A High Gain Low Noise Mixer With Cross-Coupled Bleeding

Dae-Young Yoon, Seok-Ju Yun, Justin Cartwright, Seok-Kyun Han, and Sang-Gug Lee

***Abstract*—A mixer implementing a cross-coupled bleeding circuit for improved conversion gain and noise performance is reported. The proposed mixer is implemented in 0.18 μm CMOS technology. The measured results show a 17 dB conversion gain, -4.7 dBm IIP3 for an RF signal frequency of 765 MHz, 7.9 dB noise figure, and 125 kHz flicker noise corner while consuming 3.12 mA from a 1.8 V supply.**

***Index Terms*—Bleeding, CMOS, flicker noise, mixer, thermal noise.**

I. INTRODUCTION

THE direct-conversion receiver (DCR) has attracted widespread attention for its simple architecture, ease of integration, low power consumption, and low cost [1]. In spite of these advantages, a number of issues exist such as dc offset, second order distortion, self mixing, and flicker noise. To reduce the amount of flicker noise in CMOS implementations, passive mixers are often utilized [2], [3]. However, due to their conversion loss, additional transconductance and trans-impedance amplifiers are needed to maintain acceptable noise performance. Active mixers can provide higher amounts of conversion gain, but the switching transistors generate 1/f noise due to the dc bias current. This substantially decreases the noise figure (NF) of the mixer. The current bleeding technique is often adopted to alleviate this issue by further increasing conversion gain, while also reducing the 1/f noise [4]–[6]. However, the parasitic capacitances introduced by the bleeding transistors along with the increased source impedance of the switching transistors limit the improvement in conversion gain by shunting the RF signal [7]. In addition, the white noise injected by the bleeding circuit degrades the noise figure of the mixer. This letter presents an active mixer that achieves a high conversion gain and low noise figure by implementing a cross-coupled current bleeding circuit.

II. MIXER DESIGN

Fig. 1 illustrates the conventional bleeding mixer (CBM) and cross-coupled bleeding mixer (CCBM). The bleeding mixer consists of a transconductance stage ($M_1 - M_4$ and $C_5 - C_6$), a switching stage ($M_5 - M_8$), load (R_L and C_L), and current bleeding circuit. The bleeding circuits, shown in Fig. 1(b) and (c), supply the transconducance stage ($M_1 - M_2$) with dc current, allowing less current in the switching stage ($M_5 - M_8$). The voltage conversion gain of the mixer implementing the conventional bleeding circuit, $M_9 - M_{10}$ in Fig. 1(b), is given by

$$A_{V,conv} = \frac{2}{\pi} g_{mt} R_L \tag{1}$$

where g_{mt} is the transconductance of the differential transconductance stage and R_L denotes the load resistance. Due to the current reduction in the switching transistors, higher values of R_L can be used to increase the conversion gain.

However, the increased source impedance of the switching transistors results in higher attenuation of the RF signal, limiting the improvement in conversion gain. Furthermore, the white noise contributed by the bleeding transistors increases with the amount of current they provide [1].

In the case of the proposed bleeding circuit, $M_{11} - M_{12}$ and $C_3 - C_4$ in Fig. 1(c), the voltage conversion gain is given by

$$\begin{aligned} A_{V,prop} &= \frac{2}{\pi} g_{mt} \left(\frac{g_{ms}}{g_{ms} - g_{mp}} \right) R_L \\ &= \left(\frac{g_{ms}}{g_{ms} - g_{mp}} \right) A_{V,conv} \end{aligned} \tag{2}$$

where g_{ms} and g_{mp} are the transconductance of the switching and bleeding transistors, respectively. From (2), the conversion gain of the CCBM ($A_{V,prop}$) can be made significantly higher than $A_{V,conv}$ by appropriate selection of g_{ms} and g_{mp}. Due to the positive feedback of the cross-coupled bleeding circuit, the values of g_{ms} and g_{mp} should be carefully chosen to ensure stability. This is achieved when the loop gain (g_{mp}^2 / g_{ms}^2) is lower than unity in accordance with the Barkhausen criteria [1].

If a sinusoidal LO signal is applied, variations in g_{mp} and g_{ms} with time must also be considered. Since the LO signal is symmetrically applied to nodes A and B, a common mode voltage appears across the CCBM. For common mode signals, the CCBM provides a low impedance path to ground. As a result, the voltage variations at nodes A and B due to the large LO signal are small. Consequently, the variations in g_{mp} are also small and can be neglected. Conversely, the low impedance at

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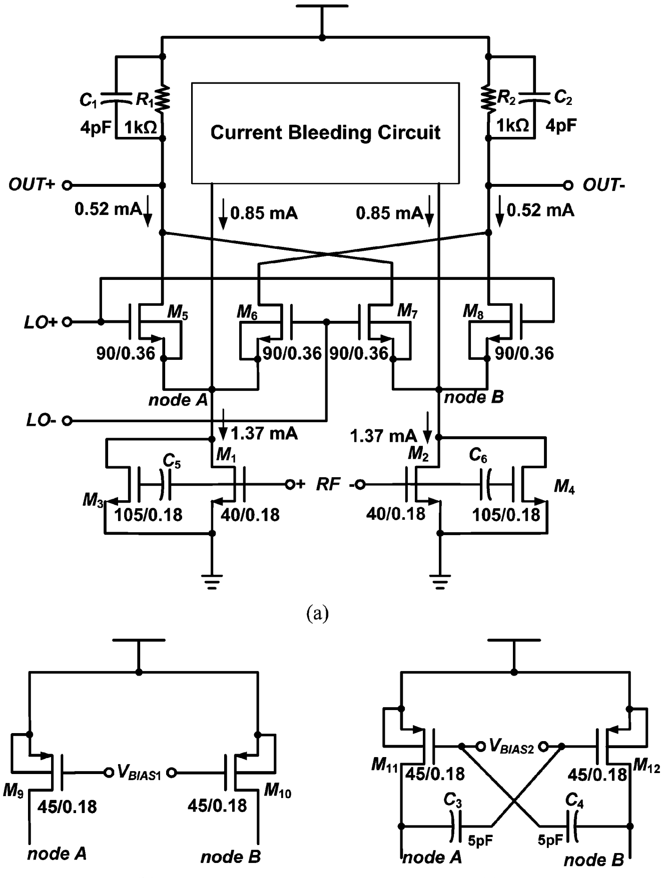

(a)

(b)

(c)

Fig. 1. (a) Double balanced mixer topology with current bleeding circuits (b) conventional bleeding circuit (c) cross-coupled bleeding circuit.

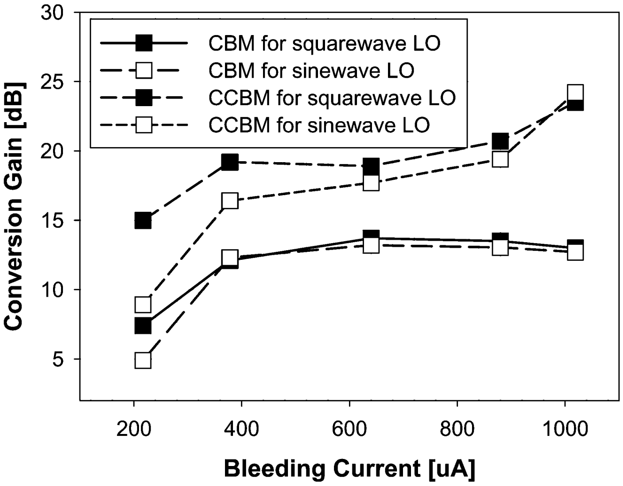

Fig. 2. Conversion gain of the CBM and CCBM as a function of the bleeding current for a square and sinusoidal LO signal.

these nodes causes substantial changes in the gate-source voltages of the switching transistors. This leads to a significant variation in g_{ms}. Fig. 2 shows the conversion gain of the CBM and CCBM as a function of the bleeding current for a square and sinusoidal LO signal. For the CCBM, the conversion gain achieved with the square-wave LO is higher than that obtained with a sinusoidal LO. This illustrates a deleterious effect of the time-varying value of g_{ms} on the conversion gain. However, the decrease in conversion gain is only 1.4 dB. For the CBM, the simulations for the square and sinusoidal LO signal are almost identical. This is attributed to the higher impedance at nodes A and B (with respect to the LO signal), which prevents large fluctuations in g_{mp}.

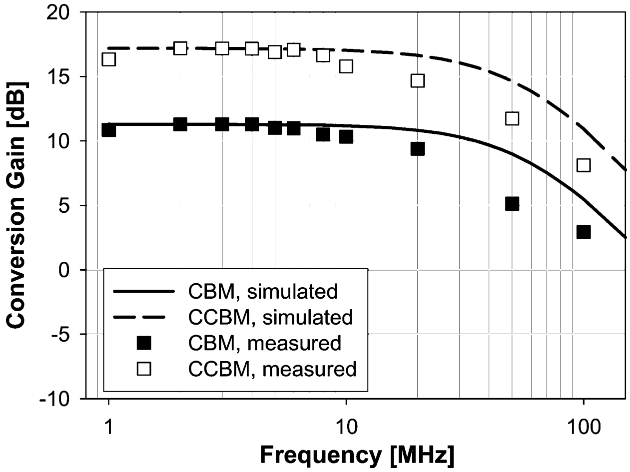

Fig. 3. Simulated and measured conversion gain with RF and LO signals of -45 and -5 dBm at 765 and 770 MHz, respectively.

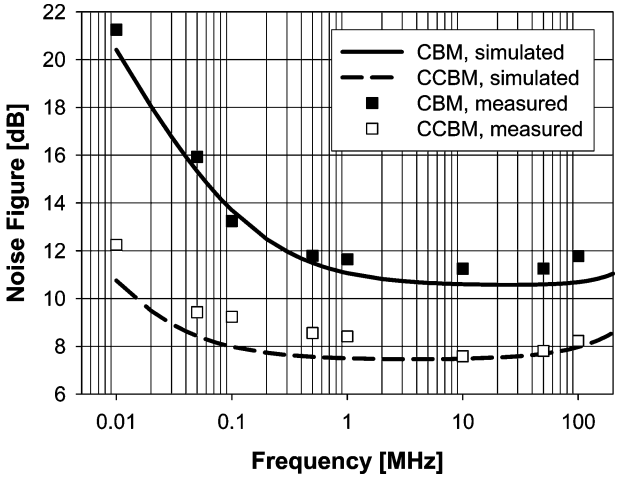

Fig. 4. Simulated and measured NF of CBM and CCBM with LO signal of -5 dBm at 770 MHz.

While the time varying value of g_{ms} has little effect on the conversion gain, design margins must be included to ensure stability. The criterion for stability is satisfied when the minimum value of g_{ms} is larger than g_{mp}. The minimum value of g_{ms} can be calculated at the zero-crossing point of the mixer. Accordingly, the current of each branch of the bleeding and switching quad transistors is set to 0.85 and 0.52 mA, respectively. The maximum and minimum ratios of g_{mp} and g_{ms} are then 0.7 and 0.56, respectively.

The time-varying nature of g_{ms} also has an impact on the non-linearity of the mixer. This is expected since, from (2), the conversion gain is directly related to g_{ms}. Simulation results show that employing a sinusoidal LO signal leads to a 5 dB decrease in IIP3. To improve linearity, multiple gate transistors (MGTR) are adopted at the trans-conductance stage [8]. The

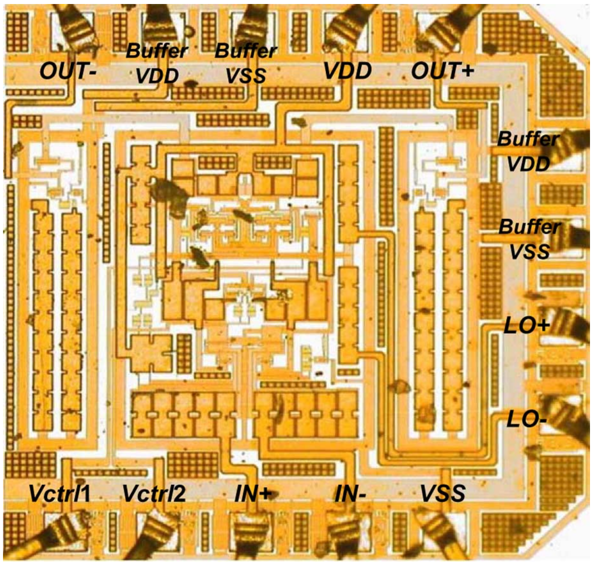

Fig. 5. Chip microphotograph of the CBM and CCBM.

TABLE I
COMPARATIVE PERFORMANCE SUMMARY

	Freq. (GHz)	Gain (dB)	Thermal Noise (dB)	Corner Freq. (kHz)	IIP3 (dBm)	Power (mW)	Tech. (CMOS)
[4]	0.9	4	11.2	-	-5.6	4mA	0.35 µm
[6]	2	0.5	11	13.5dB (20kHz)	10.5	2.4	0.13 µm
[7]	5.2	16.2	9.8	125kHz	-5	7	0.13 µm
[9]	0.9	13	27	-	-10.6	5.16	0.35 µm
[10]	2.4	11.4	10.2	-	4.4	8	0.13 µm
Conv. Bleeding	0.77	11	12.2	245	5.7	5.6	0.18 µm
Prop. Bleeding	0.77	17	7.9	125	-4.9	5.6	0.18 µm

size of the transconductance stage transistors and MGTR are $40\,\mu\mathrm{m}/0.18\,\mu\mathrm{m}(M_1 - M_2)$ and $105\,\mu\mathrm{m}/0.18\,\mu\mathrm{m}$, respectively.

For the same dc current and load resistance as the CBM, the proposed CCBM achieves a larger conversion gain. At the same time, the input referred noise due to the transconductance and input source resistor are identical to that of the CBM. However, the effect of the noise contributed by the switching, bleeding, and load stages is minimized by the larger conversion gain. As a result, the noise figure of the CCBM is lower than that of the CBM. Furthermore, the proposed CCBM improves the 1/f noise by reducing current in the switching transistors at the zero-crossing [6].

III. MIXER MEASUREMENT RESULTS

To demonstrate the validity of the proposed concept, the CBM and CCBM are implemented in a 0.18 $\mu\mathrm{m}$ CMOS technology. The additional buffers in Fig. 5 are used for measurement purposes only. The mixers are compared under the same bleeding current and transistor sizes. The total current and bleeding current of the CBM and CCBM are 3.6 and 1.7 mA, respectively. The RF and LO frequencies are selected in the DVB-H application bands and the power of the RF and LO signals are -45 and $-5\ \mathrm{dBm}$, respectively. Fig. 3 shows the simulated and measured conversion gains. The measured conversion gain of the CCBM is 17 dB, while that of the CBM is 11 dB. The gain of the CCBM is improved by 6 dB, demonstrating the gain-boosting effect of the proposed bleeding scheme. Fig. 4 shows the simulated and measured noise figures for the CBM and CCBM. The measured noise figures of the CBM and CCBM are 11.2 and 7.9 dB, respectively. The proposed design exhibits a 3.3 dB improvement in noise performance. In terms of flicker noise, the corner frequency of the CCBM is 125 kHz, while that of the CBM is 245 kHz. This data indicates that the proposed bleeding scheme is effective for reducing both white and flicker noise. The IIP3 of the CCBM measured at beat frequencies of 763 and 765 MHz is $-4.9\ \mathrm{dBm}$, which is 10.6 dB lower than that of the CBM. Table I presents a key performance summary that compares the proposed design with previous works [4]–[10]. The CCBM has a lower noise figure and higher conversion gain than the other mixers. Fig. 5 shows a micro-photograph of the CBM and CCBM with a chip-size of $930 \times 960\ \mu\mathrm{m}^2$.

IV. CONCLUSION

An active mixer implementing a cross-coupled current bleeding circuit was presented in this letter. The proposed circuit was shown to exhibit both a higher conversion gain and lower noise figure than the conventional bleeding topology. The IIP3 of the CCBM was improved by including multi-gate transistors in the transconductance stage of the mixer. The proposed design and the conventional CBM were fabricated in a 0.18 $\mu\mathrm{m}$ CMOS technology. In comparison with the CBM, the measured results for the proposed design show a 6 dB improvement in conversion gain and a 3.3 dB improvement in noise figure.

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