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ANALYSIS OF LO LEAKAGE IN CMOS GILBERT MIXER BY CADENCE SPECTRERF FOR DIRECT CONVERSION APPLICATION

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ABSTRACT

The LO-RF leakage and feedthrough in double-balanced CMOS Gilbert mixers are analyzed from three aspects in this paper. They are an ideal mixer, a non-ideal mixer with parasitic effects and an ideal mixer with LO mismatch. It is found that the LO phase mismatch and LO amplitude mismatch are both exponentially proportional to the LO feedthrough. If both of them occur at the same time, the amplitude square of LO leakage is equal to the sum of the amplitude square of each contribution.

1. INTRODUCTION

In recent years, the direct conversion architecture has increasingly gained more attention as a possible solution for a single-chip radio due to its low power, low complexity and easy integrating properties. However, a number of issues which do not exist or are not serious in the heterodyne architecture become important in the homodyne architecture, such as DC offset, I/Q mismatch, even order distortion and so on. Among these the DC offset generated by self-mixing is the most critical. Approaches to remove the offset have so far mostly been focused on three methods. For modulation formats that have no or little spectral power at DC, AC coupling at the mixer output, or at some downstream stage, can be used to remove the offset [1, 2]. This traditional method requires large capacitor values that are not realizable on-chip. The second common approach is the use of baseband analog and/or digital signal processing (DSP) techniques for offset estimation and cancellation [3-5]. It is a widely used method, but increases the complexity and cost of receivers. Another approach is to use a DC-offset-free mixing topology, such as harmonic mixers [6-8]. This method is not common in the current wireless industry.

The DC offset is caused by the LO-RF leakage that is induced by the substrate coupling and the asymmetry of the mixer. Much research has been done on DC offset cancellation techniques. Nevertheless, no detailed analysis of the LO-RF leakage has been reported in the literature. In this paper, the values of LO leakage and LO feedthrough were obtained by simulations using Cadence SpectreRF in a double-balanced CMOS Gilbert mixer and some important rules were discovered.

2. ANALYSIS OF LO LEAKAGE

To better understand the origin of DC offset, consider the received signal path shown in Fig. 1. First, the isolation between the LO port and the inputs of the mixer is not perfect, and a finite amount of feedthrough, which is known as LO leakage, exists from the LO port to the other mixer inputs. The leakage signal is reflected back at the outputs of LNA (ignoring the feedthrough from the LNA outputs to its inputs) and now mixed with the original LO signal, thus producing a DC component at the output of the mixer. So the DC offset can be expressed by Eq. (1).

$$DC\,Offset = LO\,Leakage \times \beta \times G \qquad (1)$$

where β is the reflection factor and G is the mixer gain.

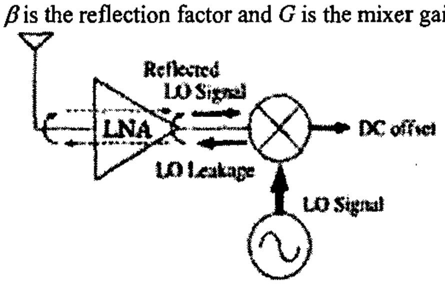

Figure 1. LO signal Self-mixing

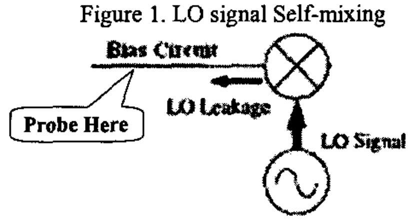

Figure 2. Method to obtain the LO leakage

The LO leakage arises from many factors, such as substrate coupling, asymmetry of the circuit and so on. It can be obtained by disconnecting RF signals and only injecting LO signals to the mixer, see Fig. 2. The signals of LO frequency appearing at the RF port is the LO leakage. In order to get the LO leakage and feedthrough, a CMOS double-balanced Gilbert mixer operating at the center frequency of 2.45GHz for direct conversion applications was designed using Cadence SpectreRF for the Chartered 0.18um CMOS Digital/Analog/RF process, see Fig. 3. The performance parameters are shown in Table 1. In the following sections, it will be discussed in three cases, that is, ideal mixer, non-ideal mixer with parasitic effects and ideal mixer with LO mismatch.

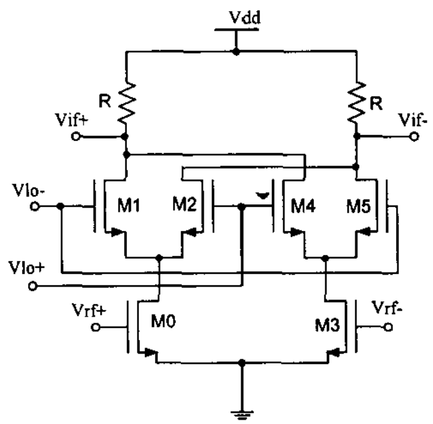

Figure 3. Double-balanced mixer

DCG (dB)	BW (GHz)	1dB (dBm)	IIP3 (dBm)	Power (mW)
15.26	9	-11.71	0.43	11.15

Table 1. Performance parameters of the mixer (DCG: Differential conversion gain)

2.1. Ideal mixer

An ideal mixer means the circuit is perfectly symmetrical without any parasitic effects. See Fig. 4, all the odd harmonics at the RF ports were cancelled due to the symmetry of the circuit. When a signal –17.72dBv was injected to the LO ports, the voltage at the RF ports was –135.7dBv, which is consider as LO leakage.

LO feedthrough = LO leakage – LO Signal
= (-135.7dBv) – (-17.72dBv) = -117.98dB.

In this case LO leakage is in the noise level, so it is concluded that there is no LO feedthrough for an ideal double-balanced mixer, which is consistent with theory.

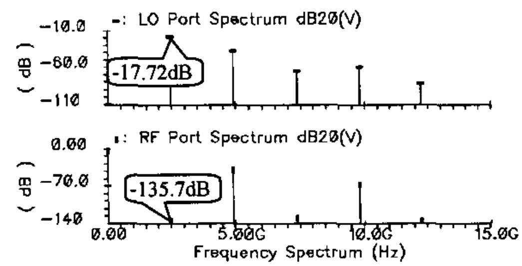

Figure 4. LO signal and LO leakage for the ideal mixer

2.2. Non-ideal mixer with parasitic effects

In real circumstance, there are no ideal conductors and connections, and they must be considered as resistors and capacitors. So the parasitic effects were extracted from the layout, and added back to the schematic to run the post-layout simulations. Fig. 5 shows the layout of the mixer.

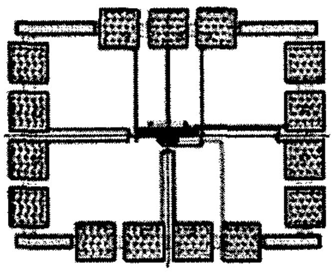

Figure 5. Layout of the mixer

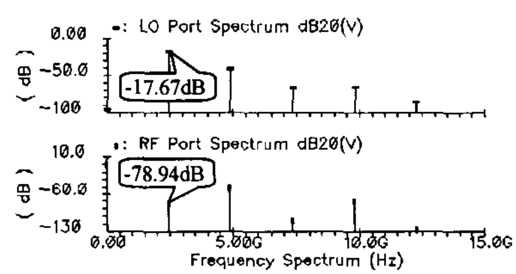

Figure 6. LO signal and LO leakage for the non-ideal mixer

In this case odd harmonics at the RF ports were induced by parasitic effects as shown in Fig. 6. We focus on the first harmonic, which is the LO leakage caused by substrate coupling.

LO feedthrough = LO leakage – LO Signal
= (-78.94dBv) – (-17.67dBv) = -61.27dB.

So for a common CMOS Gilbert mixer, the LO feedthrough is around –60dB. Sometimes it is still large enough so that the DC offset caused could possibly corrupt the desired signals and/or saturate the following stages.

2.3. Ideal mixer with LO mismatch

In the real application, the VCO does not supply balanced perfectly signals. So it is necessary to analyze how the LO mismatch affects the LO feedthrough. Three cases are analyzed here. They are (i) phase mismatch only, (ii) amplitude mismatch only, and (iii) combination of the two mismatches.

For the analysis of phase mismatch only, LO+ and LO– had the same amplitude. However, the phase angle of LO+ was changed from 0° to 5° to represent the mismatch phase while LO– kept the constant of 180°. A large number of simulations were done to obtain the relation of LO feedthrough to the mismatch phase, which was plotted in Fig.7. It is surprisingly found that the LO

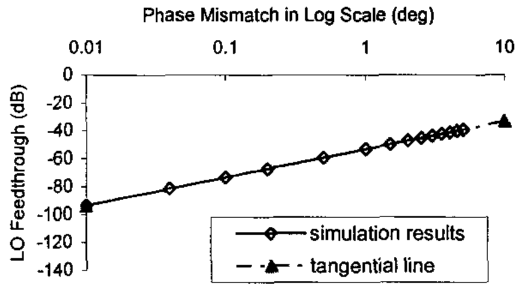

Figure 7. LO feedthrough caused by LO phase mismatch

feedthrough is exponentially proportional to the phase mismatch when the mismatch phase is small, less than 5°. If the phase is 0.5°, the feedthrough is around –60dB, which is already equivalent to the one caused by parasitic effects. From Fig. 7, it is concluded that the LO leakage in volts is directly proportional to the LO phase mismatch with the value less than 5°.

For the analysis of amplitude mismatch only, different powers of LO+ and LO– were injected while keeping 180° phase difference. The two differential LO signals were large enough to completely turn on/off the switching pairs so that the mixer had a constant gain while they were changing in a small range. The amplitude of LO– was fixed and LO+ was increased to make the amplitude mismatch change from 0mV to 50mV. Fig. 8 shows the simulation results.

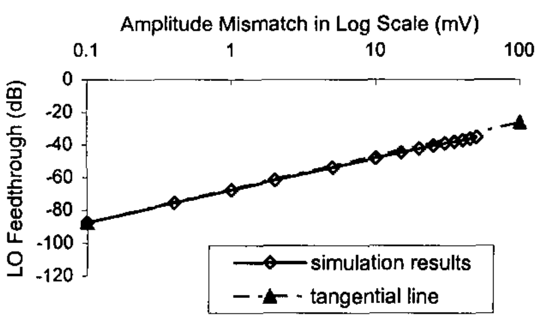

Figure 8. LO feedthrough caused by LO amplitude mismatch

It can be seen that the LO feedthrough is also exponentially proportional to the amplitude mismatch. When the mismatch amplitude is larger than 10mV, the curve starts to slightly bend down. If the mismatch is 2mV, the feedthrough is approximately –60dB. Therefore the LO amplitude mismatch should not exceed 2mV. From Fig. 8, it is concluded that the LO leakage in volts is directly proportional to the LO amplitude mismatch with the value less than 10mV.

In general case, the two differential LO signals have both phase mismatch and amplitude mismatch at the same time. From simulation results, it is amazingly found that there is a relation between the total LO leakage and the ones caused by each mismatch.

$$\left|V_{LOleakage\_total}\right|^2 = \left|V_{phase\_mismatch}\right|^2 + \left|V_{amplitude\_mismatch}\right|^2 \quad (2)$$

The amplitude square of the total LO leakage is equal to the sum of the amplitude square of each contribution.

3. CONCLUSIONS

This paper analyzes the LO leakage and LO feedthrough in double-balanced CMOS Gilbert mixers for the direct conversion application. It is found that an ideal mixer has no LO leakage. Parasitic effects extracted from the layout could cause about –60dB LO feedthrough. Moreover LO phase mismatch and LO amplitude mismatch are both exponentially proportional to the LO feedthrough and should not exceed 0.5° and 2mV respectively. If both of them occur at the same time, the amplitude square of LO leakage is equal to the sum of the amplitude square of each contribution. It can be seen that LO mismatch could cause large feedthrough and then induce DC offset. Therefore it should be drawn more attention in the direct conversion receiver design.

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