Low Flicker-Noise RF CMOS Gilbert-Cell Mixer for 2.4GHz Wireless Communication Systems

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Abstract—This paper presents a low flicker noise RF CMOS mixer using TSMC0.13-μm technology for 2.4 GHz wireless communication systems. Proposed design is based on a doubly balanced Gilbert cell mixer type with a charge injection technique and a tuning inductor. The proposed mixer presents a low flicker noise, high input matching, high linearity with a low power consumption and low noise figure. The simulated results using Agilent's Advanced Design System (ADS2009) software show that the proposed mixer achieves 7.4 dB SSB-NF, 12.8 dB conversion gain, 0 dBm IIP3, and flicker noise \((1/f)\) corner frequency of 32.6 kHz with 2.8 mW power consumption from 1.3V supply voltage. The proposed design demonstrates better performance in linearity, higher conversion gain and lower noise figure compared to conventional mixer designs.

Keywords—Gilbert-cell mixers; linearity; flicker noise; charge injection.

I. INTRODUCTION

By virtue of fast development of wireless communication technology, many types of mobile communication devices such as cellular phones, global-positioning systems, and wireless broadband Internet, have been introduced in our daily life. By using CMOS transistors, which reduces production cost, allows high level of integration, and hence provides many advantages to wireless communication systems. On the other hand, CMOS transistors have few drawbacks: low breakdown voltage, small gain, and flicker noise content. The most problem in the design of the receivers is the flicker noise which degrades the signal-to-noise ratio (SNR) and the total noise figure that results in the degradation of overall receiver sensitivity consequently. The mixer is the critical part in the receiver circuits, which translates radio frequency signals to base band frequency signal. Mixer should be designed carefully to reduce the output flicker noise. Several techniques have been proposed to reduce the output flicker noise such as static and dynamic current injection [1,2].

In this paper, a proposed mixer circuit has been developed by a charge injection technique. Two resistors have been used to inject current in the RF transconductance stage, with an addition of a shunt tuning inductor to reduce the effect of the tail capacitance \(C_p\) between the LO switches and RF transconductance stage. In order to demonstrate the improved performance, three types of mixers have been designed: 1) conventional Gilbert mixer; 2) a mixer with charge injection; 3) the proposed mixer. Mixers are compared for the noise figure, flicker noise, conversion gain, and linearity. Simulation results verified that the proposed mixer attains a good performance, compared to other conventional types of mixers.

II. GILBERT CELL MIXER

The most common used active mixer in CMOS systems is Gilbert cell mixer, shown in Fig.1. This cell involves three stages: input stage, switching stage, and load stage. Input stage is often called transconductance stage; formed by M1 and M2 which convert RF voltage signal to current signal. The switching stage formed by M3, M4 and M5, M6 turn on alternately. The load stage is formed by two resistors.

III. LINEARITY IMPROVEMENT USING CHARGE INJECTION TECHNIQUE

The mixers play a very important role in determining the linearity of the receiver chain, because the in-band interferers amplified by the Low Noise Amplifier (LNA) can produce high intermodulation products when processed by a not linear enough mixer. So, linearity is an important parameter in
designing mixers since linearity of the mixer significantly affects linearity of the whole transmitter/receiver system [3,4]. Nonlinearity results in numerous problems including harmonic generation, gain compression, and even order distortions [5,6].

Mixer performance can be improved using a charge-injection technique [11]. The enhancement of linearity (IIP3) and Conversion Gain (CG) in the same time are attained using this technique.

To explain this technique using a single-balanced mixer topology shown in Fig. 2 as proposed in [10], since the transistors in the mixer operate at the saturation region, the conversion gain and IIP3 can be approximated as follows:

\[
CG = \frac{2}{\pi} R_L \sqrt{K_{RF} I_{dsRF}}
\]

\[
IIP3 = 4 \frac{I_{dsRF}}{3 K_T}
\]

where \( R_L \) is the load resistance, \( I_{dsRF} \) is the drain current of the RF stage transistors, \( K_{RF} = 2 \mu COX W/L \) where \( COX \) is the gate oxide capacitance, \( W \) and \( L \) are the width and length of the RF transistors, respectively.

Therefore, the IIP3 and the CG are proportional to the square root of the bias current. Consequently, the conversion gain and the linearity can be improved by increasing the bias current. However, increasing the bias current automatically increases the voltage-drop across \( R_L \); which affects the good operation of the switching transistors by disturbing voltages \( V1 \) and \( V2 \), hence it affects the bias condition of the switching transistors. To improve both CG and IIP3, it is suggested to increase \( I_{dsRF} \) without increasing the drain-source current of the switching transistors. This can be achieved using the charge injection technique. In Fig. 2, charging current source \( I_{ch} \) is added to the basic core of the single-balanced mixer. Without \( I_{ch} \), total bias current is:

\[
I_{dsRF} = I_{d1} + I_{d2}
\]

with \( I_{ch} \) as an increase in \( I_{bias} \),

\[
I_{dsRF} = I_{d1} + I_{d2} + I_{ch}
\]

This improves linearity and conversion gain simultaneously.

IV. PROPOSED GILBERT CELL MIXER

In the previous section, the linearity has been improved by charge injection technique, but still the effect of the parasitic capacitance \( (C_p) \) as shown in Fig. 3. That problem cause an indirect effect which generate the flicker noise [8]. The tail capacitance should be small enough to decrease the effect of the flicker noise [9]. \( C_p \) appears from M3-M6 transistors at the node between the LO switches and RF transconductance stage. The RF current to be shunted by the tail capacitance \( (C_p) \), which decrease the bias current in the RF stage, then decrease the conversion gain and linearity. To avoid this problem using a shunt inductor \( (L) \) to compensate the parasitic capacitance as shown in Fig. 3. Consequently, increasing the conversion gain and linearity and decreasing the flicker noise [7,8]. Fig. 3 shows the Gilbert cell mixer with charge injection technique by using two resistors \((R1, R2)\) which are used to inject current into M1 and M2. This technique can ensure that M1 and M2 have an enough drain current to operate at saturation region without increasing the drain current of M3 to M6.

The proposed circuit shows a significant improvement of the conversion gain, linearity and flicker noise.

V. SIMULATION RESULTS

The proposed mixer, shown in Fig. 3, has been designed using TSMC 0.13µm technology, and simulated by Advanced Design System (ADS2009) software. The input RF and LO frequencies are 2.4GHz and 2.395GHz, respectively, to obtain 5MHz IF frequency. Three types of mixers have been designed: 1) a conventional mixer; 2) a mixer with charge injection technique; and 3) a mixer with a charge injection technique tuned by an inductor. The simulation results of three mixers at supply voltage of 1.3 V, 4 dBm LO power, - 40 dBm RF power, and resistance of the load is 400Ω. A comparison between NF-DSB characteristics of two different cases is shown in Fig. 4. In the first case the conventional mixer
obtains a flicker noise corner frequency around 57.12 kHz. In the second case, if we use charge injection technique and tuning inductor we can notice how the corner frequency decreased significantly to a value around 32 kHz.

Better results can be achieved using tuning inductor to tune out the parasitic capacitor ($C_p$). The conversion gain of conventional mixer is 11.53 dB. After using charge injection and tuning inductor, the gain has been improved to 12.89 dB; due to increasing the bias current in the RF transconductance stage by the addition of the two resistors, and the effect of the tail capacitor cancellation. There is no more RF leakage through this capacitor. Fig. 5, shows a comparison between the conversion gain of the Gilbert mixer and proposed mixer. Conventional mixer achieves an input third order intercept point (IIP3) of -12.3 dBm. However, the proposed mixer achieves an input third order intercept point (IIP3) of 0 dBm, as shown in Fig. 6. It is clear that the proposed mixer has a large improvement in the IIP3 after the addition of the two resistors to increase the bias current of the RF stage, and addition of an inductor to tune the parasitic capacitance. The proposed mixer has a low power consumption of 2.83 mW at a 1.3 V supply. A performance comparison of three mixers is shown in Table I. It shows how the proposed mixer exhibits a low flicker noise corner frequency and high linearity, compared to the other conventional mixers.

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**TABLE I. PERFORMANCE COMPARISON OF THE PROPOSED MIXER WITH OTHER MIXERS**

<table>
<thead>
<tr>
<th>Mixer parameter</th>
<th>Gilbert cell mixer</th>
<th>Gilbert cell mixer with charge injection technique</th>
<th>Proposed mixer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conversion Gain</td>
<td>11.537</td>
<td>11.749</td>
<td>12.892</td>
</tr>
<tr>
<td>IIP3 (dBm)</td>
<td>-12.385</td>
<td>-2.335</td>
<td>0</td>
</tr>
<tr>
<td>SSB NF (dB) @ 5MHz</td>
<td>7.733</td>
<td>7.764</td>
<td>7.4</td>
</tr>
<tr>
<td>Power consumption</td>
<td>2.704</td>
<td>2.821</td>
<td>2.834</td>
</tr>
<tr>
<td>S11</td>
<td>-37.966</td>
<td>-27.323</td>
<td>-29.98</td>
</tr>
<tr>
<td>Flicker noise (kHz)</td>
<td>57.12</td>
<td>70.55</td>
<td>32.6</td>
</tr>
</tbody>
</table>
VI. CONCLUSION

New double-balanced Gilbert cell mixer using charge injection technique and tuning inductor has been proposed and simulated using (ADS2009) software.

The proposed mixer has been designed using TSMC 0.13µm technology. It has an advantage of low flicker noise and high linearity. The mixer has a 7.4dB NF @5MHz. The mixer provides a 12.89dB conversion gain with 4 dBm LO power has and an IIP3 of 0 dBm. The mixer operates under 1.3V supply voltage.

REFERENCES


