz broadband RF front-end chip-set with a direct conversion architecture," *IEICE Trans. Commun.*, vol. E85-B, pp. 2732-2740, December 2002.