Sub−1V, 2.4GHz CMOS Bulk−driven Downconversion Mixer

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Abstract

This paper describes the theoretical analysis and performance of a 2.4GHz bulk−driven downconversion mixer, where the LO signal is input via the bulk. A mixer core designed with a 0.18um CMOS process is able to operate under 0.8V~1V supply voltage. The RF, LO, and IF port frequencies are 2.45GHz, 2.4GHz, and 50MHz, respectively. The measurement results exhibit conversion gain of −1.8dB, 1dB compression point of −17dBm and IIP3 of −4dBm with 0dBm LO power. The power consumption is as small as 4mW.

Keywords — Downconversion mixer, Gilbert Cell, Bulk−driven, Layout

1. Introduction

In the past few years, the growing demand for low voltage, low power, low cost and high performance mobile communications equipment has changed the way of wireless receiver design. CMOS receiver front ends will be more easily integrated with digital ICs. Gilbert cell is most widely used as RF mixer[1]. Standard Gilbert cell mixers are difficult to operate at such low voltage due to stacking architecture. By using the bulk of the MOSFET, we can reduce the supply voltage while still maintaining moderate performance[2]. The advantage of this approach is that the required supply voltage is just above the threshold voltage and it is feasible to design low voltage mixer. Until now, the operation principle of the bulk−driven mixer has not provided. We investigate new theoretical analysis of the proposed topology. Finally, we compare the proposed theory and the measured results.

2. Theoretical Analysis of Bulk-driven Gilbert Cell Mixer

As shown in Fig.1, bulk terminal is driven by a large square signal. If PMOS device is switched between on and off according to Vsb(the bulk terminal voltage) variation, PMOS device is

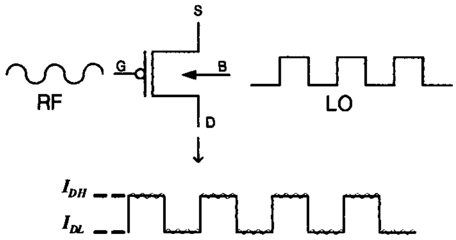

Fig.1 Basic concept of one PMOS mixer

linear system under small signal RF swing in the saturation region[3]. It is an appropriate assumption because the LO signal is sufficiently larger than the RF signal. LO signal and RF signal is applied to the bulk and the gate, respectively. Then output of drain current can be shown as equation (1) with Fourier series.

$$I_D = \frac{I_{DH}+I_{DL}}{2} + \frac{2}{\pi}(g_{DH}-g_{DL})V_{RF}\cos\omega_{RF}t\cos\omega_{LO}t...$$
$$= \frac{I_{DH}+I_{DL}}{2}$$
$$+\frac{1}{\pi}(g_{DH}-g_{DL})V_{RF}[\cos(\omega_{RF}-\omega_{Lo})t+\cos(\omega_{RF}+\omega_{Lo})t..] \quad (1)$$

I_{DH}, I_{DL} and g_{DH}, g_{DL} are currents and transconductances at on and off conditions, respectively. If load resistor R_L is connected to drain terminal, conversion gain is expressed as equation (2).

$$CG = \frac{1}{\pi}(g_{DH}-g_{DL})R_L \quad (2)$$

In this paper, the proposed mixer is shown in Fig.2. This mixer is Gilbert cell type, where LO signal is input through the bulk. M1,M2,M3,M4 are PMOS devices and the gate terminals are driven with differential RF signal of 2.45GHz ,the bulk terminals are driven with differential LO signal of 2.4GHz. M5,M6 are NMOS devices.

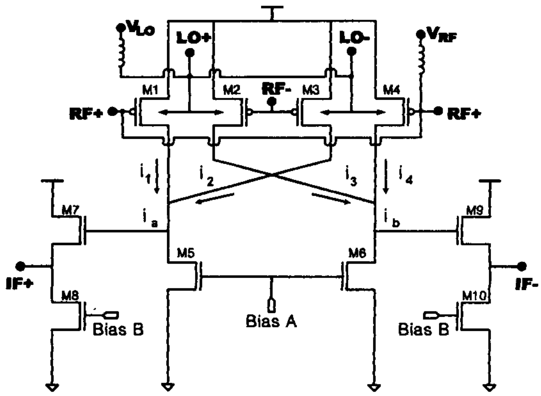

Fig.2 The proposed mixer

They are used as load resistor(R_L) to realize the desired conversion gain. They can be set to work in the desired conversion gain adjusting the V_{RF} and the Bias A. M7,M8 and M9,M10 are output buffers designed for driving 50 Ω load easily. In order for simple analysis, PMOS widths are the same. M5,M6 have identical widths and behave active loads with controlled Bias A. The analysis is done by using the equation(1). Equation(3) shows the result of the simplified conversion gain analysis. Moreover, it is not well known by what mechanism the mixing occurs. Swing of LO and RF signals changes the channel charge between the weak inversion and the strong inversion. In order to express conversion gain with V_{RF} gate voltage variation, we have to use current equation valid in all regions. Using current equation is valid in all regions, we can see the variations of the threshold voltage with respect to the source-substrate bias (Vsb) [4].

$$i_1 = \frac{I_{DH}+I_{DL}}{2} + \frac{2}{\pi}(g_{mH} - g_{mL})V_{RF}\cos\omega_{RF}t\cos\omega_{LO}t...$$
$$i_2 = \frac{I_{DH}+I_{DL}}{2} + \frac{2}{\pi}(g_{mH} - g_{mL})V_{RF}\cos\omega_{RF}t\cos\omega_{LO}t...$$
$$i_3 = \frac{I_{DH}+I_{DL}}{2} - \frac{2}{\pi}(g_{mH} - g_{mL})V_{RF}\cos\omega_{RF}t\cos\omega_{LO}t...$$
$$i_4 = \frac{I_{DH}+I_{DL}}{2} - \frac{2}{\pi}(g_{mH} - g_{mL})V_{RF}\cos\omega_{RF}t\cos\omega_{LO}t...$$
$$i_a = i_1 + i_2 = I_{DH} + I_{DL} + \frac{4}{\pi}(g_{mH} - g_{mL})V_{RF}\cos\omega_{RF}t\cos\omega_{LO}t...$$
$$i_b = i_3 + i_4 = I_{DH} + I_{DL} - \frac{4}{\pi}(g_{mH} - g_{mL})V_{RF}\cos\omega_{RF}t\cos\omega_{LO}t...$$
$$i_{out} = i_a - i_b = \frac{8}{\pi}(g_{mH} - g_{mL})V_{RF}\cos\omega_{RF}t\cos\omega_{LO}t + ...$$
$$= \frac{4}{\pi}(g_{mH} - g_{mL})V_{RF}[\cos(\omega_{RF} - \omega_{LO})t + \cos(\omega_{RF} + \omega_{LO})t + ...]$$
$$\therefore \text{CG} = \frac{4}{\pi}(g_{mH} - g_{mL})R_L \qquad (3)$$

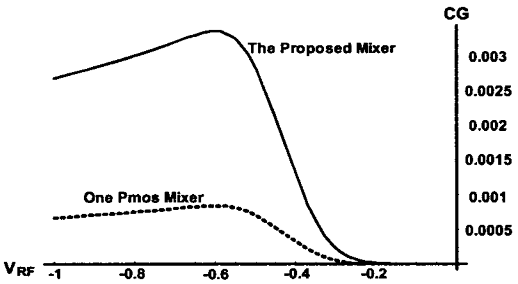

Fig.3 Conversion gain analysis

Comparing equation (2) with equation (3), we can see that the proposed mixer is four times larger than the one PMOS mixer. Fig.3 shows conversion gain analysis using valid in all regions current equation with R_L = 1Ω. The maximum conversion gain is shown nearby threshold voltage.

3. Fabrication and Measurement Results

This mixer was fabricated in a 0.18um CMOS process and tested in the form of COB(Chip On Board) type. The fabricated die was mounted on a FR-4 PCB board with wire bonding and the layout is shown in Fig.4.

Fig.4 Test Board

The differential ports of RF and LO inputs and IF output are connected to external single-ended equipments. The conversion loss of RF and LO balun is 4.5dB, and the loss of IF combiner is 3.4dB. Measured conversion gain includes conversion loss of the balun. The RF, LO, and IF frequencies are 2.45GHz, 2.4GHz and 50MHz, respectively. All ports are matched with lumped elements. Fig.5 is shown S11 for the RF port. The resulting match was a poor because lumped matching in high frequency is very difficult to accuracy. As shown in Fig.6, the desired conversion gain was optimized by adjusting through V_{RF} voltage and Bias A with 1V supply voltage. Fig.7 shows measured result of conversion gain, where V_{RF} voltage is swept form 0.3V to 0.67V. As expected in the analysis, Maximum conversion gain is around the threshold voltage. Fig.8 and Fig.9 illustrate the measured results of P_{1dB} and two tone test.

The measured P_{1dB} is −17dBm and IIP3 is −4dBm. The total power consumption is 4mW. Fig.10 shows conversion gain with supply voltage variation. As shown in that figure, this mixer operates down to 0.8 V supply voltage. Fig.11 shows conversion gain with LO power variation. With increasing LO power, conversion gain is increased.

4. Conclusion

In this paper, we suggest bulk−driven Gilbert cell mixer and theoretical analysis. The proposed conversion gain analysis and measured conversion gain result is much the same. Table 1 summarizes the measurement results of the mixer. The proposed mixer shows moderate performance under as little as 1V supply. This architecture can be a low−voltage solution.

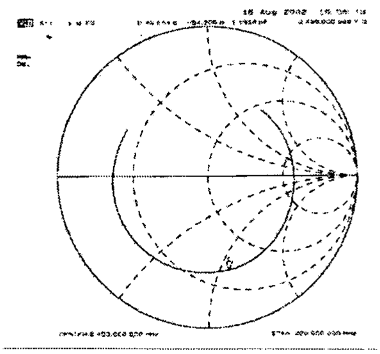

Fig.5 Measured S11 at RF port

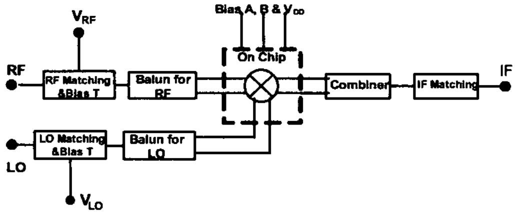

Fig.6 Diagram for measurement

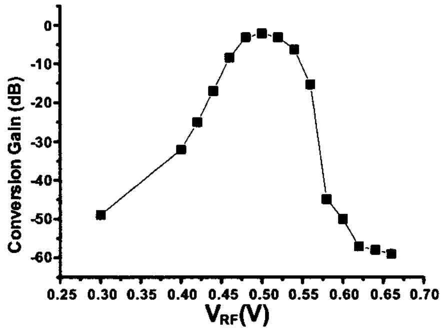

Fig.7 Measured conversion gain

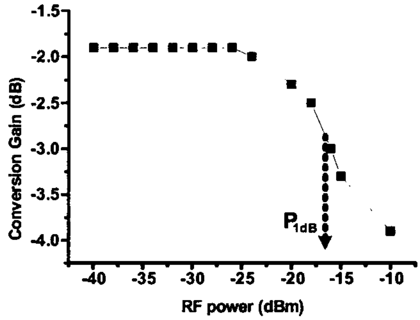

Fig.8 Measured P_{1dB}

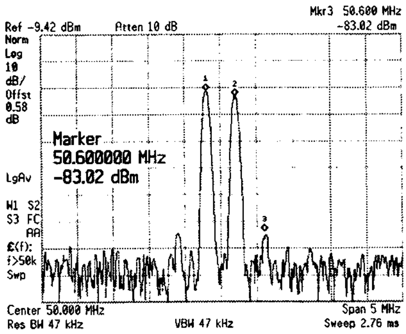

Fig.9 Two Tone Test

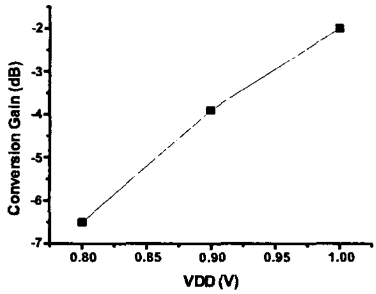

Fig.10 Measured CG vs. V_{DD}

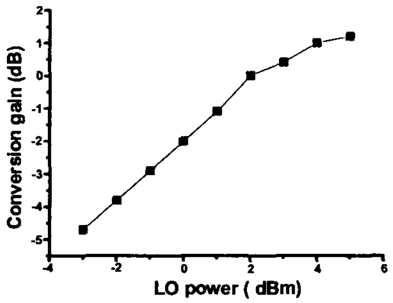

Fig.11 Measured CG vs. LO power

Table1 The proposed mixer performance

RF=2.45GHz,LO=2.4GHz	Measured Results
LO power (dBm)	0
Conversion gain (dB)	−1.8
IIP3 (dBm)	−4
P_{1dB} (dBm)	−17
Supply voltage (V)	1
Power consumption (mW)	4
LO to RF isolation (dB)	−34
LO to IF isolation (dB)	−40

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