Volume 3, Issue 5, May 2013 ISSN: 2277 128X
International Journal of Advanced Research in Computer Science and Software Engineering
Research Paper
Available online at: www.ijarcsse.com

A 3.5 GHz Low Noise Figure Mixer with High Conversion Gain for WiMAX Systems

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Abstract— In this paper a 3.5 GHz down conversion mixer with 20 MHz IF output signal for location-fixed WiMAX systems is presented. The proposed mixer is implemented with TSMC 0.18µm RF CMOS technology with 1.5V supply voltage which utilizes Current-Bleeding and Current-Reuse techniques to improve noise figure and conversion gain of conventional Gilbert-type structure. This mixer achieves 12 dB of conversion gain. For input power less than -36 dBm. The SSB and DSB noise figures are 6.5 dB and 3.5 dB, respectively. The proposed mixer achieved -15 dBm for P1dB and 11dB for IIP3 with power consumption of 10.12 mW.

Keywords— Current-bleeding, Current-reuse, Down conversion, CMOS mixers, Conversion gain

I. INTRODUCTION

The latest progress made in development of telecommunication networks has enabled data transmissions at higher speeds. Therefore WiMAX technology with data transmission speed of 100 Mbps and coverage area of 30 to 50 kilometers has been in focus more than ever before [1].According to IEEE 802.16-2004 standard, location-fixed WiMAX systems are allowed to utilize frequency band of 3.5GHz [2]. WiMAX mixers have more stringent specification of noise figure than those of other IEEE 802.11 standards and it is essential to obtain both low noise figure and high conversion gain for mixers in WiMAX systems[2], so design of such mixers is of great importance.

This paper applies Current-Bleeding and Current-Reuse techniques to design a new circuit with high conversion gain and low noise figure based on conventional Gilbert-type structure. Exhibiting other defining characteristics of a WiMAX system, it is applicable to fixed-location ones.

II. MIXER DESIGN

Figure 1 shows the conventional Gilbert-cell mixer. This double-balanced mixer consists of 3 stages; M_1 and M_2 have the characteristics of the transconductance stage, M_3 to M_6 represent the switching stage and R_L as the load stage. This structure, especially when enjoying the total symmetry, offers very good port-to-port isolation. Conversion gain, IIP3 and noise figure of this structure are calculated through equations 1, 2 and 3 accordingly. [2, 3, 4]

$$C.G. = 20\log(\frac{2}{\pi} g_{mRF} R) = 20\log(\frac{2}{\pi}(r_{dsLO} \,||\, R_L)\sqrt{k_{nRF} \times I_{DRF}}) \quad (1)$$

$$IIP3 = 4\sqrt{\frac{2}{3} \times \frac{I_{DRF}}{K_{nRF}}} \quad (2)$$

$$NF_{(SSB)} = 10\log\left(2 + \frac{4\gamma}{g_{mRF} R_s} + \frac{\pi^2}{2 g_{mRF}^2 R R_s}\right) \quad (3)$$

R_S is the impedance of the signal source, which drives the mixer RF port. K_{nrf} is determined by the technology and size of devices. R is the equivalent load resistance at the IF output and the transconductance value of M_1 and M_2 is shown by g_{mrf}. The coefficient γ is derived to be equal to 2/3 for long-channel transistors and may need to be replaced by a larger value for submicron MOSFETs [5]. Bias current of transconductance-stage transistors is also shown by I_{DRF}. As equations 1 and 2 indicate, increasing of bias current will improve conversion gain and IIP3 values, however this will increase not only the power consumption but also voltage drop on R_L resistors. As the voltage drop increases, Load stage delivers less voltage amount to next stages. In order to preserve switching-stage transistors conditions and operating region, the value of R_L resistor has to be decreased. This approach, according to equation 1, will decrease the conversion gain. Noise figure can be improved via increasing transconductance-stage g_m value. Note that this results in higher power consumption if accompanied by increasing the bias current.

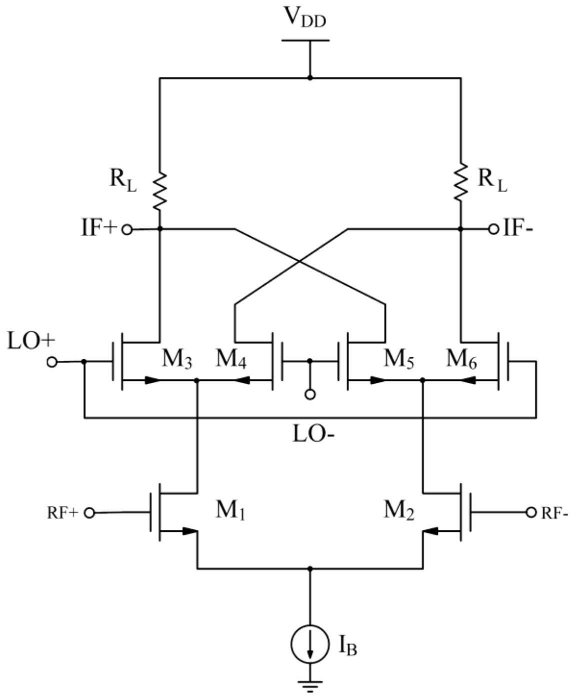

Fig. 1 Conventional Gilbert-cell mixer

Modified Gilbert-type structure, as shown in fig. 2 , can increase transconductance-stage current without causing any fluctuations in switching-stage current with the help of Current-reuse technique [6].In this structure, two additional transistors of M_{p1} and M_{P2} provide part of the transconductance-stage current without changing the current flowing through R_L resistors, so conversion gain and noise figure can be calculated through equations 4 and 5 as M_{P1} and M_{P2} transistors are part of the transconductance stage.

$$C.G. = 20\log(\frac{2}{\pi}(r_{dsRF} \,||\, R_L)(g_{m1} + g_{mp1})) \tag{4}$$

$$NF_{(SSB)} = 10\log[2 + \frac{4(\gamma_n g_{mn} + \gamma_p g_{mp})}{R_s(g_{mn} + g_{mp})^2} + \frac{\pi^2}{2(g_{mn} + g_{mp})^2 R_L R_s}] \tag{5}$$

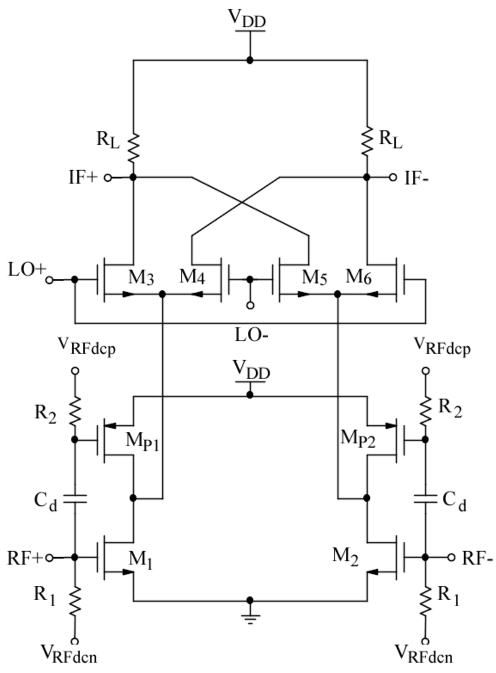

Fig. 2 Double-balanced mixer with Current-reuse thechnique

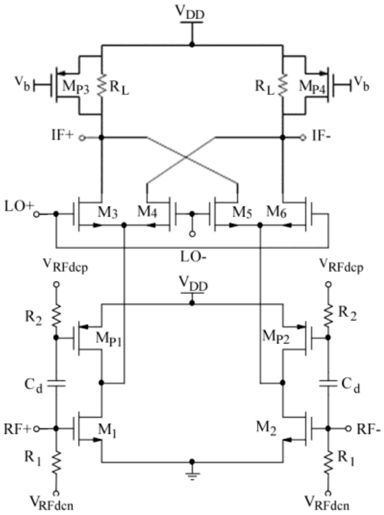

Fig. 3 Architecture of the proposed mixer

As can be deduced from equations 3 and 4, M_{P1} and M_{P2} transistors improve transconductance-stage g_m value, which leads to better noise figure, conversion gain and IIP3 but higher power consumption.

In order to decrease power consumption, as depicted in figure 3, a new circuit design is presented using Current-bleeding technique [2]. Exploiting M_{P3} and M_{P4} transistors allow higher values of R_L without making any changes in the flowing current through the resistors. Therefore increasing the load-stage resistors, as shown in equation 4, results in higher conversion gain. So conversion gain can be partially improved using this technique and by decreasing the current of M_{p1} and M_{P2} transistors, the injected current of transconductance stage can be reduced in order to decrease the power consumption to some extent. Also higher voltage level is delivered to the lower stages via this technique and no negative effect is produced upon the switches performance.

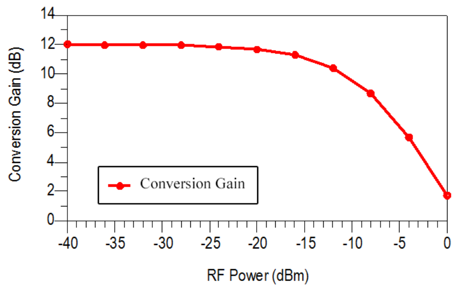

Fig. 4 Conversion gain of the proposed mixer

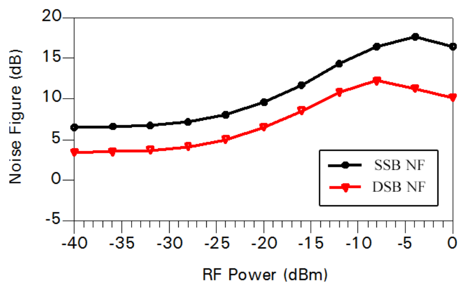

Fig. 5 DSB and SSB noise figures of the proposed mixer

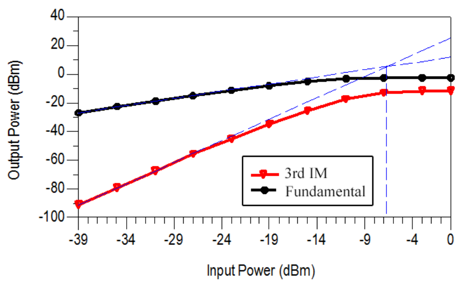

Fig. 6 IIP3 of the proposed mixer

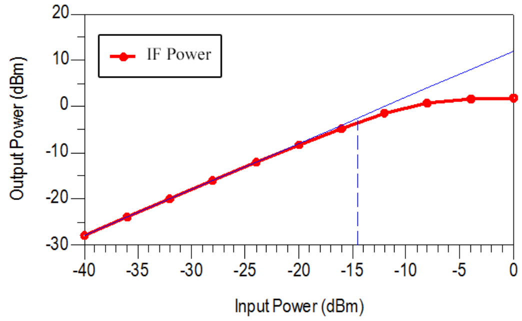

Fig. 7 P_{1dB} of the proposed mixer

III. SIMULATION RESULTS

The designed mixer simulated using TSMC 0.18µm RF CMOS technology with 1.5 v supply voltage. In order to conform to location-fixed WiMAX standard, this mixer is designed for RF input signal power of -40 dBm and 3.5 GHz frequency and input LO signal power of 0 dBm and 3.48 GHz frequency and this makes IF frequency equal to 20 MHz . Simulations have been done using Advanced Design System (ADS) and the results are as follows:

In figure 4 the conversion gain curve is shown. For an input RF power less than -20 dBm, the maximum conversion gain of the mixer is about 12 dBm. Figure 5 shows when input RF signal power is less than -36 dBm, maximum value of noise figure for single side band (SSB NF) and double side band (DSB NF) is 6.5 dB and 3.5 dB, respectively. IIP3 is used to describe the linearity performance of the mixer. As shown in figure 6, two-tone test shows IIP3 of -7 dBm. According to figure 7, P_{1dB} or input 1dB compression point is almost equal to -15 dBm.In order to inspect the input return losses; S-Parameters simulator is used. As figure 8 shows, at the frequency of 3.5 GHz S_{11}, which is input return losses for RF, is about -23.76 dB and S_{33}, which is input return losses for LO is about -32.76 dB which are both less than -10 dB and demonstrate that proposed structure meets an acceptable impedance matching. Note that these values are calculated with the power consumption of 10.12 mW and supply voltage of 1.5 volts.

To Summarize and compare, characteristics of the proposed circuit and previous mixers are brought together in table 1.

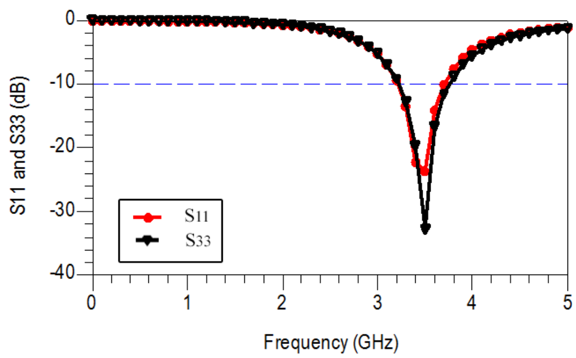

Fig. 8 The return losses of input RF/LO port

IV. CONCLUSIONS

The proposed mixer is designed by a conventional Gilbert-type structure. Both Current-Reuse and Current-Bleeding techniques were used to improve conversion gain and noise figure considerably. As is shown in table I, the proposed mixer has the highest conversion gain and still the lowest noise figure comparng to the previous mixers. And the design met the specifications of 3.5 GHz location-fixed WiMAX systems standards.

TABLE I
Performance Comparison of Mixers

	[1]	[2]	[6]	[7]	This work
Process (µm)	0.18	0.18	0.18	0.18	0.18
Supply Voltage (V)	1.8	1.5	1.8	1.8	1.5
RF (GHz)	2~11	3.5	2.4	2~11	3.5
Conversion Gain (dB)	18.9~21.5	10.7	15.7	21.5~22.8	12
Noise Figure (dB)	13.5~17.6	6.5	12.9	21.5~25.8	6.5
IIP3 (dBm)	.2~4.4	-11	1	4~5.5	-7
P_{1dB} (dBm)	-	-21	-	-	-14
P_{dc}(mW)	11.8	9.52	8.1	11.32	10.12

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