A 2.6 V GSM/PCN Dual Band Variable Gain Low Noise RF Down Conversion Mixer

Bonkee Kim, Kyung-Suc Nah, Tae-Won Ahn, Han-Il Lee, Je-Kwang Cho and Byeong-Ha Park

RF projects, Samsung Electronics Co., Ltd.
Suwon P.O.Box 105, Kyunggi do, Korea 440-600.
e-mail: bonkee@dreamwiz.com

Abstract - **As a building block of a GSM/PCN dual band RF transceiver IC, a low noise variable gain RF down conversion mixer is designed and fabricated using 15 GHz-f_T, 0.5 μm 3-metal 2-poly BiCMOS process. Careful consideration is concentrated on low noise performance of the mixer. Moreover, using constant-impedance input / output stages, RF input and IF output return losses are maintained under -16 dB for both of high and low gain mode. Measured gain and DSB noise figure of the mixer are 10.9 dB and 9.1 dB, respectively, for GSM band, and 9.6 dB and 8.1 dB, respectively, for PCN band. Gain difference between high and low gain mode is 11 dB and 11.8 dB for GSM and PCN, respectively. Total DC currents are 13 mA for GSM, and 11.5 mA for PCN from 3V supply voltage. Mixer performance is maintained with supply voltage down to 2.6 V.**

I. INTRODUCTION

Gilbert cell is most widely used as RF mixer [1], [2]. Almost all of wireless RF receiver systems have variable gain characteristics because received signal strength varies significantly. Although most of gain variation is responsible to PGA (programmable gain amplifier) in IF band, modern RF LNA (low noise amplifier) has variable gain characteristic to increase dynamic range of a system [3], [4]. The variable gain characteristic in RF band loosens the P_{1dB} and IP_3 specification of IF band blocks. Moreover, the variable gain range of PGA could be reduced, which can result in reduced number of cascade stage, and consequently, reduced DC power consumption.

Using only variable gain LNA, the gain difference is around 20 dB. Although by simply turning off the active transistors, around -30 ~ -20 dB gain can be obtained, but input/output impedance will be changed significantly. At the input and output of LNA, usually filters are connected, which require constant impedances. Because of this fact, it is difficult to acquire more than 20 dB gain variation in RF band with only variable-gain LNA.

Because of the above reasons, variable gain characteristic for not only LNA, but also RF mixer, is preferred. Usually, image rejection filter and channel selection SAW filter are connected at input and output of a mixer, respectively. Because filters are designed with constant input/output impedances, different impedances at input or output collapse the sharp characteristic of filters. So, it is required to maintain constant input/output impedances in both of high and low gain mode of a mixer.

Noise figure of a mixer is affected by various factors such as transistor size, LO signal level, LO buffer load resistance, noise decoupling from bias blocks, etc. Because f_T of the fabrication process is very low (15 GHz) relative to operation frequency (upto 1.9 GHz for PCN band), careful consideration is concentrated on low noise performance and sufficient gain with minimum DC power consumption.

In this paper, dual band variable gain low noise RF down conversion mixer will be introduced. It has almost constant input/output impedances in both of high and low gain mode.

II. VARIABLE GAIN MIXER CORE DESIGN

Fig. 1 shows block diagram of implemented mixer. Differential RF input is connected to each GSM/PCN Gilbert cell core. LO signal is divided to GSM/PCN paths. In GSM mode, PCN Gilbert cell core (C_{PCN}) and LO buffer for PCN (B_{PCN}) are turned off, and in PCN mode, GSM Gilbert cell core (C_{GSM}) and LO buffer for GSM (B_{GSM}) is turned off. IF output ports of GSM and PCN are directly tied. At IF output ports, a discrete 2.5 kΩ IF load resistor is connected to differential outputs. All of input/output nodes (GSM and PCN RF input nodes, LO input nodes, and IF output nodes) are matched to 50 Ω using off-chip LC elements.

Fig. 2 shows schematic of variable gain Gilbert-cell mixer

0-7803-7246-8/02/$10.00 © 2002 IEEE

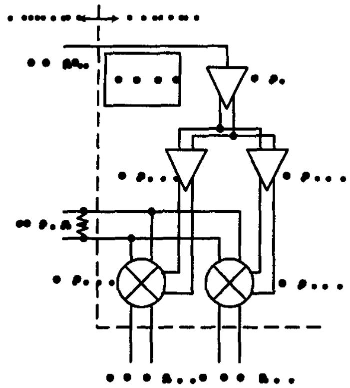


Fig. 1 Block diagram of implemented dual band mixer.

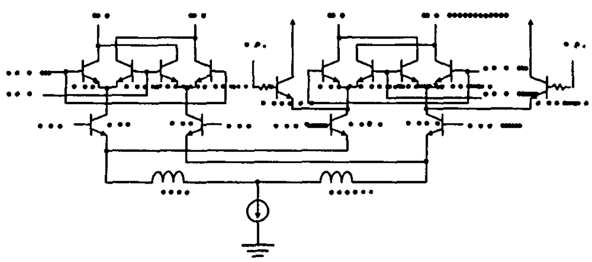


Fig.2 Schematic of variable-gain Gilbert cell core.

core. The emitter sizes of Q7 and Q8 are n times larger than those of Q1 and Q2, and those of Q9 – Q12 are n times larger than those of Q3 – Q6. In high gain mode, V_G is 0 V, Q13 and Q14 are turned off. Core cell operates as a normal Gilbert cell with (N+1)·(emitter area of Q1) and (N+1)·(emitter area of Q3) emitter areas of RF and LO input transistors, respectively. In low gain mode, V_G is set to V_{cc}, Q13 and Q14 are turned on, and Q9, Q10, Q11, and Q12 transistors are turned off. Because Q1, Q2, Q7, and Q8 operates normally, RF signals are divided to Q1/Q2 cell and Q7/Q8 cell by the ratio of N. Then the RF signals at collectors of Q7 and Q8 leak through Q13 and Q14 to V_{cc}. The emitter ratio N determines the gain ratio between high and low gain mode.

In both of high and low gain mode, RF input transistors Q1, Q2, Q7, and Q8 maintain normal operation, which results in constant RF input impedances. At IF output ports, although Q9 - Q12 is turned on and off according to high/low gain mode, output impedance is mainly determined by external 2.5 kΩ IF load resistor.

On-chip degeneration inductors L1 and L2 determine the gain, P_{1dB}, and IP_3 of the mixer. In our mixer, dominant noise comes from the base resistance of current switching transistors Q3 - Q6, and Q9 - Q12. Smaller noise figure can be obtained using larger emitter size transistors, however, which require more current consumption in LO driver circuit. In our design, design target is to obtain moderate noise figure (~ 9 dB) with minimum DC current consumption. With more current consumption, noise figure can be reduced. This will be explained in the nest section.

III. Low Noise LO Buffer Design

LO buffer circuits are constructed using conventional differential amplifier structure as shown in Fig. 3. DC current of LO buffer and load resistors R1 and R2 values should be carefully determined considering gain, noise figure, and LO drive capability.

Fig.4 shows gain and noise figure of the Gilbert cell core as LO drive voltage varies. As shown in that figure, sufficiently large LO drive voltage maximizes conversion gain and minimizes noise figure. From the critical LO drive voltage Vc in Fig. 4, required driving current, in other words required DC current of LO buffer, is calculated as,

$$I_C = 2V_C(j\omega C_\pi + \frac{1}{r_\pi}) + i_{SW} \qquad (1)$$

where, C_π, r_π and isw are the input capacitance and resistance of LO switch transistors, and switching current, respectively.

From the determined DC current, the gain of the LO buffer is determined by load resistors R1 and R2 in Fig. 3. As load resistors increase, the gain of LO buffer increases and noise figure decreases. However, too high gain of LO buffer amplifies not only LO signal but also noise generated by transistors Q15 and Q16, current source, and bias blocks, which results in poor noise figure. There exists optimum load resistor for minimum noise figure.

Considering base resistance of LO switch transistors, large-size LO switch transistor reduces noise figure, however, which results in higher total DC current consumption as shown in equation (1). Consequently, LO switch transistor size, LO buffer DC current, LO buffer load resistor should be determined by required specification of DC power consumption and noise figure. In this design, they are selected to acquire moderate noise figure (~ 9dB) with minimum DC power consumption.

Resistor R3 adjusts DC level of output nodes, which eliminates the need of low-Q and noisy DC decoupling polysilicon capacitor in LO signal path. Capacitor C1 suppresses noise generated by R3.

IV. LAYOUT AND FABRICATION

Using 15 GHz–f_T, 0.5 μm BiCMOS process, dual band mixer is fabricated. BJT's are used as core cell transistors, and MOSFET's are used in bias block and power-down control blocks. Fig. 5 shows the microphotograph of the fabricated mixer.

Symmetrical characteristic is kept for Gilbert cell core layout. All bias currents are supplied from BGR (band gap reference) block. N+, P+, and trench layers are used to construct multiple guard rings, which suppress interference and noise contribution from another block.

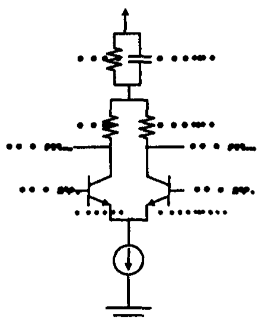


Fig.3 LO buffer circuit.

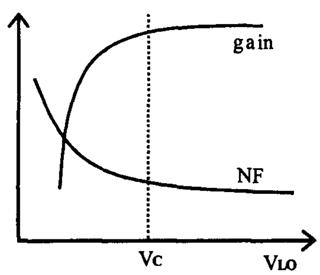


Fig. 4 Gain and noise figure of a mixer as LO drive voltage varies.

V. MEASUREMENT RESULTS

Fabricated wafer is packaged into QFP 48-pin SMD. RF performances of the mixer are measured using packaged chip on FR4 PCB.

RF input ports of GSM and PCN are matched to 50 Ω using discrete inductors and capacitors. At IF output ports, transformer is used to convert differential signal output to single-ended measurement equipment. Fig. 6 shows the evaluation circuit for measuring RF performance of the mixer.

Table I shows measurement result of the mixer. Gain difference of high and low gain mode is 11 dB and 11.8 dB for GSM and PCN mode, respectively. Measured return losses for GSM RF input, PCN RF input, and IF output ports show under −16 dB for both of high and low gain mode, which means constant input/output impedances.

Fig. 7 shows gain and noise figure characteristics of mixer with V_{cc} variation. As shown in that figure, this mixer operates down to 2.6 V supply voltage without significant performance degradation. All of the measured results fulfill the specification for GSM/PCN dual band RF receiver.

VI. CONCLUSIONS

As a building block of a GSM/PCN dual band RF transceiver IC, a low noise variable gain RF down conversion mixer is designed and fabricated using 15 GHz-f_T, 0.5 μm 3-metal 2-poly BiCMOS process. Using constant-impedance input / output stages, RF input and IF output return losses are maintained under −16 dB for both of high and low gain mode. Measured gain and DSB noise figure of the mixer are 10.9 dB and 9.1 dB, respectively, for 940 MHz GSM signal, and 9.6 dB and 8.1 dB, respectively, for 1840 MHz PCN signal.

All of the measured results fulfill the specification for GSM/PCN RF receiver. With proper LNA and IF circuit blocks, this mixer is expected to be used as a building block of a commercial wireless transceiver product.

This paper shows low-f_T (15 GHz) process is sufficient to fabricate GSM (900 MHz) and PCN (1.9 GHz) mixers.

REFERENCES

[1] F. Stubbe, *et al.*, "A CMOS RF-receiver front-end for 1 GHz applications," *IEEE Symposium on VLSI Circuits Digest of Technical Papers*, pp. 80 – 83, 1998.

[2] S. Colomines, *et al.*, "Design of high performances Gilbert-cell mixers for GSM/DCS front-ends," *IEEE Radio Frequency Integrated Circuits (RFIC) Symposium Digest of Papers*, pp. 143 - 146, 1998.

[3] S. Pennisi, *et al.*, "A new design approach for variable-gain low noise amplifiers," *IEEE Radio Frequency Integrated Circuits (RFIC) Symposium Digest of Papers*, pp. 139 – 142, 2000.

[4] Keng Leong Fong, "Dual-band high-linearity variable-gain low-noise amplifiers for wireless applications," *IEEE International Solid-State Circuits Conference Digest of Technical Papers*, pp. 224 – 225,1999.

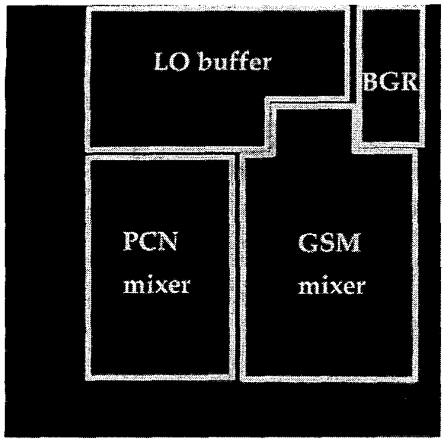


Fig. 5 Microphotograph of fabricated mixer.
(1400 x 1400 μm^2)

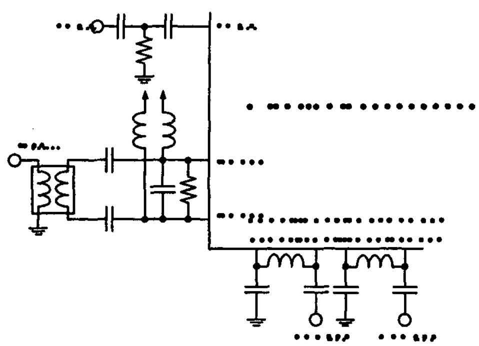
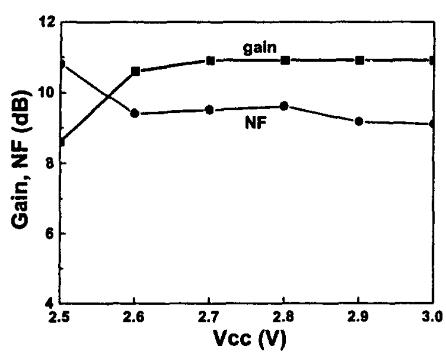
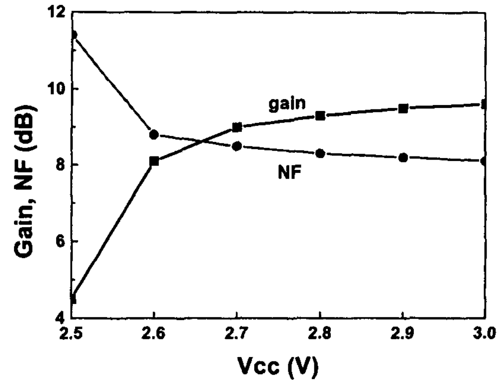


Fig. 6 Evaluation circuit for measuring RF performance of the mixer.



(a) Gain and noise figure of the mixer (GSM mode)



(b) Gain and noise figure of the mixer (PCN mode)

Fig. 7 Gain and noise figure characteristics of the mixer with V_{cc} variation

TABLE I

Measurement results of the mixer

	GSM	PCN	unit
Frequency (RF)	925-960	1805-1880	MHz
Frequency (LO)	1125-1260	1505-1680	MHz
Frequency (IF)	225	225	MHz
LO power	-10	-10	dBm
Gain (H)	10.9	9.6	dB
Gain (L)	-0.1	-2.2	dB
NF (H)	9.1	8.1	dB
NF (L)	15.2	11.7	dB
IIP_3 (H)	-0.7	-4.9	dBm
IIP_3 (L)	-0.8	-2.5	dBm
OIP_3 (H)	10.2	4.7	dBm
OIP_3 (L)	-0.9	-4.7	dBm
input P_{1dB} (H)	-12.8	-13.0	dBm
input P_{1dB} (L)	-10.0	-10.2	dBm
output P_{1dB} (H)	-2.9	-4.4	dBm
output P_{1dB} (L)	-11.1	-13.4	dBm
Total current	13	11.5	mA
Idle current	< 1	< 1	μA

(H) : high gain mode, (L) : low gain mode