Enhanced IIP_2 Chopper Stabilized Direct Conversion Mixer Architecture

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***Abstract*—This paper presents an improved Second Order Input Intercept Point (IIP_2) Direct Conversion Mixer architecture by introducing chopping in the standard active double balanced mixer. The mixing frequency required is half of the RF frequency. This technique improves the second order linearity of the mixer. There is only one active mixer in the signal path enabling low power design. Simulation results for the enhanced mixer are compared with a standard active double balanced mixer. An IIP_2 improvement of around 8 dB is demonstrated.**

***Index Terms*—IIP_2, Direct Conversion, Sub Harmonic Mixer**

I. Introduction

There has been a tremendous increase in the demand of high frequency wireless applications. The market for low power circuits for these applications is continuously rising. One such device is the mixer for a Direct Conversion Receiver. It has various advantages over the traditional super heterodyne architecture as discussed in [1], [2] and [3]. No image rejection filter is required as the image frequency is same as the signal frequency. Since the down-converted signal is close to DC, the design constraints of the ADC will be relaxed. RF-LO leakage, flicker noise and influence of the even order inter-modulation are some of the challenges associated with the design of a Direct Conversion Mixer. This work will focus on improving the second order linearity of the mixer. In section II, the fundamentals of second order linearity are presented, followed by the principle of chopping in section III. Section IV and V present the proposed architecture followed by the simulation results and conclusion in section VI and VII.

II. Second Order Non Linearity

Second order inter-modulation is a major contributor to the non linearity in the Direct Conversion Mixer. Suppose the LO frequency is f_{lo} and the two undesired signal frequencies are f_{rf1} and f_{rf2}. Mismatches in the circuit result in additional undesirable squaring action of the signal. For example,

$$(acos(\omega_1 t) + acos(\omega_2 t))^2 = a^2 + \frac{a^2cos(2\omega_1 t) + a^2cos(2\omega_2 t)}{2}$$
$$+a^2cos((\omega_1 + \omega_2)t) + a^2cos((\omega_1 - \omega_2)t) \quad (1)$$

The output contains a DC term : a^2 and an unwanted base-band component $a^2cos((\omega_1 - \omega_2)t)$ which will corrupt the desired base-band signal. The above expressions indicate the squaring action which results in the amplification of the undesired signal. In dB scale the inter-modulation term's slope will be twice that of the desired linear signal. Figure 1 depicts the effect of the second order non linearity. The two tones (f_{rf1} and f_{rf2}) are undesired interferers.

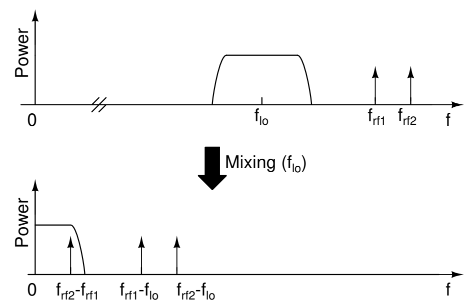

Fig. 1. Effect of 2^{nd} order non linearity

The 2^{nd} order inter-modulation term (IM_2) is a critical issue for a Direct Conversion Receiver because it is very close to DC. These inter-modulation products can corrupt the translated desired signals. Sometimes these unwanted signals can be of very high power and can block the desired signal altogether.

III. Dynamic Matching in Mixers

In the dynamic matching technique, as described in [2], chopping is introduced at the input and the output of a standard double balanced mixer. The structure is depicted in Figure 3.

In this design, the main RF core is preceded and succeeded by switches. They ensure that the second order non linearity generated by the main RF mixer core will be translated out of the desired band. This phenomenon can be explained by the frequency domain analysis as shown in Figure 2. Suppose f_{rf1} and f_{rf2} are two out of band interferers. The input switching stage translates the input signal to the chopping frequency (f_{chp}) that is (f_{rf1}-f_{chp}) and (f_{rf2}-f_{chp}). As shown in the figure, these signals are still at high frequency as f_{chp} is much lower as compared to the RF frequencies. These signals are then down-converted by the main RF mixer working at f_{lo}. The IM_2 generated by the main RF core is also shown. This inter-modulation is generated due to the non linear mixing of the four signals shown. This IM_2 (f_{rf2}-f_{rf1}) will be generated in the desired band of the RF output. Finally, the output switches translate the shifted spectrum back to the desired

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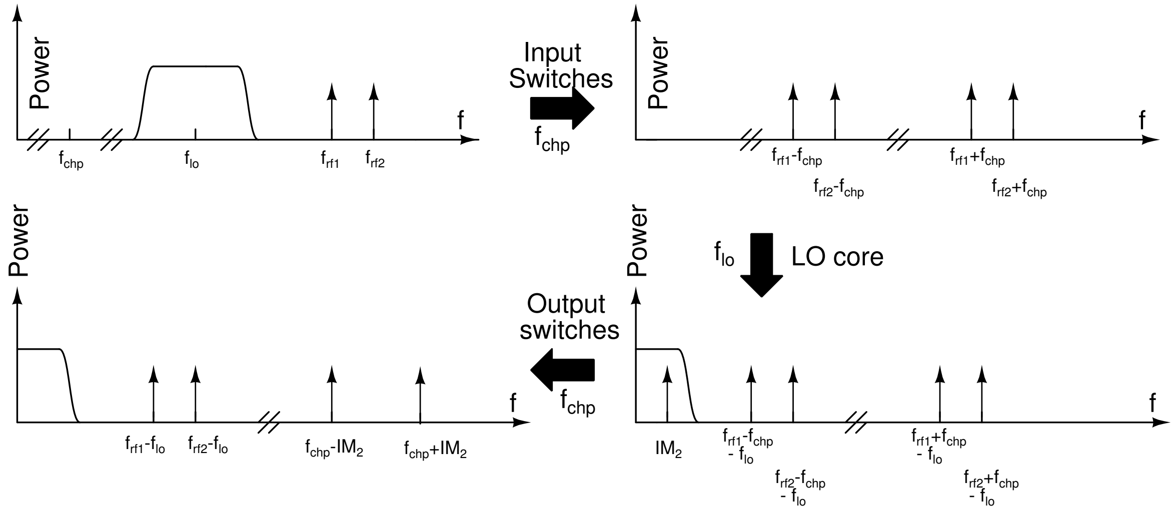

Fig. 2. Frequency domain analysis (Chopping [2])

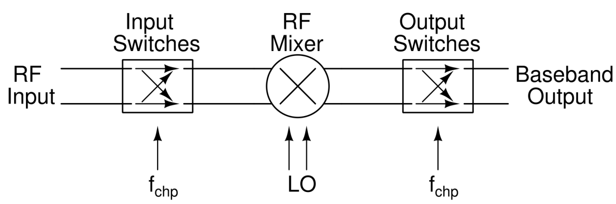

Fig. 3. Dynamically matched Mixer [2]

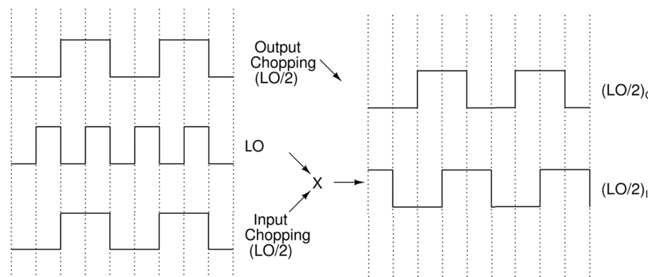

Fig. 4. Equivalent Chopping Signals

signal band to DC. This switching will translate IM_2 out of the desired band.

The IM_2 generated by the main RF mixer core is translated to an intermediate chopping frequency (f_{chp}). The non linearity generated by the output stages will be in the desired signal band. Hence, the output stage has to be highly linear. The implementation of dynamically matched mixer in [2] has stacked mixers for the input stages and the main RF mixer core. The output of the main mixer is then sampled by using a passive mixer which acts as the output switching stage.

The two active mixers in the signal path leads to stacking of transistors making the low supply voltage design difficult. Besides an extra frequency generator for the chopping signal is needed.

IV. New Chopper Stabilized Mixer

Various IIP_2 improvement techniques have been discussed in the literature. In [5], authors used $2f_{lo}$ mixing to prevent the non linearity of the main mixer. A digitally assisted linearization technique is presented in [6] which requires calibration. We try to address the higher supply voltage and the need of an extra frequency generator in this work.

Analyzing the dynamically matched mixer([2]), for the chopping frequency (f_{chp}) of $\frac{f_{lo}}{2}$. The multiplication of chopping signal and the LO is a phase shifted version of the chopping signal itself as shown in Figure 4. This works only when f_{chp} is equal to $\frac{f_{lo}}{2}$. Due to the 90°phase difference, resultant mixing signals can be referred to as $(\frac{LO}{2})_I$ and $(\frac{LO}{2})_Q$.

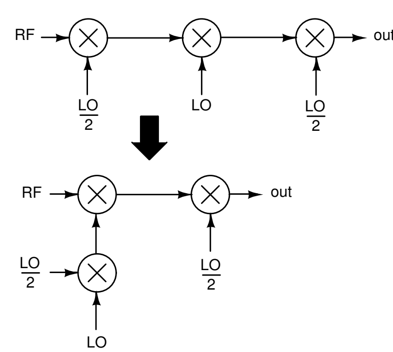

Fig. 5. Modification to obtain the new topology

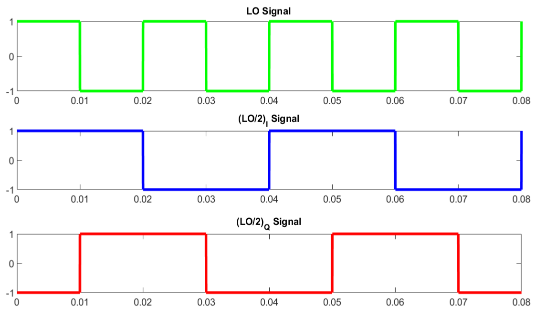

Fig. 6. LO signals

Figure 6 depicts the LO signals used in the standard double balanced mixer and the new chopper stabilized mixer. Figure 7 illustrates the mixing action of both the mixers and it can be verified that the output signal (in time domain) is identical. The RF input in the figure has a frequency of $1.5f_{lo}$. It can be seen in the output waveforms that the mixer output has a frequency of $0.5f_{lo}$ as expected.

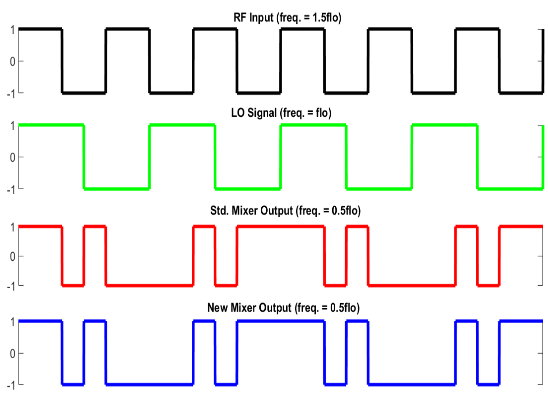

Fig. 7. Functionality verification of the New Mixer

These modified signals can be used for switching as demonstrated in Figure 6. The mixing in the signal path has been reduced as compared to the dynamically matched mixer. The $\frac{LO}{2}$ stage now chops the LO instead of the RF signal. It can be observed that for a mixing by a frequency LO we only require phases of the $\frac{LO}{2}$. The mixer in this work uses an active mixer followed by the passive mixer as depicted in Figure 8 leading to reduction in gain (by $\frac{2}{\pi} \approx$ -4 dB) as compared to the standard active double balanced mixer.

A similar mixing option can also be generated by using multiple stages of $\frac{LO}{4}$ or $\frac{LO}{8}$ and so on. The proposed new chopper stabilized mixer uses the introduction of chopping in the standard active double balanced mixer. The final architecture is similar to the sub harmonic mixer ([7]- [13]). However, none of them attribute IIP_2 improvement to the sub harmonic mixer.

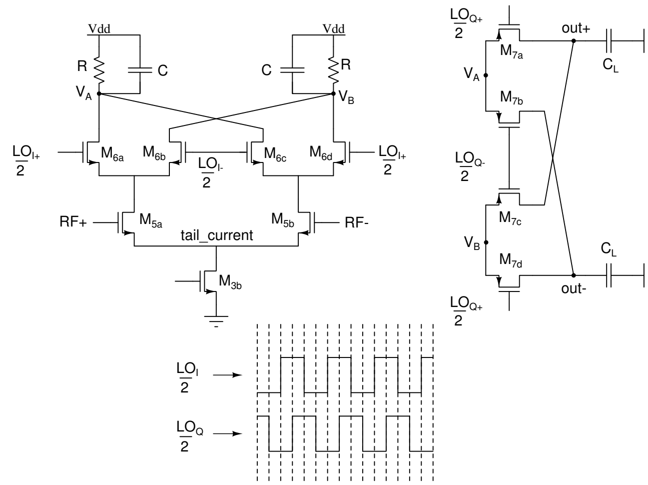

Fig. 8. New Chopper Stabilized Mixer Circuit Diagram with the LO phases

V. Design

UMC 65nm Low Leakage CMOS process has been used for the design of the circuit with the supply voltage of 1.2 V. A few mechanisms of IM_2 generation in a mixer are RF-LO self mixing, parasitic capacitance of the tail current source and mismatches in the switching transistors.

The circuit consists of an active mixer followed by a passive mixer. The active mixer will generate some non linearities but they will be translated to a higher frequency ($\frac{f_{lo}}{2}$) by the passive mixer. The active mixer will provide gain to the overall mixer.

The tail current source is designed to avoid high parasitic capacitance which will otherwise degrade the linearity as proved in [14]. The overdrive voltage of the input transistors is kept as high as possible to ensure maximum linearity ([15]). The switching transistors must be matched to each other.

The widths and lengths of the input transistors and the switching transistors of the active stage are equal in proposed mixer and the double balanced mixer. This has been done to make a fair comparison of IIP_2.

VI. Simulations

The IIP_2 of a standard active double balanced mixer with perfect matching is infinity. This is the case for all even order intercept points. Monte Carlo Simulations are used to generate mismatches in the circuit and compare the IIP_2 of standard active double balanced mixer with the new chopper stabilized mixer. From Figures 9 and 10, it can be observed that there is a mean and median shift to the right in the proposed mixer compared to the standard mixer. This shows the improvement in IIP_2 of the proposed architecture. This can be also verified by manually introducing mismatches in the circuit as described in Table I.

TABLE I
CONSOLIDATED RESULTS - SCHEMATIC MISMATCHES

Mismatch Introduced	Standard Double Balanced Mixer	New Chopper Stabilized Mixer
Resistors (R_D) - 1%	46 dBm	251 dBm
Switching Transistors - 2% width	55 dBm	84 dBm
Input Transistors - 1% g_m	263 dBm	52 dBm
Passive Mixer Transistors - 1% width	-	68 dBm
All Combined	**44 dBm**	**52 dBm**

(1).png

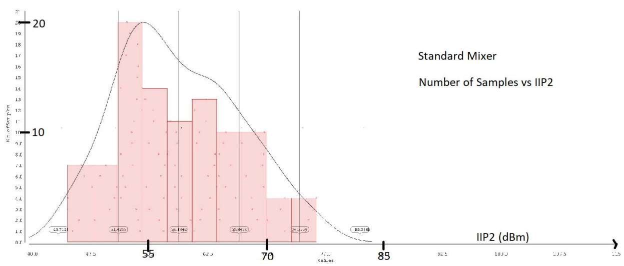

Fig. 9. Monte Carlo Histogram - Standard Mixer

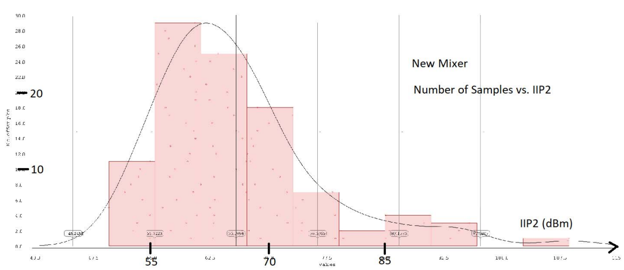

Fig. 10. Monte Carlo Histogram - New Chopper Stabilized Mixer

Table I shows the sensitivity of IIP_2 to individual component mismatches possible in the circuit. The IIP_2 of the new chopper stabilized mixer is higher than the standard active double balanced mixer. The proposed mixer is insensitive to all the mismatches except the input g_m stage. Hence, it should be ensured that the input stage transistors are very well matched.

TABLE II
COMPARISON

	Standard Mixer	New Mixer
Gain	6.083 dB	2.293 dB
RF Freq	2.4 GHz	2.4 GHz
IIP_2	43.66 dBm	51.71 dBm
IIP_3	3.68 dBm	1.81 dBm

VII. CONCLUSION

In this work we proposed a new chopper stabilization mixer that can be used in a direct conversion receiver where high IIP_2 is required. An improvement in IIP_2 of at least 8 dB is demonstrated. For a mixing with f_{lo}, the architecture requires only I and Q phases of $\frac{f_{lo}}{2}$. This architecture also does not require any stacking of transistors thereby enabling low power design. The Monte Carlo Simulations also depict the said improvement of IIP_2. However, the presented advantages are accompanied with a reduced conversion gain of the proposed mixer.

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